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TerrAsia 2011

2011 INTERNATIONAL CONFERENCE ON EARTHEN ARCHITECTURE IN ASIA

Edited by Heyzoo HWANG, Soonwung KIM, Hubert GUILLAUD, David GANDREAU



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TerrAsia 2011

2011 INTERNATIONAL CONFERENCE ON EARTHEN ARCHITECTURE IN ASIA

Preface

The Earth Architecture Institute of Korea welcomes international and domestic earth architecture experts who have taken time out of their busy schedules to be here today. Your active participation and enthusiasm will most definitely help to spread the spirit of earth architecture.

Korea has a heritage of 5,000 years. Throughout this long history, the Korean people have experienced many events. Korea was under occupation during the age of imperialism and was at war during the Cold War era. The country saw rapid growth during the Industrial Age but also experienced the aftereffects of a military dictatorship. Therefore, it is not a surprise to find that the Korean people have strong passion for peace and democracy. To be able to host the earth architecture conference, an architecture of peace, in such a country is undoubtedly meaningful.

Today all around the world, the dominance of capital is ever increasing in the name of globalization. The invaluable cultures and the values of each nation are ignored and only the logic of capital in all fields then becomes the only value to recognize. Architecture is not an exception - only architecture effective in accumulating capital is being stressed rather than the architectural values cultivated in different regions. At this time, the values of earth architecture will shine far greater. The spirit of earth architecture is one of respect towards diversity, which will build a foundation so that each and every individual can live a full and meaningful life. Like that of favorable earth construction materials, where large and small particles within the earth have to be well dispersed, earth architecture has contributed to the building of a beautiful world where the rich and the poor, the educated and the illiterate, and men and women alike can live in harmony, and it is my belief that earth architecture will continue to play this crucial role.

This conference, which aims to examine the history of earth architecture, assess the current situation of various types of earth architecture in different nations, and search for future possibilities related to earth architecture, will be host to the proposals of sincere and genuine architecture solutions in which mankind and nature can live together, therefore presenting a focus different from that of capital-efficient architecture. Therefore, we hope and look forward to spread the message of earth architecture throughout the globe to protect the valuable relationship between mankind and nature.

I truly hope that this event will expand the human network between the participants and deepen the level of understanding, even though our schedule might be tight, the food unusual, and sleeping quarters unfamiliar. I welcome all the international and domestic earth architecture specialists here once again. Thank you.

2011.10.11

Representative director of TERRAKorea, Prof. Heyzoo Hwang

서문

한국흙건축연구회를 대표하여, 먼 곳 마다하지 않고 이곳에 오신 국내외 흙건축 전문가 여러분들을 환영합니다. 여러분들의 이러한 발걸음들이 흙건축의 정신이 무엇인지를 알리는 계기가 될 것으로 생각합니다.

한국은 오천년의 역사를 가진 나라입니다. 우리는 긴 역사 동안 여러 일들을 겪어 왔습니다. 제국주의시대에는 식민지배를 겪었고, 냉전시대는 전쟁을 겪었습니다. 산업화시대에는 고도성장의 성과를 이루기도 하였지만, 동시에 그에 따르는 군사독재로 인한 후유증을 겪기도 하였습니다. 그러하다보니 한국은 민주주의와 평화에 대한 열망이 그 누구보다도 강한 사람들이 모여 사는 곳이 되었습니다. 이러한 곳에서 평화의 건축인 흙건축 컨퍼런스가 열리게 된 것은 참으로 의미 있는 일이라 하겠습니다.

지금 세계는 세계화의 이름으로 자본의 힘이 광포화하고 있습니다. 각 나라의 소중한 문화와 가치를 무시한 채, 전 분야에서 자본의 논리만이 유일무이한 가치로 받아들여기를 강요받고 있습니다. 건축도 예외가 아니어서 각 지역별로 가꾸어 온 건축적 가치보다 자본축적에 더 효율적인 건축만이 강조되고 있습니다. 이러한 때에 흙건축은 그 가치가 더 빛날 것이라 생각합니다. 흙건축의 정신은 다양성에 대한 존중이며, 한 사람 한 사람이 가치있고 의미있는 삶을 살아가게 하는 토대를 만드는 것이라 생각합니다. 흙 속에 크고 작은 입자들이 골고루 어우러져야 좋은 흙건축재료가 되듯이, 가진 사람과 가난한 사람, 배운 사람과 못 배운 사람, 남녀노소 모두 어우러져 아름다운 세상을 만드는데 흙건축은 기여해왔고 앞으로도 그 중차대한 역할을 계속해 가리라 믿습니다.

흙건축의 역사를 살피고 각국의 다양한 흙건축의 현재를 점검하여 흙건축의 가능성을 모색하고자 하는 이번 컨퍼런스는, 자본효율적 건축이 아니라 사람과 자연이 함께 하는 참다운 건축에 대한 대안을 제시하는 자리가 되리라 믿습니다. 따라서 우리는 사람과 자연의 소중한 가치를 지키자는 흙건축의 메시지가 이곳에서 온 세상으로 퍼져나가기를 기대합니다.

이번 행사 기간 중 익숙하지 않은 잠자리와 음식, 고된 일정이 되더라도 참여자들 간의 교류의 폭이 넓어지고 이해의 정도가 깊어지는 자리가 되길 바랍니다. 다시 한번 이곳에 모이신 국내외 흙건축 전문가들을 환영합니다. 감사합니다.

2011.10.11

한국흙건축연구회 대표 황혜주

Preface

No major event on earthen architecture has been held since the first international conference organised in Beijing, China, in 1985 for the Asian region. Considering the cultural importance and value of the earthen architectural heritage in Asian countries, and also the worldwide interest for the conservation of the earthen architectural heritage and for a revival of the construction using this abundant and precious building material that has grown steadily in the past three decades, this international conference can be considered has a major event for the region.

On the other hand, looking back at the last ten years, since the beginning of this 21st Century, we can observe a stronger commitment of academic and scientific institutions, of governmental and non-governmental entities in organising a permanent agenda of conferences, colloquias and symposiums on earthen architecture. The international scale of such events, with the famous congresses that have been organised since 1971 and 1976 in Yazd, Iran, in Ankara, Turkey in 1980, in Lima and Cusco, Peru in 1983, in Las Cruces, New Mexico, USA, in 1990, in Silves, Portugal in 1993, in Torquay, England in 2000, again in Yazd, Iran in 2003, then in Bamako, Mali in 2008, and the close next one, again in Lima in April 2012, does not reduce the quality and scientific value of numerous regional events that are regularly organised in the world. These regional conferences throw light on the specific characters of less known earthen architectural heritages and the quality of the scientific research that often has limited possibilities of being valorised. These regional events are offering numerous forums to the international academic community and facilitate the exchange of knowledge and information. They show the evidence of new forces that are supporting the revival of earthen construction and architecture in many countries, acting for a better access to housing for less favoured people, for the conservation and valorisation of the worldwide earthen archaeological and historical heritage that is progressively abandoned and exposed to more decay and risk of disappearance, and for the coming out of a more sustainable built environment. They also offer very interesting opportunities for developing relationships between the persons and the institutions, sometimes giving a decisive support for defining new perspectives of academic and scientific collaborations. But above all, these regional events are contributing to the development of a increasingly structured network for connecting people that contribute to give a global coherence and visibility to the field of earthen construction and architecture, confirming each past days, months and years, that this field is gradually recognised as a specific discipline. A discipline with its proper scientific perimeter producing knowledge, with its proper academic and teaching contents being more and more integrated in universities and in vocational institutions, contributing to the development of qualified professions and crafts, and offering new services to the civil society.

At the recent regional conference *Mediterra2009*, that was held at the Department of Architecture of Cagliari University in Sardegna, Italy, we raised the fact that « *we have reached a crossroad in the way we are addressing earth architecture* ». We pointed out that we should not « *continue the dogmatic approach, advocating the advantages of the material and this type of architecture, defending entirely the earth tradition, (...) repeating research and lab experimentations already done by others, teaching and training in the same way* ». We called for the necessity of a new « *approach with innovative perspectives, taking into consideration the specific characters of the places and people, integrating community collaboration in research and conservation*

management, facing new challenges through interdisciplinary study, international horizontal cooperation and exchange of expertise » (1). This regional conference in the Mediterranean area was followed by a workshop that defined an action plan in research and education, for heritage conservation and for the development of a new ecological habitat in the region. Our hope today is that TerrAsia 2011 could contribute to a similar approach and possible new outputs for a better national, regional and international horizontal cooperation.

Earthen architecture in the Republic of Korea is an old tradition tracing back to centuries and testified by some monuments and several vernacular human settlements among which we can quote the famous Hahoe village, listed as UNESCO World Heritage, the national site of Naganeupseong, still inhabited by a hundred of families, Donghak village, today abandoned, or the famous Buddhist temple of Bulguksa, a typical model of this religious architecture built in wattle and daub. Most Asian countries and particularly Japan, China, India, Bangladesh, Afghanistan, Iran, Irak, Tajikistan, Turkmenistan, Kazakhstan, Kirghizstan, Uzbekistan, are testifying of a wonderful earthen built heritage and vernacular traditions. Through the last decades research and studies have been carried out progressively valorising this cultural wealth and many countries of the region are considering the major challenge of preserving their earth architectural heritage. Simultaneously, there is a stronger commitment of the nations for promoting sustainable architecture and living environment that contributes to valorising a return to the use of natural materials, and among them earth that offers a great potential given its economical, social, cultural and energetic advantages. TerrAsia 2011 offers a good opportunity for sharing more information, for discovering unknown faces of Asian earth heritage, for facilitating the connection between researchers and professionals who are pushing ahead the revival of earth construction and architecture in the region.

Finally, we are particularly pleased to have offered our scientific support in organising this conference, in close collaboration with the Department of Architecture of Mokpo National University, member of the UNESCO Chair « Earth architecture, building cultures and sustainable development », with TerraKorea, the National Institute of Earthen Construction, and thanks to the decisive support of the National Research Institute of Cultural Heritage (NRICH). We are also very pleased to remind you that this conference is organised under the aegis of the International Scientific Committee for Earthen Architectural Heritage (ISCEAH) of ICOMOS. We wish to thank all members of the scientific committee who have reviewed the contributions of numerous authors coming not only from Asian countries, but also from Africa and Europe. We also wish to warmly thank our hosts and call for a full success of this international conference.

Welcome to TerrAsia 2011 in this nice country of the Republic of Korea.

Prof. Arch. Hubert Guillaud
Architecture, Environment & Construction Cultures
AE&CC Research Unit, CRAterre-ENSAG
National Superior School of Architecture of Grenoble, France

(1) Achenza, M., Correia, M. and Guillaud, H., (2009). *Mediterra 2009* proceedings. Edicom Edizioni, Monfalcone, Italy, 2009, 679 p., p. 9.

서문

1985년 아시아 지역에서는 처음으로 중국 베이징에서 흙건축에 관한 국제 행사가 열린 뒤로는 이 분야의 대규모 행사가 아시아에서 열린 적이 없습니다. 아시아 국가들의 흙건축 유산의 가치와 문화적 중요성, 그리고 흙건축 유산의 보존에 관한 전 세계적인 관심과 지난 30년 동안 풍부하면서도 소중한 자원인 흙을 자재로 사용하는 건축물들이 꾸준히 증가하며 흙건축이 새로운 부활을 맞이하고 있다는 점에서 아시아의 한국에서 열리는 이번 국제 컨퍼런스는 중요한 의미를 갖고 있습니다.

다른 한편으로, 우리는 21 세기가 시작된 이래 지난 10년 동안 흙건축에 관한 학회, 세미나, 그리고 심포지엄을 개최하면서, 학계와 과학계, 정부와 비정부 단체들의 이 분야에 대한 관심이 많이 증가했다는 것을 느낄 수 있었습니다. 국제적 규모의 유명한 회의들이 개최된 곳을 들자면 1971년과 76년 이란의 야즈드, 1980년 터키의 앙카라, 1983년 페루의 리마와 쿠스코, 1990년 미국 뉴멕시코주의 라스 크루케스, 1993년 포르투갈의 실브즈, 2000년 영국의 토키, 그리고 2003년 다시 이란의 야즈드, 그리고 2008년 말리의 바마코가 있고, 2012년 4월에는 다시 페루의 리마에서 큰 회의가 열릴 예정입니다. 국제적 규모의 행사들이 많이 개최된다고 해서 전 세계 곳곳에서 정기적으로 개최되고 많은 지역 행사들의 중요성과 과학적 가치가 줄어드는 것은 아닙니다.

지역 회의들은 덜 알려진 흙건축 유산의 구체적 특징과, 그 가치를 별로 인정받지 못하고 있는 과학적 연구의 중요성을 밝히는 역할을 하고 있습니다. 이 같은 지역 회의들은 국제 학계에 많은 토론의 장을 제공하는 한편, 지식과 정보의 교류를 용이하게 합니다. 이 같은 지역 행사들을 통해서 많은 국가들에서 흙건축의 부활을 지원하는 새로운 움직임들을 확인할 수 있습니다. 이러한 활동들은 소외된 이들이 거주지를 더욱 쉽게 얻을 수 있도록 해주는 것은 물론, 전 세계적으로 빠르게 황폐화되고 사라져가고 있는 고고학적 그리고 역사적 유산의 보존을 지원하고, 환경 친화적 개발을 확대하는데 중점을 두고 있습니다. 또한 흥미로운 것은 이러한 지역회의들이 사람과 기관들간의 관계를 맺어주는 기회를 제공하는 것은 물론, 가끔은 학계와 과학계의 협력을 위한 새로운 아이디어를 도출해내는데 결정적 도움을 주고 있습니다. 그러나 무엇보다도 지역 회의들은 흙건축 분야의 국제적 위상을 높이는데 중요한 역할을 하는 사람들을 서로 연결시켜주는 네트워크의 형성에 크게 기여하고 있습니다. 지역 회의의 이 같은 활동 덕분에, 흙건축은 구체적인 하나의 학문으로 점차 인정을 받고 있습니다. 이것은 흙건축 분야가 적절한 과학적 경계 안에서 지식을 생산해내고, 학문적으로나 교육적으로 적절한 관련 콘텐츠를 대학이나 직업교육기관들이 수용하는 한편, 자격을 갖춘 전문 인력과 기능인이 양성되어, 시민 사회에 새로운 서비스를 제공하게 되었다는 것을 의미합니다.

최근 이태리 사르데냐 주의 칼리아리 대학 건축과에서 열린 지역회의 메디테라 2009 (Mediterra 2009)에서 우리는 “이제 흙건축을 다루는 방법에 있어서 중요한 전환점에 다다랐다”고 선언했습니다. 여기서 우리가 주장한 것은 “흙이라는 재료나 그것을 이용한 건축 형태의 장점만을 내세우고, 흙건축의 전통만을 전적으로 수호하며, 다른 사람들이 이미 한 연구나 실험들을 반복하고, 똑같은 방식으로 가르치고 훈련시키는 독단적인 접근방식을 더 이상 계속해서는 안 된다”는 것이었습니다. 우리는 “지역과 민족의 구체적인 특성을 고려하고, 연구와 보존 관리를 위해 지역사회의 협력을 이끌어내는 한편, 융합연구와 국제적인 수평협업, 그리고 전문 지식의 교류 등을 통해 제시된 새로운 과제들을 적극적으로 수용하는” 새로운 혁신적 접근 방식을 추구했습니다. 지중해 지역을 중심으로 한 이 지역 회의에 뒤이어 열린 워크숍에서는 연구와 교육, 유산 보존 그리고 그 지역에 새로운 생태 서식지를 개발하기 위한 구체적 행동 계획이 정해졌습니다. 우리는 테라시아 2011 도 이와 비슷한 접근 방식을 도입하도록 힘쓰고, 더 나은 국가 간, 지역 간 그리고 범국제적인 수평협력을 통해 새로운 성과물들이 도출되기를 바랍니다.

수세기에 걸친 전통을 사랑하는 한국의 흙건축은 기념비적인 건축물들과 여러 곳에 위치한 토속적 민속 마을로 대표됩니다. 그 가운데는 유네스코 세계 유산에 등재된 유명한 하회 마을과 아직도 100 여 채의 가구가 살고 있는 낙안읍성, 현재는 거의 사라진 동학마을 그리고 유명한 불교사찰 불국사가 있는데, 불국사는 심벽(wattle and daub) 방식으로 지어진 종교 건축물의 전형적인 형태를 보여줍니다. 대부분의 아시아 국가들, 특히 일본, 중국, 인도, 방글라데시, 아프가니스탄, 이란, 이라크, 타지키스탄, 투르크메니스탄, 카자흐스탄, 키르기스스탄, 우즈베키스탄 같은 국가들은 흙으로 지은 훌륭한 유산과 고유한 전통을 보유하고 있습니다. 과거 수십 년 동안 이들 국가들은 자국의 흙건축 유산을 보존하는 것을 중요한 과제로 인식하고, 이 같은 문화적 보고들을 보존하기 위한 연구와 조사들을 진행해 왔습니다. 이 와 동시에, 이들 국가들은 환경 친화적인 건축과 생활환경을 더욱 장려하고 있는데, 그 덕분에 자연재료로 회귀하는 추세는 더욱 가속화되는 효과를 낳고 있습니다. 자연재료 가운데서도 흙은 경제, 사회, 문화 그리고 에너지 측면에서도 많은 이점을 갖고 있습니다. 테라시아 2011 은 더욱 많은 정보를 공유하는 물론, 아시아 흙건축 유산의 알려지지 않은 면들을 새롭게 조명하는 한편, 흙건축물의 건설을 통해 그 지역의 흙 건축 부활에 앞장서고 있는 연구자들과 전문가들 사이의 협력을 더욱 촉진시키는 기회가 될 것입니다.

마지막으로, 이번 회의는 한국 국립문화재 연구소의 열성적인 지원 하에 유네스코의 흙건축위원회 (UNESCO Chair <<Earth architecture, building cultures and sustainable development>>의 회원인 국립목포대학 건축학과, 한국흙건축연구회 테라코리아 (TerraKorea)가 함께 주최하게 되었습니다. 특히, 저희가 이번 회의에 학술적인 지원을 하게 된 점을 매우 기쁘게 생각합니다. 저희는 또한 이번 회의가 국제기념물유적협회 (International

Council on Monuments and Sites) 산하 흙 문화유산을 위한 국제과학 위원회(International Scientific Committee for Earthen Architectural Heritage)의 후원 하에 열린 게 된다는 점을 말씀 드리고 싶습니다. 아시아는 물론이고, 아프리카와 유럽의 많은 저자들이 제출한 기고문들을 검토해준 학술 위원회의 모든 회원들에게 감사의 말씀을 전합니다. 이 회의를 준비한 주최 측의 노고에 다시 한 번 감사를 드리며 이번 국제회의의 성공적인 개최를 기원합니다.

훌륭한 국가 대한민국에서 열리는 테라시아 2011 에 오신 모든 참석자들을 환영합니다.

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Proceedings – technical file

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Conference file

Organization

TerrAsia 2011 international conference is organized by:

- The Department of Architecture of Mokpo National University
- The National Research Institute of Cultural Heritage of the Republic of Korea (NRICH)
- TERRAKorea: Earth Architecture Institute of Korea

In cooperation with:

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- CRATERRE-ENSAG, International Centre for Earth Construction of Grenoble of the National Superior School of Architecture of Grenoble, France
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Framework

Mokpo National University, its Department of Architecture, partner of the UNESCO Chair "Earthen Architecture, building cultures and sustainable development", the National Research Institute of Cultural Heritage of the Republic of Korea, and the Institute of Earth Architecture in Korea (TERRAKorea), are the organizers and hosts of the 2011 International Conference on Earthen Architecture in Asia, that will be held from October 11th to 14th, 2011, in Mokpo. The conference is the result of the will to activate exchanges between the public, academic, scientific and private sectors involved in research and study activities on immovable earthen cultural heritage, on earth materials, and on earth construction techniques, as well as in the revival of up-to-date earthen architecture in the Asian Region, and to confront this regional background to the international community also involved in the field. This type of event has not been carried out at such a large scale since the international conference in Beijing, China, in 1985, and is an unique opportunity for discussing the most recent achievements in specific fields related to earthen architecture as well as the substantial and significant work carried out by the countries of the Asian Region, and to disseminate updated information on a regional and international level.

Background

Asian countries possess a rich archaeological, historical, and vernacular earthen architectural heritage. Research studies have been carried out through the last decades, gradually promoting this cultural wealth even though many Asian countries haven't yet finished drawing up their immovable heritage inventory. Moreover, many more countries of the region are considering the major challenge of preserving their earthen architectural heritage. Thus, additional conservation and enhancement of sites projects, many of them having been listed on a national scale and by the UNESCO's prestigious List of World Heritage, are being set up. Another important challenge is the necessity of promoting sustainable architecture and living environment at the core of which the use of natural building materials plays a decisive part. Among these, earthen materials are both abundant and accessible, and together with the rich knowledge and knowhow related to them, offer a great potential. Many fundamental investigations on the material, experimentations on building techniques, but also R&D projects aiming at promoting innovations, have been carried out during the last decades in Asian countries. All these scientific, cultural, social and economic assets, all these progresses, which are decisive for the future of the Asian Region, should be reviewed and much more widely disseminated within the international community. This conference offers such an opportunity.

Goals

The conference chiefly aims at assessing the state of the art in research, fundamental and applied, as well as the research and development (R&D) related to earth architecture in the Asian Region, to study recent developments in the field of heritage conservation (archaeological sites, historical and monumental architecture, vernacular building cultures), recent architectural design and housing projects, and recent achievements valorising the use of earth to promote cultural continuity and contribute to the sustainable development and preservation of the cultural diversity.

Contributions

This conference is opened to specialists throughout the Asian Region but also to other international contributions that have been selected by the scientific commission with the aim of promoting more active exchanges and networking among professionals of the academic, scientific, public and private sectors in relation to earth construction, architecture, and innovation in earth building materials and techniques.

Themes

Theme 1 : History of earthen architecture in Asia and other regions of the world

Sub theme 1.1.:

- Archaeological sites and historical monuments

Sub theme 1.2.:

- Vernacular architecture and traditional building cultures

Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world

Sub theme 2.1:

- Fundamental investigations on the material, research and development (R&D)

Sub theme 2.1.:

- Architectural design and sustainable development

Programme of the conference:

• Tuesday 11th October 2011:

Opening of the conference

Presentations of the 1st Theme, part one

• Wednesday 12th October 2011:

Presentations of the 1st Theme, part two

Presentations of the 2nd Theme, part one

• Thursday 13th October 2011:

Guided tour

• Friday 14th October 2011:

Ending presentations of the 2nd Theme

1st visit: Damyang Changpyeong Slowcity

A city which has been classified 'Città Slow' in 2007 for the first time in Asia. This city retains a traditional urban fabric which allows us to identify a typology of the Korean village which is in the midst of transition from the past era to the modern era, including the house in wattle and daub and wall in stone and earth that help understanding the Korean tradition in earthen architecture.



Wall in stone and earth



Traditional house in wattle and daub



Traditional house

2nd visit: Gimje Jipyeongseon middle&high school

Since 2002, this school has implemented an educational philosophy based on ecology: eating, living and educating ecologically. This ensemble has therefore been built by using several earth-based constructive systems: pisé, BTC, earth plastering, etc.



Principal building in BTC



Building in pisé



Residence in earth plastering

Theme 1: History of earthen architecture in Asia and other regions of the world

Sub theme 1.1.: Archaeological sites and historical monuments

Sub theme 1.2.: Vernacular architecture and traditional building cultures

The history of earthen architecture in Asian countries has been studied for a long time through numerous archaeological excavations that have highlighted the use of earth for human settlements since the Antiquity. Unbaked earth brick, commonly called “adobe”, has been the major building material, from the birth of the Asian civilizations and throughout millennia up to modern times. This is shown by a very diverse and rich vernacular heritage. The richness of the vocabulary that concerns earthen construction in the region, since the Antiquity, is a proof of such historical permanence. *Sahar* and *eperu* were designating raw earth in transcribed Sumerian and Akkadian, *im* and *tidu* (old Babylonian, 3rd to 2nd millennium A.C.), or *kalakku* (middle and new Assyrian, 3rd to 1st millennium A.C.) were naming earth to build for the same Sumerian and Akkadian languages (Aurenche et al., 2011)¹. The correspondence between these old languages and the modern Arabic today used in near oriental countries is also surprising for denominating the earth brick: the Arabic *libn* corresponds to the Akkadian *libnatu* (*Ibid*, p. 19). Looking up to the generic Chinese term *tu*, various types of clayey soils are denominated: *hangtu*, for the loess, *huangniantu*, for the yellow clay, and *heiniantu*, for black clay, (*Ibid*, p. 17), and *tupi* for the earth brick. In Iran, *chiney* is naming the cob, and *khagel* the traditional mortar made of mixed earth and straw. From Jericho (Cisjordania), to China, Korea and Japan, crossing Iran, Afghanistan, all central Asian countries, Pakistan, India, we can not cover all this semantic diversity which is not studied so much by the scientific community, opening new directions for a decisive research on the worldwide earthen construction languages that could aim at producing a specific dictionary. The archaeological heritage of the whole region is really impressive and we can quote some of the most famous sites that are revealing the use of earth, bricks or rammed earth on this huge continent. The sites of Ur, Eridu, Larsa, Uruk, in Mesopotamia; Mari in Syria; Erbil in Kurdistan; Susa and Jiroft, in Iran; Fayaz Tepa and Merv, in Turkmenistan, Ajina Tepa with its famous Buddha today exposed in Dushanbe, Tajikistan; old Neolithic sites of Amsa-dong and Gouha, in the Republic of Korea; sites tracing back to the Longshan period (3000 – 1800 A.C.), in central China (Henan), as Yongcheng or the so impressive ruins of Jiaohe city in Xinjiang dating from the more recent Tang period (618-907 B.C.); and so on in all countries.

This ancient heritage has been continuously prolonged in time giving birth to many vernacular traditions that can be still observed today, thereby giving a testimony of flourishing building cultures enlightening the genius of builders, and contributing to the cultural identity of the places. Here too, we can not express all this magnificence and intelligence just looking at Shibam and its unique sky scrappers in adobe, at Seiyun or Tarim, in the Wadi Hadramaut Valley, southern Yemen; or looking at the wonderful villages of Himachal Pradesh, north India, as Tabo in the Spiti river valley; and to all traditional human settlements in rammed earth and earth brick along the southern slopes of the Himalaya chain, in Nepal, Bhutan, or to the old city of Leh and to the Buddhist monasteries in rammed earth of Ladakh and Tibet that are dominating landscapes in rocky and desert altitude. The Republic of Korea, itself, is blessed with

¹ Aurenche, O. et al., (2011). Aurenche, Olivier, Klein, Alain, de Chazelles, Claire-Anne, Guillaud, Hubert, « Essai de classification des modalités de mise en œuvre de la terre crue en parois verticales et de leur nomenclature ». Les cultures constructives de la brique crue. Montpellier. Editions de l'Espérou, 2011, 501 p., pp. 13-34.

an old vernacular earthen architecture tradition as shown by the famous Hahoe village, featured on the List of World Heritage, the national site of Naganeupseong, still inhabited by a hundred of families, Donghak village, today abandoned, or the famous Buddhist temple of Bulguksa, a typical model of this religious architecture built in wattle and daub.

Can we really appreciate all this magnificent archaeological, historical and modern heritage that the entire Asian continent possesses today? Numerous pieces of researches have been carried out through the last decades, gradually promoting this cultural wealth and the declension of its contextualized identities, even though many Asian countries and numerous worldwide countries have not yet fully achieved drawing up their immovable heritage inventory. However, many more countries of the region are considering the major challenge of preserving and valorising their earthen architectural heritage which represents a substantial economical resource for their local development. Thus, since the end of the 20th Century, additional conservation projects of conservation and management of archaeological sites and historical architectural properties have been listed on a national level, and on the UNESCO prestigious List of World Heritage. Among them, let us briefly mention for China the Great Wall (1987) and Mogao Caves (1987), the mausoleum of the First Qin Emperor (1987), Potala Palace in Lhasa (1994), Yin Xu (2006), and more recently the wonderful Fujian Tolous, these unique fortified collective housing in rammed earth. Let us also remind Persepolis (1979), Chogha Zanbil Ziggurat and Complex (1979), Bam (2004), in Iran, Ashur (Qal'at Sherqat) and Samarra archaeological in Irak (2003 and 2007); the proto-urban site of Sarazm, Tajikistan (2010), or the historical monuments of Old Kyoto (1994) and Nara (1998), Japan, partially built in wattle and daub; the wall city of Baku, Azerbaijan (2000), the historical centre of Bukhara in Uzbekistan (1993), the old Parthian fortresses of Nisa in Turkmenistan (2007), the site of Moenjodaro, in Pakistan (1980), and Lumbini, the Birthplace of Lord Buddha in Nepal (1997).

The conservation of earthen archaeological sites and traditional vernacular earthen architecture is subject to more research. But, even if previous practices using polymer-based physic and chemical treatments (such as silicate ethyl), or frequent use of cement for structural strengthening, have been progressively abandoned, because not really compatible with earth based materials, whatever the building techniques are, a lot of progress still must be made. Likewise, it was believed for many years that the deterioration of outdoor vestiges could be protected and preserved by roofs built over the more exposed structures. But, certain side effects are contributing to accelerating deterioration and decay. These include surface erosion and progressive loss of structural cohesion between the grains of the matter, under the effect of the modification of the ambient hygrometry, none of which are anticipated in most cases. Nevertheless, accumulation of failed intervention, the incompatibility of the means employed and the ensuing modification of the balance between earthen structures and their natural environment have gradually been acknowledged by professionals. However, some inappropriate practices still occur, particularly in the restoration and the rehabilitation of traditional earthen dwellings. Many of them, in most regions of the world are undergoing cosmetic treatments, resulting not only in an irreparable loss of authenticity, thus contributing to reducing the diversity of regional and local cultural identities, but also in more pathologies and decay. Earthen architecture, beyond its vulnerability to environmental threats (rain, frost, salinity, etc.), is also exposed to human action. Yet, negative attitudes about earthen architecture, the lack of maintenance, careless interventions, vandalism and even the conflicting interests of

scientific disciplines and practitioners of conservation can turn out to be more devastating.

Likewise, the tourism industry can considerably affect the local development process, socially, economically, and culturally. This is the case for mass cultural tourism for countries which are chiefly dependant of this sector. And the risk is greater for earthen heritage which is insufficiently protected. Thus, it is of paramount importance to redefine a correct balance between technical practices, and management processes because, although they are inseparable, any excess in favour of one or the other will inevitably be harmful.

In the light of the above-mentioned outline of the current situation of earthen archaeological and vernacular architectural heritage, we can point out a real threat of destruction and even extinction of a magnificent worldwide collective property. In the current state of globalization, a global form of “trans-culturation” brings considerable risks of “de-culturation”. This actively fosters a dramatic loss of cultural identity that is superbly expressed in the range of earthen architecture worldwide. However, there is a hope for earthen architecture as we can observe much more commitment from nations in scientific research, specialised higher education and vocational training for archaeologists, architects, conservators, site managers and other concerned professions. All this contributes to raising political and public awareness of the value of earthen heritage, and also encourages public dedication to the preservation and continuity of cultural diversity. The UNESCO Convention on the Protection and Promotion of the Diversity of Cultural Expressions (2005), which promotes links between cultural diversity and local development, takes up the challenges of cultural exchanges and pluralism, viewed as precious facets of cultural diversity. Earthen architecture, in Asia and worldwide, which stands as irrefutable evidence of that diversity cannot fail to gain from this. In this context, giving new consideration to the Hegelian concept of *Aufhebung*, with its twofold meaning of “conserving” and “rising beyond”, the “spirit” of earthen heritage inherent to cultures using earth as main building material may be thought to herald a truly sustainable future.

This first theme of TerrAsia 2011 international conference, with its twin sub themes on archaeology and history, and on vernacular architecture, contributes to throwing light on an approach of the values of the heritage in the region, adding to the documentation of ancient earthen building techniques (Mesopotamia), presenting new tools for documenting the pathologies on ancient vestiges (Tajikistan), theoretical and practical approaches of preventive conservation (Turkmenistan). This first theme also contributes to the inventory of specific characters of less known aspects of the regional earthen architectural heritage (South Korea, Morocco, Bangladesh, and Iran). Other contributions will highlight the subtle balance between the natural desert environment and earthen architecture (Iran). All authors contributing to this first theme must be thanked for their provision to the knowledge.

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EARTHEN ARCHITECTURE IN SOUTH KOREAN ARCHAEOLOGY: UNDERSTANDING VALUES

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Theme 1: History of the earthen architecture in Asia and other related region

Sub theme 1.1: Archaeological sites and historical monuments

Key words: Earthen archaeology, South Korea, values, interpretation, presentation

Abstract:

At the end of 20th century, South Koreans' are well aware of the importance of earthen architecture; based not only on the recognition of excellent traditional techniques, but also through scientific research on the excellence of earth as a building material. In contrast, earthen archaeological sites have not had such interest, perhaps due to ambiguities between architectural and archaeological definitions. As a result, assessments of the value of earthen archaeological sites often underestimate or ignore their diverse values. Accordingly this also complicates interpretation and presentation. In order to preserve earthen archaeological sites in South Korea, some extended definition for context is necessary, with wider assessments of value, and interpretation and presentation to the general public as well as scholars. From this perspective, the paper examines two case-studies: the Jeongok-ri Prehistoric Culture Experience Programme, which is an example of valuing and interpreting an earthen archaeological site; and Sosadong, where the preservation approaches would be a good case for this rescue excavated site.

1. BACKGROUND AND AIMS

Since the end of the 20th century earthen architecture has drawn much attention by the South Korean people, as the quality of life, which is called as "well-being life style" in Korean culture. This new trend places more interest in healthy life style, and the Korean traditional earthen building has been regarded as an excellent building material for the healthy life. In an intellectual context, earthen architecture often used to be associated with negative values, such as backwardness, poverty, and dirty or unsanitary conditions (Cooke, 2010:1). This used to be the case in South Korea. However, it has been significantly transformed, due to the growing appreciation of earth as an eco-friendly and health-friendly building material. In addition, research into the Korean traditional architecture, such as *Hanyok* or *Chogajib*, where a complex of wooden frame earthen walls and fired earthen roof tiles, or rice straw roof, has been constructed as contemporary architecture (fig. 1 & 2). As a result, earthen structures based on the Korean tradition have been popular research topics in Korean architecture.

In contrast, in South Korean archaeology, despite many archaeological sites being composed of earthen architecture, little research into this material has been carried out. From the Palaeolithic to the 19th century, earth was the most common building material in South Korea. Rescue archaeology, since the 1990s, has excavated a large number of archaeological sites with earthen architecture, but they have not drawn much attention from Korean professionals or the majority of the Korean people. This could be the result of the ambiguity of definition of earthen architecture in South Korean

archaeology. The intellectual definition of earthen architecture would be different between Korean archaeologists and architects. It seems that they have different definitions of earthen architecture depending on the location of earthen structures and building time. Although it is obvious that earthen archaeology and earthen architecture are sharing a common part, it seems that both of fields are dealing with different subjects. Korean architects place more interest in traditional building on the ground, and Korean archaeologists also do not pay enough attention on architectural approaches on their research of earthen archaeological sites.

This also raises a value issue: the assessment of value of archaeological sites, and their appropriate interpretation and presentation, currently underplays the importance of earthen archaeological sites in South Korea. Earthen archaeological sites should pose a crucial part of architecture in principle, such as the oldest habitation form of Korean ancestors. However, this architectural value of the sites is often underestimated or less considered by Korean archaeologists. Consequently, it is hard to say that diverse values of archaeological sites have been identified and discovered. It also makes its public interpretation and presentation complicated.

This paper explores the issues of definition, value, and interpretation. This paper will not focus attention on technical approaches, such as the scientific preservation, but rather on the theoretical framework for such technical issues. For this, this paper will identify the relevant issues in South Korea and will suggest some possible approaches using the case studies of Jeongokri Prehistoric Site and the Sosadong Site.



Fig. 1 & 2 - examples of Korean traditional houses; *Hanyok* and *Chogajob*, which were built of earthen material with wooden structures (captured from the web page of the Cultural Heritage Administration of Korea).

2. DEFINITION: EARTHEN ARCHAEOLOGY IN SOUTH KOREA

As an independent academic field, the earthen structure is an important research subject shared by the field of archaeology and architecture. In general and comprehensive point of view, the earthen architecture shared by the field of archaeology and architecture could be the archaeological remain built of earth or earth and other materials and having cultural, historic, and social values (fig. 3a). It could be called as earthen archaeological sites or earthen archaeology. It is necessarily a common or cooperative research field by archaeologists and architects

Accordingly earthen architecture can encompass a wide range of structures, from a simple pit type habitation to complex and substantial structures built of multiple-materials (Warren, 1999: 3-5) and from prehistoric time to historic time. However, in South Korean practice, it seems that the definition of earthen architecture has been

separately accepted depending on relevant professionals' context; for example, a structure on and under the ground. For Korean architects, earthen architecture is generally accepted as structures built of earthen materials on the ground in the historic period. In contrast, it means the survival underground in the prehistoric period for archaeologists. Consequently, it may appear that archaeologists and architects deal with different subjects (fig. 3b).

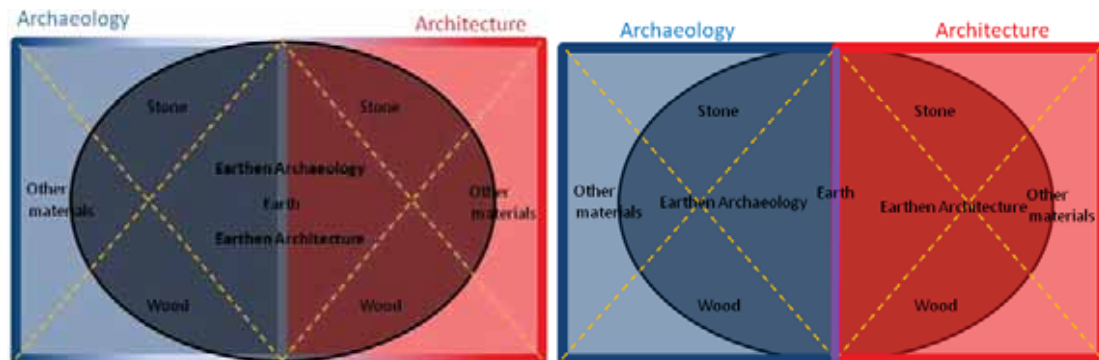


Fig. 3 – (a) The general and comprehensive concept for the definition of earthen archaeological sites; and (b) in South Korean practice by Author

For example, Warren (1999: 6) identified four forms of construction to define earthen architecture in an archaeological context : “dried component (mud brick), semi-plastic form (earth construction), semi-liquid earths, and compaction of earth (framework)”, while Cooke suggests five construction methods: “shaped blocks (mudbricks)”, ‘rammed earth (*pisé*)’, placed earth, turf and sod construction, and earth placed onto a supporting frame and armature” (Cooke, 2010: 8-11). In Korean practice, the architectural heritage is categorised by main materials: wooden, stone, and grave (the National Research Institute of Cultural Heritage of Korea, 2008: 10).

These definitions may be applied to Korean earthen architecture. The typical Korean earthen architectural structures on the ground, such as *Hanyok* and *Chogajip*, with typical traditional habitation buildings, can be located in a multi-manner of “rammed earth (*pisé*)”, “placed earth”, “turf and sod construction” and “earth placed onto a supporting frame and armature” by Cooke, and also pose in the “wooden” category, because structures often consist of wooden frames with earthen walls. This type of structure have been placed much attention by Korean architects as well as Korean people with the quality of life trend.

However, another typical type of earthen architecture, earthen archaeological site, in Korea poses ambiguous position; such as the Neolithic or Bronze age settlement consisted of pit type house and ditch structures. This type of construction has a rich history dating back to the 1st century, since the Neolithic Age in Korea. The pit dwelling house, first seen around 5,000 years ago (fig. 4a), is generally built by excavating the bank of a river or the top of a hill, normally with a wooden roof structure covered by reed. It continued up to the 17th century in Korea (fig. 4b). It is hard to identify this type of construction in the suggested forms of earthen architecture defined above: but in terms of the quality and quantity of this type of site in Korea, it should be categorised as an earthen architecture. In addition, it is hard to say that this oldest type of earthen structure has drawn much attention by Korean people.

In order to explore Korean earthen architecture or earthen archaeology, it is necessary to consider an excavated or investigated pit or trench in the Palaeolithic. In fact, it may not be an archaeological remain, and it may be modern creation caused from academic research. However, the pit or trench would be an important tool or resource to interpret

and present the value of the Palaeolithic. Sometimes, it could be regarded as an archaeological site itself. For example, the Jeongok Prehistoric site could be the most important site to discover the human behaviour in the Palaeolithic period in Korea. However, there are just little remains for the interpretation and presentation of the site such as stone tools. Much considerable information is included in the excavated pits and trenches such as the E55S20 pit. Therefore, the pit or trench could deserve to be regarded as an earthen archaeology though it is a modern creation.



Fig. 4 – (a) A Neolithic house in the Amsa-dong Site; and (b) pit dwelling house in 17th century in the Gouha Site in South Korea (captured from the Amsa-dong Site webpage and the excavation report of Gouha Site)



Fig. 5 – (a) The excavated Palaeolithic pit (E55S20 pit) and (b) the museum for displaying the pits in the Jeongok-ri Prehistoric Site (photographs taken by Author)

3. THE ISSUE OF VALUES: SOUTH KOREAN EARTHEN ARCHAEOLOGICAL SITES

In the field of Archaeological Resource Management, the term “conservation” does not mean only the physical protection of the sites, but also the preservation of their diverse values, such as historic and artistic, social, spiritual, natural, and economic values (Avrami and Mason, 2000: 15-17). However, in South Korea this diversity of values is seldom considered or assessed in the decision-making on protection. Since the 1990s in South Korea, although a number of earthen archaeological sites have been discovered due to rescue excavations, few excavated earthen archaeological sites have been preserved (fig. 6). At first glance, this would seem to be due to the conflict of two types of values: “socio-cultural values” and “economic value” (Mason, 2008: 103-107). It seems that economic values are prioritised. It could also mean that the socio-

cultural value including the academic value has been inappropriately assessed because of the ambiguity of definition of earthen archaeological sites.

In order to identify diverse values of earthen archaeological sites, the cooperative research is necessary because it is a common part of archaeology and architecture. However, in South Korean practice, the earthen archaeological sites, especially underground structures in prehistoric period, have not been appropriately dealt. It would be true that the excavated sites are still not the major subjects for architects, but for archaeologists in South Korea. Accordingly the values identified and assessed by archaeologists are inevitably incomplete. Recently one of the significant issues in Korean archaeology is the quality of rescue excavations. Korean archaeologists are still applying a “dig and run technique” (Chiari, 2000: 107); giving little consideration relevant to the issues of preservation and management after the investigations. In order to protect the earthen archaeological sites, archaeologists should consider not only the archaeological value of the site, but also the architectural value of the site as the oldest form of Korean architecture. It would be the first step to discover the wider “socio-cultural values” of Korean earthen archaeological sites.

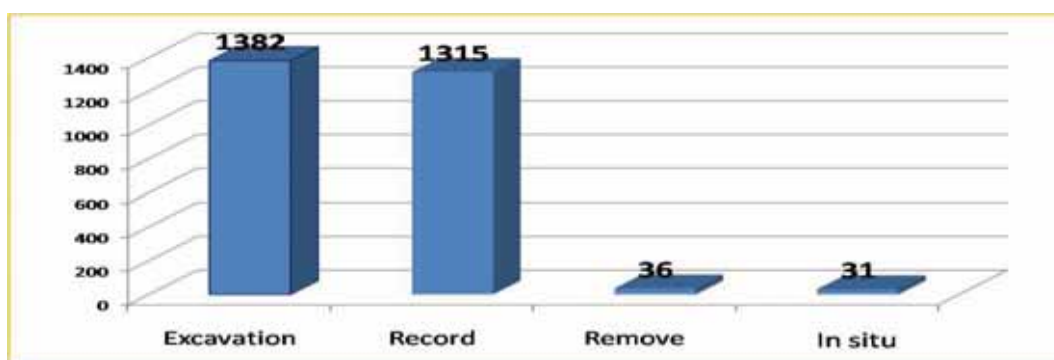


Fig. 6 - The number of excavations and preservation manners in South Korea in 2007

Given the intellectually insignificant position of earthen archaeological sites in the Korean culture and history, it also would be useful to raise the awareness of intangible values. It is generally accepted that archaeological sites are a complex of tangible and intangible culture, and in the case of earthen sites this may include traditional building techniques. In addition, earthen structures are physically vulnerable to deterioration; which means that continued maintenance activities are needed (Oliver, 2008: 80). Research in earthen architecture places much attention on the aspect of materials and craftsmanship, as well as physical conservation. In South Korea, research into building maintenance techniques for earthen structures has been also carried out, within the existing limited definition of “earthen architecture” in South Korea. In the case of earthen archaeological sites, some recent attempts have been carried out by archaeologists to explore the intangible values: for example, the approach to the reconstructed and rebuilt prehistoric pit dwelling houses by Jajin Koo (2011), or the experimental approach to the Bronze Age pit dwelling house (Kyu-jin Oh and Uihaeng Heo, 2006). However, the intangible value of earthen archaeological sites is still ambiguous. In order to reconstruct and protect the diverse values of earthen archaeological sites in South Korea, it is necessary to accumulate results of rich

scientific approaches for the intangible culture and history, as well as the conservation of the sites.

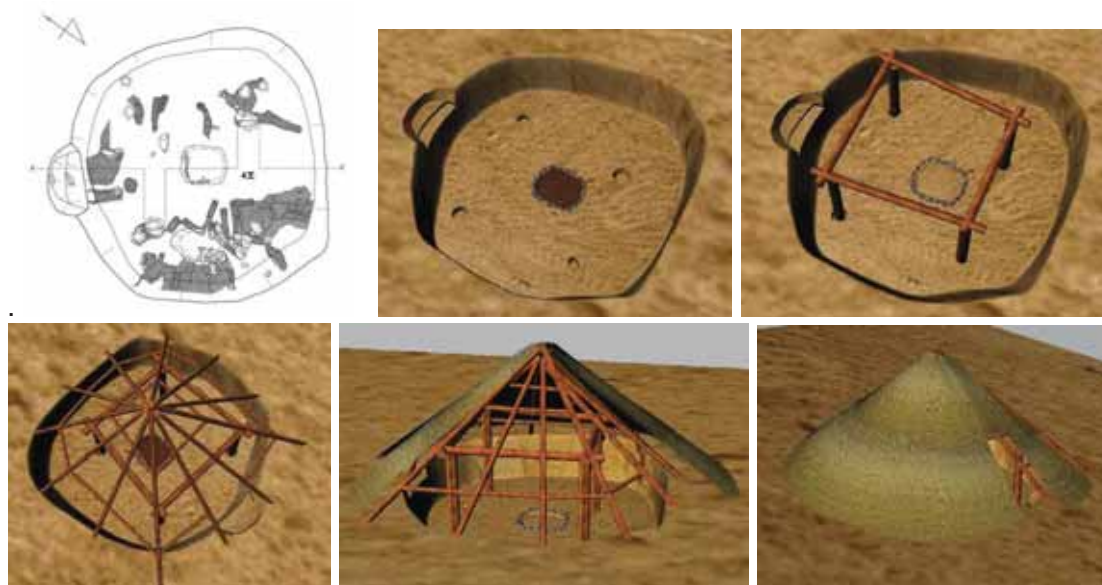


Fig. 7 - An example of the image based reconstruction of the Neolithic house in the Amsadong Site (Jajin Koo, 2011: 20)

4. INTERPRETATION AND PRESENTATION IN SOUTH KOREA

It could be said that interpretation and presentation issues surrounding earthen archaeological sites in South Korea is related to the lack of a clear understanding of values.

The first issue is the lack of physical resources to interpret and present values. The ambiguity of definition often leads under valuing the sites, and is perhaps the reason for the lack of resources for the interpretation and presentation, both in terms of displayed sites and delivered significance. As research by Oliver (2008: 80) argues, “the values of archaeological sites is derived the physical remnants of a lost culture or tradition in many modern cultures”. Here the physical remnants mean the archaeological site, but in South Korea this resource has been disappearing, being replaced by just an archaeological record. As shown in the previous section, more than 95% of archaeological sites, a considerable part of them earthen archaeological sites, have been physically destroyed and only “preserved by record”. It means that few interpretation and presentation resources are now left in South Korea. This paper does not suggest that all archaeological sites have to be preserved *in-situ*, but the diverse values of sites should be identified, even in the case of preservation by record. These sites might be excellent tools to interpret and present values and professionals should bear this in mind.

Another issue relevant to the interpretation and presentation of earthen archaeological sites in South Korea would be its main subject, the general public and the Korean people. The ICOMOS *Charter for the Interpretation and Presentation of Cultural Heritage Sites* (ICOMOS, 2008: 3) defines interpretation as “the full range of potential activities intended to heighten public awareness and enhance understanding of cultural heritage site”. The Charter clearly states the importance of the general public. For the appropriate interpretation, the accessibility to the sites is necessary. However, in South

Korea practice, the public access is often limited. It is because of the conflict between stakeholders as well as the physical fragile, especially during the process of archaeological investigation. It is generally acceptable to limit the public access for protection, but it should be reconsidered to limit access due to the development or preservation of the site. In order to resolve the conflict, the public awareness of the diverse values would be the better approach.

After the end of the archaeological investigation, interpretation of the excavated values of the sites can still take place: for example, through more accessible excavations reports or simple signage. Archaeologists need to use a different language, with the interpretation and presentation focused on the South Korean people as its main subject. Possible approaches to this have been suggested, such as rules for writing or speaking for the non-specialized audience (Allen, 1995), the use of story-telling as a presentation manner (McCarthy, 2008: 538-544), using a “playwright” (Gibb, 2008: 545-555), and emphasising writing skills for the public (Zimmerman, 2003: 21-40). At present, Korean earthen archaeological sites are not clearly interpreted or presented to a wider audience. For example, in the case of archaeological remains in prehistoric period, many of South Koreans have not recognized the rich value of the sites. It is because the investigation and archaeological research do not interpret the values for the general public, but for the relevant professionals.

5. POSSIBLE APPROACHES: CASE STUDIES

There has been a recent awakening of the importance of archaeological sites as a useful tool for Korean identity. Some significant attempts have been made to address the issues discussed above. These case studies may not be best exemplary, but they deserve to be explored as possible approaches.

The Jeongok-ri Prehistoric Site and the Prehistoric Culture Experience Programme

According to the suggested definition in this paper, the excavated Palaeolithic pit at Jeongok-ri could be regarded as an earthen archaeological site. The site has been an example of interdisciplinary study, since the discovery of the first Acheulean hand axes in East Asia in 1978. Diverse interdisciplinary studies have been carried out and considerable conservation work has been done on the excavated pits: for example, the conservation of the E55S20 pit, the construction of both a site museum for displaying the excavated pits and the Jeongok Prehistoric Museum (fig. 5). Since 1993 a “Prehistoric Culture Experience Programme” has been developed at the site, as a part of the annual Festival of Yeonchen Jeongokri Palaeolithic Site. The main purpose of these activities is to interpret and present the diverse values of sites to a wide range of the general public, in a participatory way and with the aim of creating contemporary social values. The programme is an exemplary case for communication and educational interpretation for archaeological sites in South Korea. The visitors, of which most are children and teenagers, are provided with an experience of Palaeolithic daily life, along with archaeological information based on interdisciplinary research. The programme consists of an introduction to prehistoric life, making stone tools, making pottery, building prehistoric houses, a virtual archaeological excavation and using stone tools (The Institute of Cultural Properties Hanyang University, 2009). This communicates the site values to the general public in an interesting, exciting, and effective way. In addition, this can develop diverse values in a participatory way, with people having the opportunity to explore the values through interpretation. Additionally,

international conferences, which are also a part of the festival, are developing the rationale of preservation and use of earthen archaeological sites in South Korea.



Fig. 8 - The Prehistoric culture experience programme in the Jeongik-ri Site

The Sosa-dong Site

The Sosa-dong site is a different situation. The site was excavated by the Korean Institute of Heritage, between 2004 and 2006, as a rescue excavation in advance of a new development for the area. As a result, 365 archaeological remains, including 81 Bronze Age settlements, were discovered and this is regarded as a very significant site for the Korean Bronze Age (the Korea Institute of Heritage, 2008). However, the whole of the site could not be protected *in-situ*, due to the rescue excavation and the high costs of conservation and maintenance. As with many of the significant earthen archaeological sites in Korea, the site was thus partly preserved sites *in-situ*; and this portion was reburied to protect the remains. The area was intended to be used as a public park for the local habitants, but reburial made it difficult to appropriately display the site. In order to resolve this, the outline of excavated Bronze Age houses were marked with tree-lines (fig. 9) and signage was provided explaining the discoveries. The trees used to mark the houses were selected with two considerations: to avoid root damage to the reburied site and to reflect the conjectured Korean flora of the Bronze Age. In addition, in the excavation report, image-based reconstruction was attempted (fig. 10). In order to save time and costs 3D Scanning Technology was used on all the remains. This was both beneficial for documentation and for the creation of images for interpretation. This is a positive alternative for the presentation of the site, rather than *in-situ* presentation using protective structures or wall cappings.



Fig. 9 - Pictures of the reburial plan and the current condition of the site after the preservation



Fig. 10 - The image-based interpretation in the excavation report
(Korea Institute of Heritage, 2008)

6. EARTHEN ARCHAEOLOGICAL SITES IN SOUTH KOREA

It is evident that the Korean earthen archaeological sites pose a significant resource for cultural and historical identity, due to the rich quality and quantity. Nevertheless, their value often seems to be underestimated, due to issues with definition, wider values, and interpretation and presentation. These issues result in the role and importance of Korean earthen archaeological sites being somewhat ambiguous. The unbalanced assessment of diverse values and the lack of approaches to intangible factors by archaeologists are the main reasons why the interpretation and presentation of earthen archaeological sites is generally poor. Accordingly, extending the definition and intellectual context of earthen sites, and more widely assessing their values, will enable them to be better interpreted and presented to the Korean people (who are the conceptual owners of the sites). The case studies in this paper show that new attempts to work with these sites can offer considerable potential.

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Curriculum

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DEVELOPMENT OF EARTHEN ARCHITECTURE IN IRAN

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Theme 1: History of earthen architecture in Asia and other regions of the world

Sub theme 1.1: Archaeological sites and historical monuments

Keywords: Earthen heritage, archaeological sites, mud-brick, *chineh*, *kahgel*, history of architecture

Abstract:

Earthen materials (mud-brick, *chineh*, and *kahgel*) have been used in Iran for thousands of years, in its diverse geographical and environmental conditions, as amongst the most essential building materials in constructing residential buildings and historic monuments, and in particular rural dwellings. Earthen architecture can be observed in various regions of the country, from the humid environment of the northern part near the Caspian Sea to the peripheries of the Great Desert (Kevir) and to the cold, mountainous regions of the East. Contrary to the preliminary impression arisen from the simplicity and similarities of various adobe, the original materials (clay, additives and fillers), curing and manufacturing techniques, and the ways they are utilized based on the cultural and environmental characteristics of each geographical regions, have produced, during the course of history, very diverse compositions in the type of the products, forms, dimensions, and their qualities.

The remaining earthen building materials in the historic sites, from the prehistoric and ancient periods to the present day rural houses, are therefore bringing to the fore the development and

the evolution of manufacturing techniques and their influences on the quality of remaining architectural heritage. It is thus intended in this research, to study, individually and comparatively, these evidences using technical, artistic, architectural and pictorial documents, features and data.

Up to now, a large number of studies have been made on the architectural earthen heritage of Iran, mainly from the archaeological and architectural viewpoints either on specific architectural remains in a given region or on particular historic periods. Technical investigations have also been carried out, intermittently, on the mud-bricks in some historic sites such as Chogha Zanbil World Heritage Site in South-western part of the country, Arg-e Bam, another World Heritage Site in the South-western Province of Kerman and Jiroft a very important archaeological site again in Kerman Province, to find and obtain the best possible methods of the conservation and protection of earthen architecture.

Based on existing sources the first method of producing mud-brick traces back to around eight millennium BC, in Ganj Darreh and Ali Kosh in west of Iran, where a form of mud-brick were used in early architectural features. These remains are being correlated to the beginning of Palaeolithic era (5800 to 6200 BC). Earthen materials developed architecturally, artistically and technically during the Achaemenids, Parthian and Sassanid periods to an outstanding level. Adobe was also used as the main building material in constructing public and social buildings and in general, residential structures after the advent of Islam. It is to be said that mud-brick either isolated or in combination with baked brick are almost constantly used in the Iranian buildings. However what can be observed in these studies as a vacuum is the lack of comparative studies (technical characteristics, manufacturing techniques and their applications) between different sites and regions which seem to be less investigated.

This paper intends to describe, technically and historically, the development and utilization of mud-bricks in different historical periods and its influence on the regional architecture in Iran.

1. INTRODUCTION

Recent excavations have shown that constructing mud-brick buildings in Iran traces back to the 6th millennium B.C. The remains in Choghamish and Zagheh, are some evidences of using mud-bricks during this ancient period.

Contrary to the baked brick, mud-brick resistance is increasing intermittently. While baked brick has the maximum resistance when it is brought out of the oven, it will be weakening little by little with its use in the building. Besides, baked brick is not integrated with its mortar. This is why the resistance of the foundations and the building structure of old Iranian mosques (which are constructed in mud-brick) does not face serious problem and thus does not require essential interfering for consolidation.

According to the location and use of the adobe in the building, Iranians have applied changes in its form, dimensions, and in the matter, in order to obtain an optimum performance. But even when baked brick has been used in building structures, mud-brick did not lose its role and importance in Iranian architecture. The use of this material in rural buildings (for stables, stores or different other constructions) and in different regions of the country (except for the humid moderate climate in the north), especially in great desert (kevir) and in central regions of Iran are evidences of this claim. It is said that more than 50% of the country's buildings (rural buildings are the major part of this percentage) are constructed in mud-bricks.

1.1. Dispersion of earthen buildings in different climates of Iran

Iran is located in dry and semi-dry region which is mainly divided in dry and humid climate. Since ancient times, adobe monuments have been scattered in different geographical regions of Iran. The residents of these areas have been used soil as the most abundant and economical material, according to the geography, the culture and requirements for creating numerous masterpieces, such as Dahane gholaman, Kuh-e Khajeh and Shahre Sookhteh (East), Narin castle (Central plateau), Bam citadel (East), Ziwieh castel (West), Great wall of Gorgan (North-eastern), Chogha zanbil Ziggurat (South-western), ...

2. RESEARCHES ON EARTHEN BUILDINGS IN DIFFERENT CLIMATES IN IRAN

2.1. Results and analyses

	Site	Geographical location	Historical period	Adobe dimension (Cm)	Explanations
1	Ganj Darreh	Kermanshah, West	Late 8 th -early 7 th millennium	Different dimensions length: 50-59	<i>Chineh</i> and plano-convex, cigarette adobes
2	Tappeh Ali Kosh	Dehloran, West	7 th -3 rd millennium	50x40x10	Pieces of sedimentary mud
3	Tappeh Zagheh	Qazvin, Central plateau	8 th millennium	40-80x25-35x10-12	<i>Chineh</i> , handmade mud-brick, <i>panjeh Keshideh</i>
4	Jeyran Tappeh & Yan Tappeh	Savojbolagh, Central plateau	6 th millennium	15-10x15-10x15-10	Small cubic handmade mud-brick
5	Tappeh Sialk	Kashan, Central plateau	5 th -4 th millennium	Irregular with different sizes	Handmade hunk of mud-brick, <i>Chineh</i>
6	Sagz Abad	Qazvin, Central plateau	7 th -5 th millennium	40x40x11-15	<i>Chineh</i> and handmade mud-brick
7	Ziggurat of Haft Tappeh	Shush, South-western	Late 4 th millennium	40x40x10	Molded mud-bricks
8	Tali Iblis	Kerman, South-eastern	5 th millennium	38-80x35x20	<i>Panjeh keshideh</i> adobes, without foundation
9	Tappeh Hesar	Damghan, Central plateau	4 th -1 st millennium	47x23x11 65x33x9	Rectangular mud-bricks, Rarely <i>Chineh</i>
10	Shahr-e Sookhteh	Zabol, East	3 rd millennium	40x20x10	Molded rectangular mud-bricks
11	Konar Sandal	Jiroft, South-eastern	3 rd millennium	40x40x10 60x30x15	Vary large adobes
12	Shahdad	Kerman, South-eastern	3 rd -2 nd millennium	39x22x8.5	Rectangular mud-bricks
13	Cheshmeh Sheykh (Delazian)	Semnan, Central plateau	Early 2 nd millennium	40x30x11 36x28x11	Mud-bricks coated with mud
14	Ozbaki	Karaj, Central plateau	Median period-Iron Age III 1 st millennium	40x40x10-15 45x45x10-15 34x34x10-15	Two colored mud-bricks and <i>Panjeh keshideh</i>
15	Nooshijan	Hamedan, West	Median period-Iron Age III 1 st millennium	40x25x13	Rectangular mud-bricks and primary <i>Muqarnas</i>
16	Sialk massive structure	Kashan, Central plateau	Iron Age III 1 st millennium	35x35x15	Constructed on a platform (<i>Mastaba</i>)

17	Hasanlou	Orumieh, North-western	Iron Age III, 1 st millennium Mannai	40x23x14-15	Rectangular mud-bricks, Stone foundation
18	Chogha Zanbil Ziggurat	Shush, South-eastern	1 st millennium Elam	40-41x40-41x10 38-39x38-39x8/ 33x33x8	Mud-bricks combined with brick debris and straw
19	Haftvan Tappeh	West Azerbaijan, North-western	1 st millennium, Urartu, Median, Achaemenids, Parthian, Sassanids	410x40x10 42x42x12 / 32x32x13	Stone foundation
20	Ziwieh	Kordestan, West	1 st millennium, Mannai	46x46x14	Red and grey color mud-bricks
21	Altin Tappeh	Tajan, North-eastern	1 st millenium	60x50x15	Stone foundation
22	Tappeh Hegmataneh	Hamedan, West	Median, Seleucid	33x33x12/36.5x36.5 x15 40-41x40-41x12-14 47x47x12 / 45x45x12	Usage of mud and gypsum in foundation
23	Narin Castle	Meybod, Central plateau	Median, Achaemenids, Parthian, Sassanids	40x24x10	Rectangular mud-bricks
24	Dahaneh Gholaman	Zabol, East	Achaemenids	32-34x32-34x12 49-51x49-51x12	<i>Chineh</i> and mud-bricks, Toric and domical roofs
25	Persepolis	Shiraz, South of central plateau	Achaemenids	32-34x32-34x13	Cubic mud-bricks, mud and straw
26	Kuh-e Khajeh	Zabol, East	Parthian	40x15x9 22-24x13-15x3-5	Rectangular and small mud-bricks
27	Showaz	Yazd, Central plateau	Parthian, Sassanids	40x40x10 / 72x72x3 30x30x5	Usage of fine mud or sedimentary mud-bricks
28	Marazad Castle	Jolfa, North-western	Parthian	45x45x20	Cubic mud-brick
29	Arg-e Bam	Kerman, East	Parthian	23x23x5/ 25x25x5 23x23x4/23x23x7	Large variety in dimensions
30	Yasaghi Castle	Gorgan, North-eastern	Parthian	45x45x5 50x50x5	---
31	Isfahan Fire Temple (Atashgah)	Isfahan, Central plateau	Sassanids	40x40x13	Usage of reed inside the wall
32	Takht-e Soleyman	Takab, North-western	Sassanids	47x47x13	Short stone foundation made of debris
33	Bandian	Khorasan-e Razavi, North-eastern	Sassanids	40x40x10 40x40x8	Mud-brick and <i>Chineh</i> (trace of fingers on mud-brick)
34	Drazin Castles	Kerman, Bam, East	Sassanids	27x27x7	Combination of mud and straw
35	Great wall of Gorgan	Gorgan, North-eastern	Sassanids	40x40x6 50x50x10-11	A part of wall in mud-brick (50x50x10 m) and the rest is made

					by brick
36	Sheykh Tappeh	Orumieh, North-western	700-800 AH	30x30x8	---
37	Birjand Castle	South Khorasan	Safavid	23x23x5 / 25x25x3	Small cubic mud brick, <i>Chineh</i>
38	Mochi Castle	Sistan and Baluchestan	Safavid	23x23x5 25x25x5	<i>Chineh</i> and mud-brick
39	Rey fortification	Rey	Āl-i-Buyeh	17x17x3	<i>Chineh</i> and small cubic mud-bricks
40	Dastgerd castle	Kerman	Seljuk	35x35x11	---

Table 1: Dimensions of mud bricks in historical and archaeological sites of Iran

2.2. *Chineh*

As *chineh* was uneven, sometimes a row of mud brick had been set between two or three layers of *chineh*. *Chineh* has been used as one of the oldest and simplest materials in sites buildings such as Tappeh Zagheh and Sagz Abad in Qazvin (Central plateau), Ganj Darreh in Elam (West) and Sialk in Kashan (Central plateau) since the sixth millennium B.C. In this method, mud (in portable pieces) had been put together to make a wall. *Chineh* is made as a frustum. Bottom of the wall close to the ground was too thick while reducing its thickness in upper parts. *Chineh* did not need any mortar as it had been made of mud mortar.

It has been seen also that two sides of the wall had been put up in adobes filed with *chineh* inside with 60-70 cm height. Then a row of mud brick had been set up over the wall. This procedure would have been continued again.

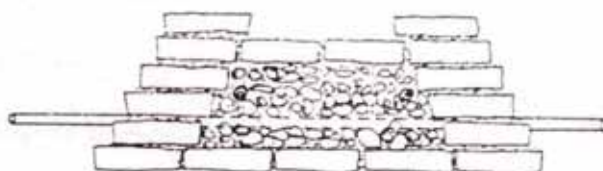


Fig.1: Schematic drawing of the use of reed in *chineh*

Chineh is usually constructed on the natural ground without foundation. In some regions where the land is not so dry, some lime powder would be added to the first row (*laad*). The ice houses walls were made in *chineh* in 10 to 12 meters high in Islamic period, such as the ice house of Shokat Abad in Southern Khorasan, which is strengthened by adding sand to *chineh*. In some regions, in order to prevent wall breakdown, reed was put inside the *chineh* (fig. 1). Nowadays the fences of gardens, farms ...are made in *chineh* too. After *chineh*, primary handmade mud-bricks (without using mould) and then moulded mud-bricks were used, which are described as follows:

2.3. Mud brick dimensions

Statistics studies on the mud-brick dimensions (Fig. 2-4):

1st millennium B.C. (Median era) in the West and North of Iran:

- Mostly rectangular mud bricks, thickness: 10 cm

1st millennium B.C. (Median era) in great desert and central plateau regions:

- Mostly rectangular adobes (about 70%), thickness: 10-20 cm

1st millennium to the Achaemenid era in the West and North regions of Iran:

- Mostly square mud-bricks (about 75%), thickness: about 10-15 cm

1st millennium to the Achaemenid era in great desert and central plateau regions:

- Mostly square mud-bricks (about 90%), less variety in thickness, average thickness: about 10cm.

Achaemenid era up to now, in West and North regions:

- Almost all of the mud-bricks were made in square shape (about 100%), diversity in thickness between 3-20 cm can be observed (average 9 cm); the mud-brick thickness in this duration and this region is minimum.

Achaemenid era up to now, in great desert and central plateau regions:

- The shape of mud-bricks is square and rectangular but mostly square (about 72%), thickness: 3-13 cm (average 7 cm).

In fact after the Achaemenid era, the average thickness is reducing, while this amount of thickness in great desert and central plateau is less than in West and North of Iran. Besides, from the first millennium the shape of mud-brick tends to be square-shaped, insofar since the Achaemenid era almost all of the mud-bricks are square in West and North of Iran.

Investigations on mud bricks' dimensions in different regions show that the ratio of surface to the thickness have been increased since the Achaemenid era, but this issue does not follow a special rule as the location of mud bricks in structures and their use in construction defines their dimensions. This is why in the same region, era and location, different mud bricks with different dimensions are found.

In addition, the mud-bricks dimensions in the Sassanid era are maximum and then reduce during the Islamic period due to the architectural requirements such as use in arches, and also in order to enhance flexibility and application convenience.

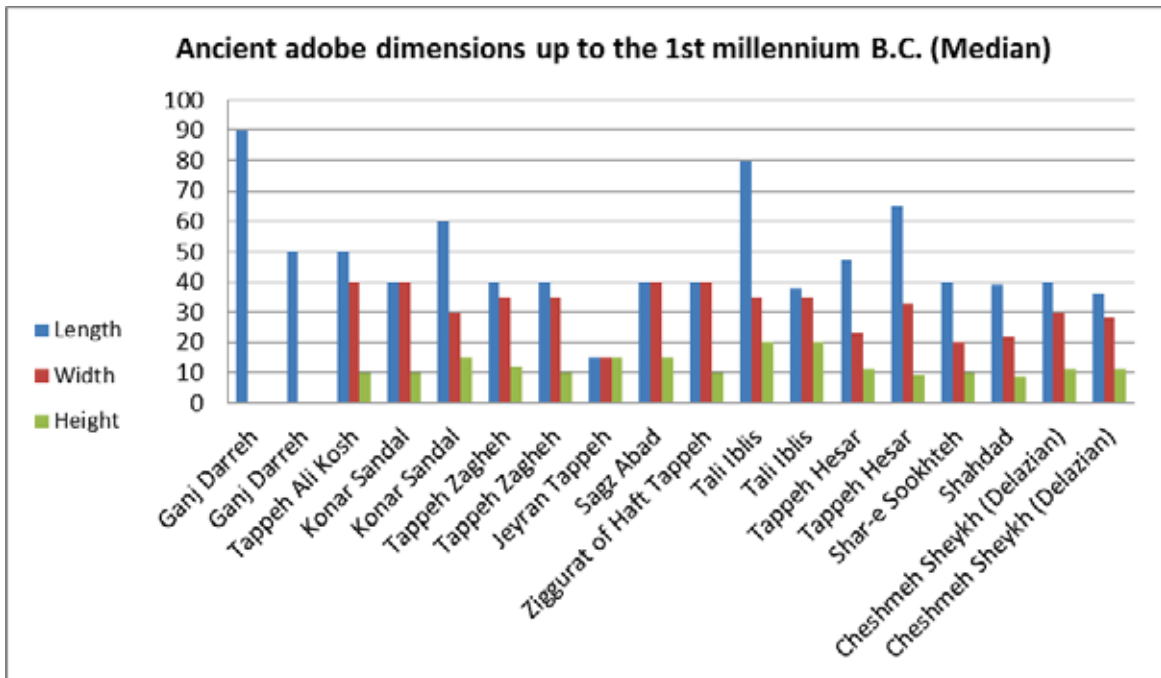


Fig. 2

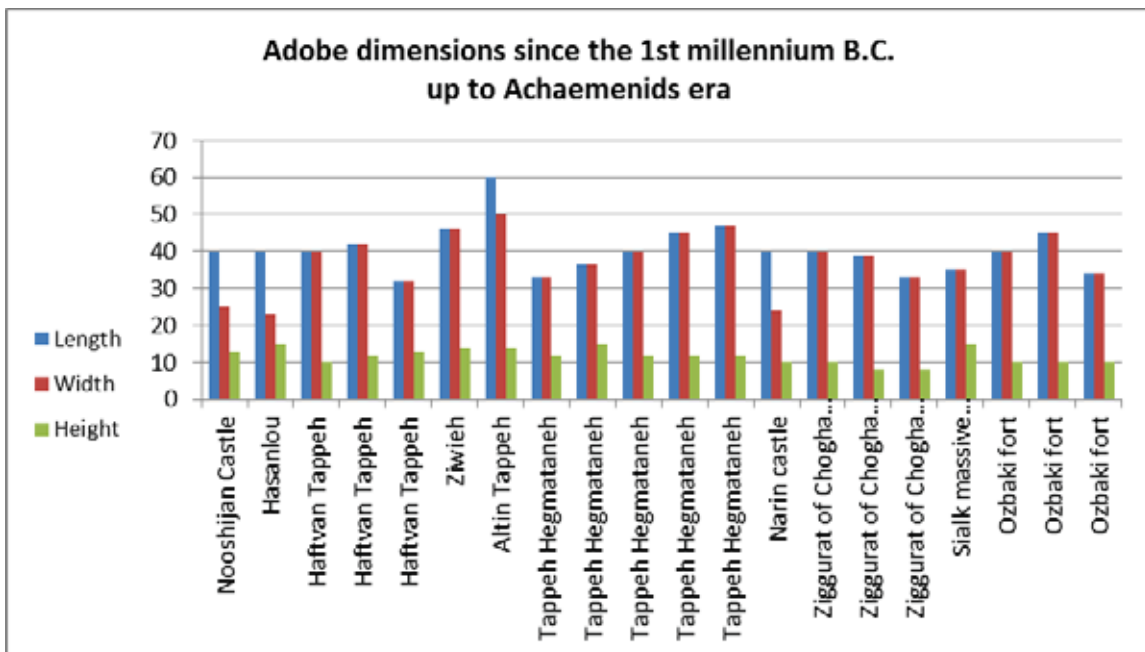


Fig. 3

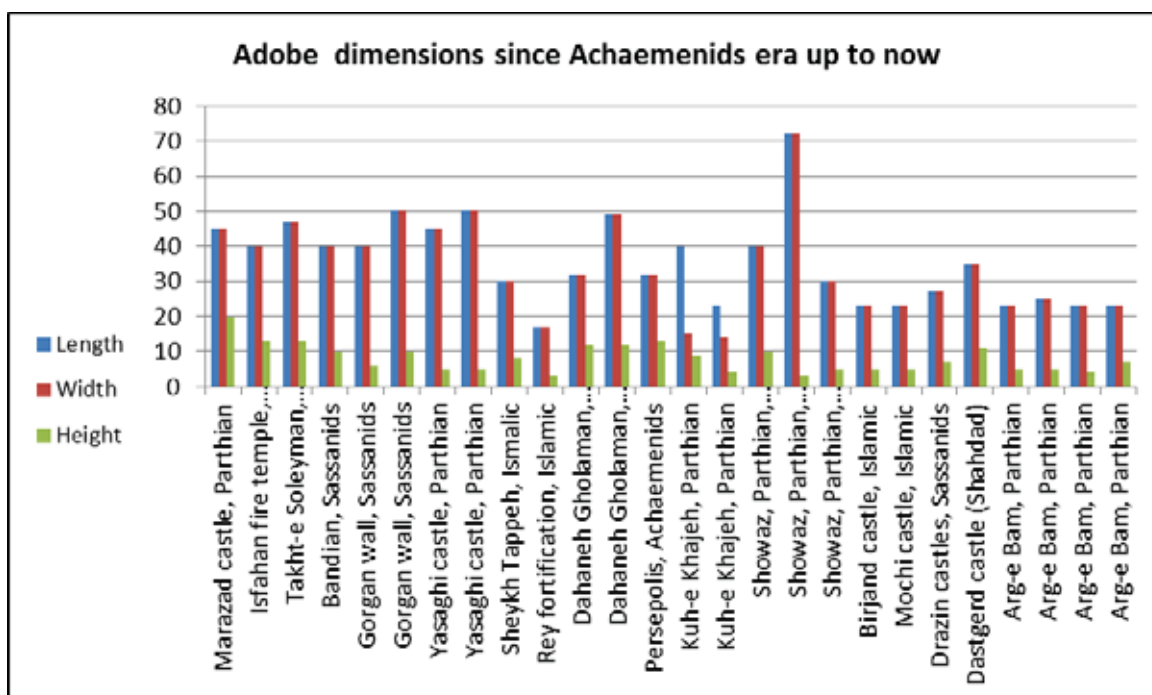


Fig. 4

Studying mud bricks' dimensions shows that sizes could differ completely in different regions of the same historical period. For example the sizes of half mud bricks (*khesht-e Nimeh*) of the Parthian period in Kuh-e Khajeh located in East region of Iran are 40x15x9 cm, while square mud bricks of Marazad Castle, in North-western, are 45x45x20 Cm and 40x40x10 Cm in Showaz in central plateau. Mud bricks of Median period have had the same size in different regions. On the other hand, in general comparison it has been observed that the mud bricks of North region of Iran with more humid climate such as Gorgan have lesser thickness compared to the other regions as reduction of drying rate could be responsible for decreasing of thickness.

On the other hand, studies on mud bricks' dimensions show that up to the first millennium B.C. large variety in forms and dimensions of mud bricks are seen. But, after this period moulded mud bricks with large sizes are mostly found. Most mud bricks dimensions in the 4th and 5th centuries (AH) are 33x33x10 cm. In Āl-i-Buyeh and Āl-i-Ziar periods, mud bricks and burnt bricks are shaped in their minimum sizes (16-17x16-17x3.5 cm). These dimensions are common now for mud bricks and burnt bricks in Khuzestan province due to its improper clay soil.

Since the Safavid period, common dimensions of mud-brick has been 23-25x23-25x5 cm, and also 17x17x3 cm in Rey.

In some historical sites, diversity of mud bricks' dimensions relates to the residential of different historic periods. While the mud bricks of some other sites such as Tappeh Nooshijan or Ziwieh from a particular period does not have dimensional variety.

2.4. Different forms of mud bricks

Plano-convex and cigarette mud bricks have been found in Ganj Darreh site in West of Iran. These scaphoid shaped mud-bricks are convex in lower and flat in upper surfaces. The convex surface had been attached to the lower mud brick with a layer of clay as

mortar. This would help mud bricks' adherence and wall reinforcement. One of the interesting specifications of the walls made of one sided convex mud bricks is the use of locks and clamps method. In the most elegant sample testifying of this method, three knobs on the flat surface of the lower mud brick and troughs on the convex side of the upper mud brick can be observed.

In some other regions such as Tappeh Zagheh (West) and Tali Iblis (South-eastern), scratches had been created on the mud bricks' surfaces in order to improve its adherence to the mortar which is named *panjeh keshideh*. This technique is currently prevalent among mud brick craftsmen in Iran.

Troughs caused by fingers on the four surfaces of mud bricks (upper, lower and two sides) can be seen in Zagheh site, and also upper and lower surfaces of mud bricks in Tali Iblis shows at least two parallel rows of troughs created by thumb, for example 70 cm mud bricks include eight rows, 52 cm with six rows and 38 cm mud bricks shows four rows of troughs.

Another kind of earthen materials are found in Tappeh Ali Kosh (West). These mud bricks are generally sediment mud layers which have been cut to the special sizes. Mud bricks are jointed together by a layer of mud mortar. Then, the walls' sides are coated with a mud layer as plaster.

During the sixth millennium B.C., cubic handmade mud bricks in small sizes are seen in Jeyran tappeh and Yan tappeh (Savojbolagh, central plateau) (fig. 5).



Fig.5: Handmade cubic mud-bricks in Jeyran Tappeh

Since the late 4th millennium moulded mud bricks with large dimensions are observed. These square shaped mud bricks, sized in 40x40x10 cm are found in *Haft Tappeh* (South-western) and Bandian (North-eastern). Sometimes rectangular shaped mud bricks, sized in 40x20x10 cm are observed in *Shahr-e sookhteh* (South-eastern), or in 40x25x13 cm in Tappeh Nooshijan in Hamedan (West) (fig. 6). Rectangular mud bricks also had been used in two rows for wall construction in *Shahr-e sookhteh*. Large moulded mud bricks show dimensional differences for different periods.

Mud bricks in Cheshmeh sheykh Delazian site (the 2nd millennium B.C., Semnan) have been made precisely, as the remained mud bricks inside the walls with completely flat and polished appearance coated with mud grout show. These mud bricks are almost square shaped too. Large square shaped mud bricks had been used during Islamic periods until 4th and 5th centuries. Since then, square mud bricks with smaller sizes were more common.

Applying color contrasts in mud bricks is another interesting point during the Median era, such as use of grey and red mud bricks in construction of Ozbaki fort (central plateau) and Ziwieh castle (West) show. Red mud bricks (more uneven than the grey ones) in Ozbaki seem to have a mortar role as well. Since using a mortar with 10 cm thickness would impede progress, red mud bricks should be used semi-humid in order to conserve their shape while binding. Color diversion in mud bricks (such as in Chogha Zanbil, Elam period) seems to be regardless to the aesthetic issue and just due to the different available soil sources.

2.5. Some techniques used in making mud brick and building

Plano-convex mud bricks: mud had been put on a flat surface, made its upper part as a convex shape by hand. This method spends less times comparing to the ordinary cubic ones. Long thick mud bricks like cigarette or sausage shape are seen in Ganj Darreh. These large 1 meter mud bricks have been probably applied at semi-humid state. This method of application had made them rather disordered.

According to the studies over buildings and sites (table 1) use of *kahgel* (mud and straw) coating on the wall surfaces made of mud brick, or *chineh*, had been prevalent. In ancient times, mud houses made of mud brick or *chineh* were built directly on the ground without any foundation. Afterward regarding to the cold climate and yearly precipitations in North and West regions such as in Hasanlou, Haftvanan Tappeh and Altin Tappeh, mud brick walls were built on a stone or lime mortar foundation.

Unlike Achaemenids architectural forms in West and central plateau regions (flat roofs), as in Dahaneh Gholaman Achaemenid site, building toric and domical roof have been seen in order to prevent severe wind effect.

Joint reinforcement by using reeds as a well known old method in Mesopotamia has been seen in Isfahan fire temple (Sassanid, central plateau). In this method, a layer of reed had been placed on each five or six mud brick layers. These thin reeds (7-8 mm of diameter) would reduce slip risk during the construction. Besides, the groves caused by reeds would help air passing and quick drying.

During the Median era (Tappeh Nooshijan, first millennium B.C.), special racks had been embedded called *panjereh koor* (blind window) which evolved to Moqarnass in Islamic period (fig. 6).



Fig. 6: Windows *panjereh koor* in Tappeh Nooshijan

The use of mud and lime, or mud and plaster mortars, has been seen during the Median, Achaemend and Sassanid eras, such as in Tappeh Hegmataneh, Ozbaki and Ziwieh, Persepolis and on Isfahan fire temple.

In addition to the using of the *panjeh Keshidan* method on the mud bricks surface (making scratches on the surface of mud brick in order to increase mortar's adherence), applying "back and forth" technique (setting mud-bricks back and forth in order to make surface uneven) has been seen in Ozbaki fort (Median era).

2.7. Current mud brick production in the central plateau of Iran (hot and dry climate):

Nowadays, experimented Yazdi craftsmen produce different kinds of mud bricks with different dimensions according to their location: foundation and wall or mud-bricks for roofing. In terms of size, mud bricks are named according to their moulds.

The Foundation/wall mud bricks are thick, heavy with low length and width. Unlike roof brick, foundation mud brick does not need much kneading, so it can be produced in large quantity

The specifications for mud bricks used for roofing are:

- 1- Kneaded (treated) more; clay is completely mixed with other additives.
- 2- Having ordered angles without chipping
- 3- Lower weight and thickness, but greater in length and width comparing to the foundation in mud brick. Lighter roof charges fewer loads on the columns.
- 4- For more strengthening and increasing the binding of mud's aggregation, some straw is added to the mud (adding some straw to the mud for more strengthening and increasing the binding between mud's aggregation).

- 5- The rate of production of this mud brick is less high as it needs more attention and precision.

Yazdi craftsmen believe that mud bricks used for roofs should be *khandan* (smiling); it means that its convex part should be a little indented in order to increase its involvement with the other mud bricks.

2.8. Current mud brick production in the North of Iran (hot and dry climate):

The use of earthen materials is so limited in North of Iran, and mostly applied with wood materials in upper stairs of the building. One of the techniques used in this region consists in applying mud which is called *zegal*. In this handmade method, the wall structure is built in timber and reeds, and filled and coated with *kahgel*. In another method called *zagmeh*, timbers and clamps are placed in the corner of the wall in decussate. The gaps between timbers are filled with mud. Eventually the wall surface is coated by two layers of *kahgeh*, one containing coarse straw and the other one containing tiny straw for the final layer. This *kahgel* is made with rice straw which seems to be less attacked by termites.

3. CONCLUSION

The mud bricks' dimensions have been varied during different historical periods. But it does not follow a regular rule as in a specific historical period, considering that regional and climatic conditions, technical requirements, and working conditions would have been changed. This makes sometimes infeasible to determine a building's historical period only according to the dimensions of the mud bricks.

During the 4th millennium B.C., handmade mud bricks and thereafter molded mud bricks have been found in different regions of Iran. Molded mud bricks with large dimensions have been created since the late 4th millennium B.C., such as in Haft Tappeh (South-western) and Bandian (North-eastern) in square form (40x40x10 cm), and in Shahr-e sookhteh (South-eastern) in rectangular form (40x20x10 cm), or in Tappeh Nooshijan in Hamedan (West) (40x25x13 cm)

Up to the 4th and 5th centuries (AH) most of the mud bricks' dimensions are 33x33x10^{cm}. During *Āl-i-Buyeh* and *Āl-i-Ziar* periods mud bricks and burnt bricks are of minimum sizes (16-17x16-17x3.5 cm). These dimensions are common now for mud bricks and burnt bricks in Khuzestan province due to its improper clay soil.

Since the Safavids, common dimensions of mud-brick have been 23-25x23-25x5 cm, and also 17x17x3 cm, in Rey.

In addition to the soil quality, the quality of mud bricks in different sites relates to the building importance and significance. That is why in some cases, good quality soil had been brought from other areas. The mud bricks of Ozbaki fort, Ziwieh and Nooshijan are some examples of this assertion.

According to the available indigenous materials in different regions of Iran, special herbal fibers had been used for strengthening and prevent cracking, such as: straw (in most country's regions), wheat bran (in North of the country) or *kharshotor* (Camelthornor *Alhagi maurorum*, Fahraj mosque, central plateau). In some cases such as in Chogha Zanbil, use of brick debris or brick powder had been more common which was effective in reducing contraction and cracking and also increasing compressive strength.

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Curriculum

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CONSTRUCTION WORK IN MESOPOTAMIA IN THE TIME OF THE THIRD DYNASTY OF UR (END OF THE THIRD MILLENNIUM BC): ARCHAEOLOGICAL AND TEXTUAL EVIDENCE

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T.1.: History of earthen architecture in Asia and other regions of the world

S.T.1.1.: Archaeological sites and historical monuments

Keywords: archaeology, epigraphy, Mesopotamia, building materials, construction work.

Abstract

The recent publication of the Sumerian archive of Garshana, with some 200 cuneiform tablets dealing with building activities and dating around 2000 BC, give us invaluable information about an ancient “constructive culture”. The textual evidence may be linked with the archaeological data in order to study in much detail the association of earthen and vegetal material in the construction.

1. INTRODUCTION

Ancient Mesopotamia has used earth as its main building material since the first Neolithic permanent dwellings around 10000 BC until now. For this long span of time, Near-Eastern archaeology has provided a very huge amount of information (Aurenche 1981, Sauvage 1998a et 2011), added to important ethnographical works and numerous epigraphic data—about a million cuneiform tablets!—unearthed in this region. Architecture is one of the rare fields of research where these three sources of information (and, to a smaller extent, iconography) can be linked together in order to provide a quite complete picture of the construction work process.

In this respect, the recent publication of the archive of Garshana gives us a rare opportunity. It contains, within others, some 200 practical texts dealing with construction activities managed not by the king but by a high rank officer for his own estate. Within this very rich corpus, we shall present here more precisely the information concerning the building materials used in Garshana: first of all, of course, earth and its different uses, but also wood and reeds.

This will be the occasion to present a “constructive culture” where earthen and vegetal materials were closely associated.

2. THE CONTEXT

2.1. The Third dynasty of Ur

2.1.1. Geographical background: Sumer

The Sumerian country corresponds to central and southern Mesopotamia that is to say the lower alluvial plain of the Tigris and of the Euphrates. It is a totally flat landscape, where rain is rare and irregular and where cultures have to be irrigated. Stone is almost completely absent but clay can be found everywhere. Wood resources consist mostly of palm-tree, tamarisk, willow and poplar which grow on rivers and canals banks where reeds were also very common.

2.1.2. Historical overview

After the Early Dynastic Period (ca 2400-2350), a first empire, with Sargon of Akkad, rules on the whole Mesopotamia for the first time. It fell around 2150. The third Dynasty of Ur built then a new empire in less than two generations. It stretched out to the whole Mesopotamia and part of South-Western Iran. The Third Dynasty of Ur lasted a century between 2100 and 2000. The five kings of the dynasty conducted a very ambitious construction policy, especially in the religious domain (fig. 1). During this period the first Mesopotamian ziggurats have been built, surrounded with very important religious complexes. These buildings required the making and the laying of millions of bricks. Only a highly developed bureaucracy could do this (Sauvage 1998b, Robson 1998). Some 40,000 Ur III cuneiform tablets have been found, most of them are administrative records.

2.2. The Archive of Garshana

2.2.1. The cuneiform tablets

The Archive of Garshana contains some 1,400 texts coming from clandestine excavations that took place in Iraq in the twentieth century (fig. 2). Most of the texts have been gathered through a donation in the collection of the Department on Near Eastern Studies at Cornell University (State of New York, United States of America). They are the household records of a general and physician, Shu-Kabta, the Brother-in-law of the reigning king of Ur.

2.2.2. The site

Garshana is probably located in the vicinity of ancient Umma in southern Mesopotamia (see fig. 1), but we do not know currently its precise location. Archives make reference to repair and construction work in the estate of Shu-Kabta, but we do not know exactly if the name of Garshana corresponds to the estate or to the city close to it. It seems that it was at the origin a fortress, reused by Shu-Kabta to make an estate including agricultural and craft production units as well as dwellings for his household.

2.2.3. The publication

The publication of the texts is managed by David I. Owen from Cornell University, by means of various specialists. A first volume presented the texts (Owen & Mayr 2007), it is followed by a volume of index and volumes of translations and comments. The one who interests us here is concerning workers and construction work, edited by Wolfgang Heimpel, emeritus professor at Berkeley University, California (Heimpel 2009). I was in touch with Wolfgang Heimpel during the preparation of his work, bringing an archaeological expertise to the problems of translation of specific architectural terms. Indeed, texts are written in Sumerian (even if it seems that the concerned population

was mainly speaking Akkadian, that is to say a Semitic language). The Sumerian language is now known well enough but always raises problems, in particular of lexicography, as far as it is connected with no known language and was written with ideograms.

2.2.4. Content of the archive

Within this archive a lot of about 200 texts describe the tasks and the persons involved in the construction of a domain in Garshana during the last three years of the life of Shu-Kabta. Texts that contain information on the topic of construction can be grouped in different types:

- construction worker inspection texts : the texts were daily reports, serving as a monitor of the progress of work;
- single task inspection texts;
- brick carrier texts;
- worker transfer texts;
- worker assignment texts;
- construction supplies deposition texts.

All these texts illustrate the management (staff and materials) set up for the building operations in Garshana. We have information concerning the workers and their tasks, the sites where took place the construction work, the types of constructed or repaired structures, the building materials and the tools, and, finally, the tasks connected to the construction. The time granted for this communication prevents us from approaching all these points, so we shall retain only two: the building materials and more particularly the case of the reed.

3. BUILDING MATERIALS IN THE GARSHANA TEXTS

3.1. Earth

3.1.1. Different uses of earth

The texts of Garshana provide several terms in reference to the earth (fig. 3, for a general survey of the terminology of earth in architecture see Aurenche 1978 , Aurenche *et al.* 2011):

- *sahar* corresponds to the soil, to the natural ground, to the clay (akk. *eperu*, arr . *trab*);
- *im* (akk. *tidu*, ar. *tin*) corresponds to the earth or mud used for building purposes in a mixture (in variable proportions) of the natural soil (ground under the too organic arable layer) with some water and a temper, in Garshana always some straw (*i-nu*, akk. *tibnu*, ar. *tibn*). Three terms are used in that case corresponding to different mixtures or at least to different uses. The generic name without precision *im* is used for the bricks, the mortar and the repairs. The second *im di' 'um* is used to indicate the material for the construction of earthen structures (probably modelled, there is no associated term corresponding to the pisé shutters). The third, *im sumur*, indicates that the earth was used as a plaster. One can think that *im di' 'um* is more loaded with straw (cob, cf. French torchis) while *im sumur* is more liquid (plaster and wash).

3.1.2. Bricks

The sundried mud bricks correspond to the main building material at Garshana. They are made in a quarry (named in the texts "the excavation": *ka-la* or *ka-al-la*) located out of the enclosure wall, near a waterway. At this place, located near a city gate were gathered pits for earth extraction, basins for the mud mixture (*agarin*), drying areas ("brickyard": *ǵá sub-ba*) and brick stacks (akk. *amara*). Another area of brick manufacturing and drying existed close to the Agammum river. Other brick stacks were also localised close to city gates. Texts of brick supply, mentioning the provided

quantities by workers teams and the related food wages, give us orders of magnitude: the Garshana text 350, for instance, an annual statement of account of brick supply, adds up the manufacturing of 1,633,200 bricks. It seems that the standard was of 240 bricks per day for a worker. While comparing with the other texts known for this period (texts of mathematical exercise as practical texts) it seems clear that this ratio does not correspond only to the moulding but probably also to the preparation of the earthen mixture or perhaps its transport from the career to the brickyard.

Baked bricks (*sig₄ al-la-ra*, *sig₄ al-ùr-ra*, akk. *agurru*) are also attested in the texts of Garshana. They are less common, used in partnership with bitumen for tight installations (for instance a quay and a storage structure for liquids).

3.2. Bitumen

Two kinds of bitumen (*ésir*) were used in Garshana: a “dry bitumen” (*ésir hād*) and a “house bitumen” (*ésir é-a*), the first being more frequent. The bitumen was used in construction as mortar and plaster for structures related to water (quays, wells, bathrooms, etc.) in partnership with baked bricks but also to waterproof boards, or to coat mats of palms. It was also used for reed containers. The text 1329 associates bitumen and gypsum for door coating. Gypsum was obviously not used as plaster for walls or floors in the buildings of Garshana.

3.3. Vegetals

3.3.1. Wood

The terminology related to the wood for construction is rather rich in Garshana. One distinguishes the “roof beams” (*ġiš-ùr*) which served as rafters. They were usually tamarisk and poplar beams. The “side house timbers” (*ġišē-da*) could serve either as joists on roof beam or as rafter on wings of the buildings and on storage rooms. A third category is that of the “gate timbers” (*ġiš ká-na*) which were probably used for gates and windows lintels.

The largest beams were 5-6 m length with a diameter of 15 cm. The length of “side house timbers” is rarely mentioned in the Ur III texts, it varies between 6 and 3 m.

Garshana text 1286, concerning the construction of the house of Ubarrria, provides us a total of 40 “roof beams” (27 in poplar, 13 in tamarisk) and 88 “side house timbers” (57 in poplar, 31 in tamarisk).

Poles (*ġiš-dal*) of poplar measuring between 1 and 3 m length were also used especially for fences, and planks of pine for door leaves.

3.3.2. Reeds and palms.

The reed, present along irrigation canals and in marshes, was abundantly used in construction for mats (also made with palms) or for ropes (Postgate 1980 and Waetzold 1982). Another use, noticed as *gi-sal* deserves a specific development

4. THE GI-SAL CASE

The documentation of Garshana abundantly refers to the term *gi-sal* (akk. *gisalu*). The Sumerian ideogram is made with the determinative *gi* which refers to the reed: is it a specific kind of reed used in the construction? or rather an architectural feature in reed? or a kind of use of the reed in architecture?

4.1. Terminology

Before the publication of the texts of Garshana, dictionaries (see the *Chicago Assyrian Dictionary*, vol. G, s.v. *gisalu*) rather incline towards a structure in reed associated with the roof, such a parapet of reed bordering a flat roof (fig. 4).

4.2. A material or a technique?

Within sight of the documentation of Garshana, Wolfgang Heimpel prefers to see in the *gi-sal* term a kind of use of the reed in the construction, for instance as a binding layer between two layers of bricks, a technique attested very well by archaeology (cf. Sauvage 1998a, and, here, fig. 5a).

In my opinion, because some texts of Garshana indicate that the *gi-sal* was transported, it seems to me that it is indeed a material and not only a technique. The reed was prepared before its use: *gi-sal gul* is translated by Heimpel “trimming *gi-sal*”. I think that this corresponds to the preparation of the reed: the workers were removing the sheets and the inflorescences and preserving only the stems. *Gi-sal* would thus mean “stems of reed”.

4.3. Different uses of *gi-sal*

4.3.1. Wall binding

In Garshana, the *gi-sal* was abundantly used in the construction. In certain cases, it was mentioned with the term “to build” and with earth transport. In this case, it possibly means that the builders were inserting reeds between the brick layers with regular intervals, which is well attested by archaeology (Sauvage 1998a and, here, fig. 5a). The reeds would then serve as binding in order to limit horizontal movements of the masonry and to avoid vertical breaks. One can also think that it had a chemical role (draining, dampness barrier, chemical stabilization) which still remains to be studied in detail. For many archaeological vestiges (in particular in the ziggurat of Uruk, dating from the period of the Third dynasty of Ur, or in that of Aqar Quf, a little more recent: middle of 2nd millennium BC), the excellent conservation of the reed layers remains to be explained.

4.3.2. Work on the enclosure wall

The *gi-sal* was also used for the basement of the enclosure wall of Garshana. In this case, it could be the layer of reed laid out on the last layer of bricks of the basement as an upper bed for the elevation (fig. 5b), which is well known by archaeology. We could also deal, according to the context of some texts of Garshana, with a repair work, for instance of the undermining furrow which often develops at the base of old earthen walls in Mésopotamia because of the rain streaming and the increase of dampness. Archaeology abundantly documents these repairs but only with non-perishable materials: usually a mud brick stuffing. In Garshana, it seems that the furrows (at least the least deep) were filled with reed before receiving a coat of plaster (fig. 5c).

4.3.3. Wall coping

The texts of Garshana also indicate the use of the *gi-sal* “at the head” of the enclosure wall, i.e. its top. In this case, the reed could have been used as coping to prevent the rain infiltrations by the top of the wall (fig. 5d).

4.4. Roofs

Finally, the reed could be used for the roofs as beds of stems or reed mats laid out on the beams (fig. 6a). Surprisingly, the lists of tasks of Garshana do not seem to mention the use of *gi-sal* at the time of the roof work. Wolfgang Heimpel thinks that the flat roof was made with a layer of pieces of wood laid side by side and on which the beaten ground of the terrace was directly put (fig. 6b). This solution hardly satisfies me insofar as the quantities of “side house timbers” are insufficient. Furthermore, this would be a much more expansive solution as reed is far cheaper than wood.

5. CONCLUSION

We have seen some aspects of an old constructive culture using earth as its principal material. Terminology and archaeology show that the Sumerians had a great knowledge of the various uses of earth for construction. They associated it with the use of perishable vegetable materials which are less documented by archaeology. From this point of view, the data of Garshana brings invaluable information. The study of these texts, which requires the supplement of the archaeological and ethnographic assets, makes it possible to draw up a very complete overview of earthen Sumerian architecture. The knowledge of this "constructive culture", associating earth and vegetals, should be associated with others to provide original solutions to the development of a natural and durable contemporary architecture.

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Curriculum

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Fig. 3: Model of earth mixes

Fig. 4: Flat roof with parapet

Fig. 5: Different possible uses of *gi-sal* in the enclosure wall at Garshana

Fig. 6: Two different solutions for flat roofs at Garshana

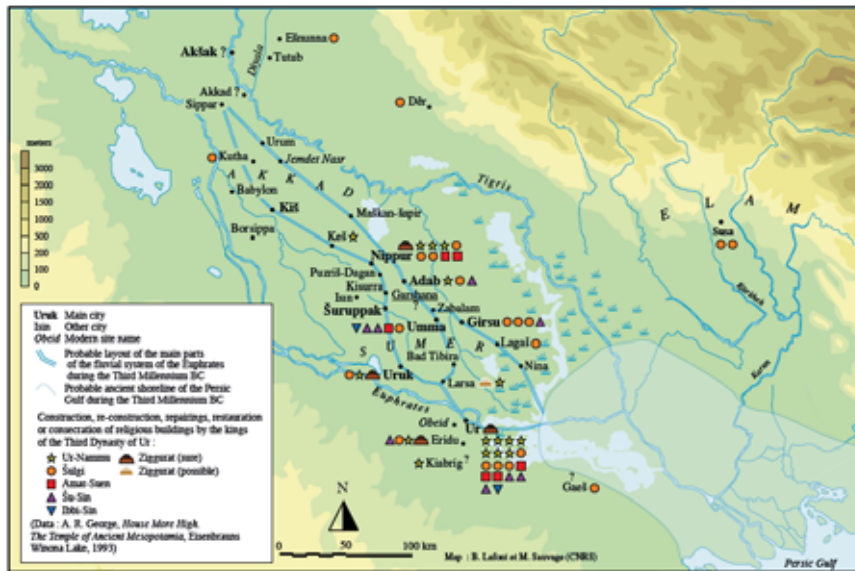


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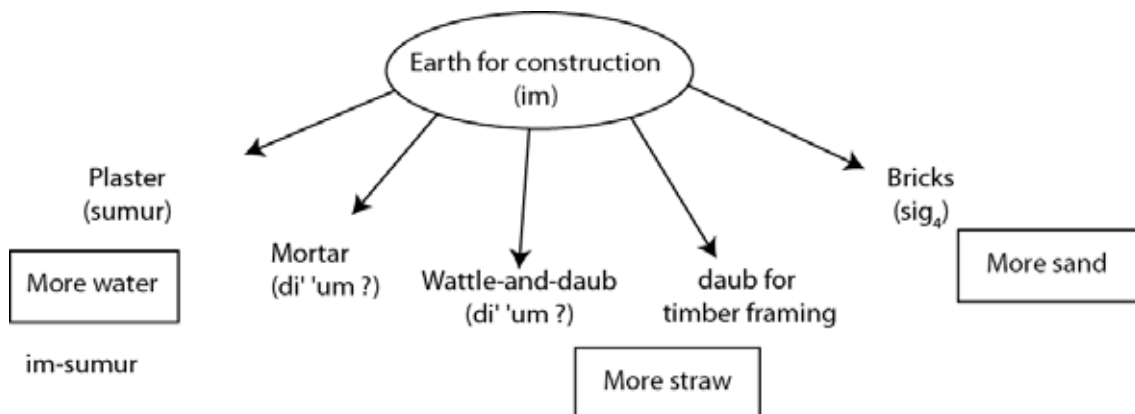


Fig. 3: Model of earth mixes

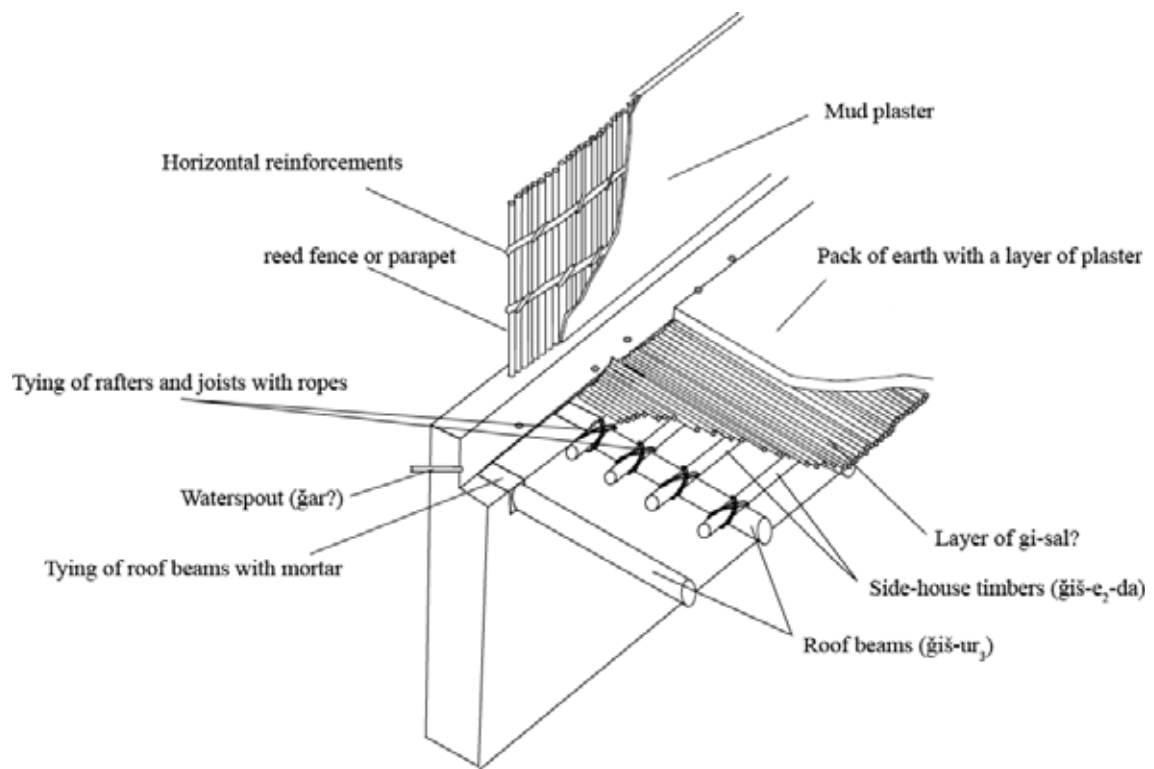


Fig. 4: Flat roof with parapet

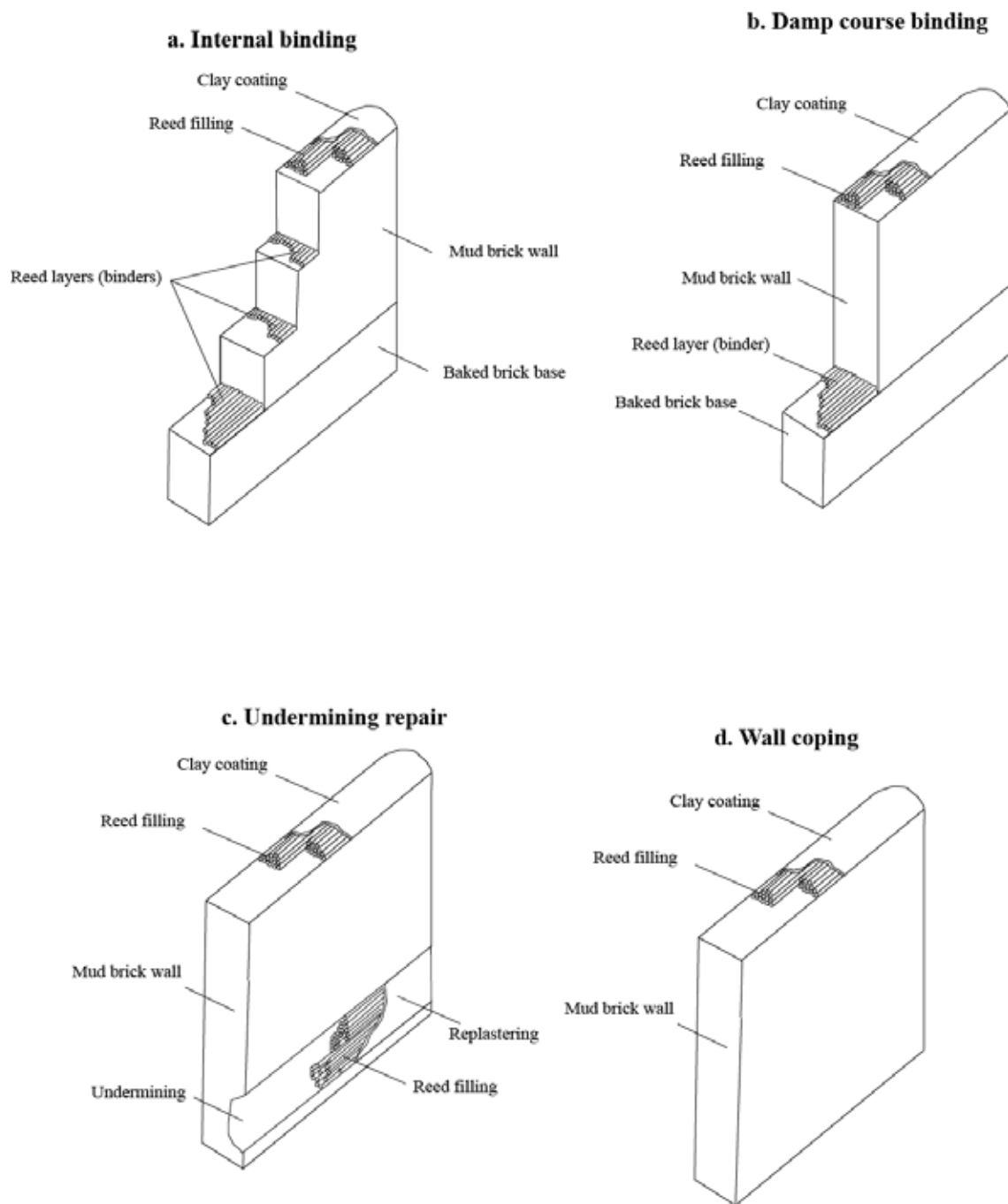


Fig. 5: Different possible uses of gi-sal in the enclosure wall at Garshana

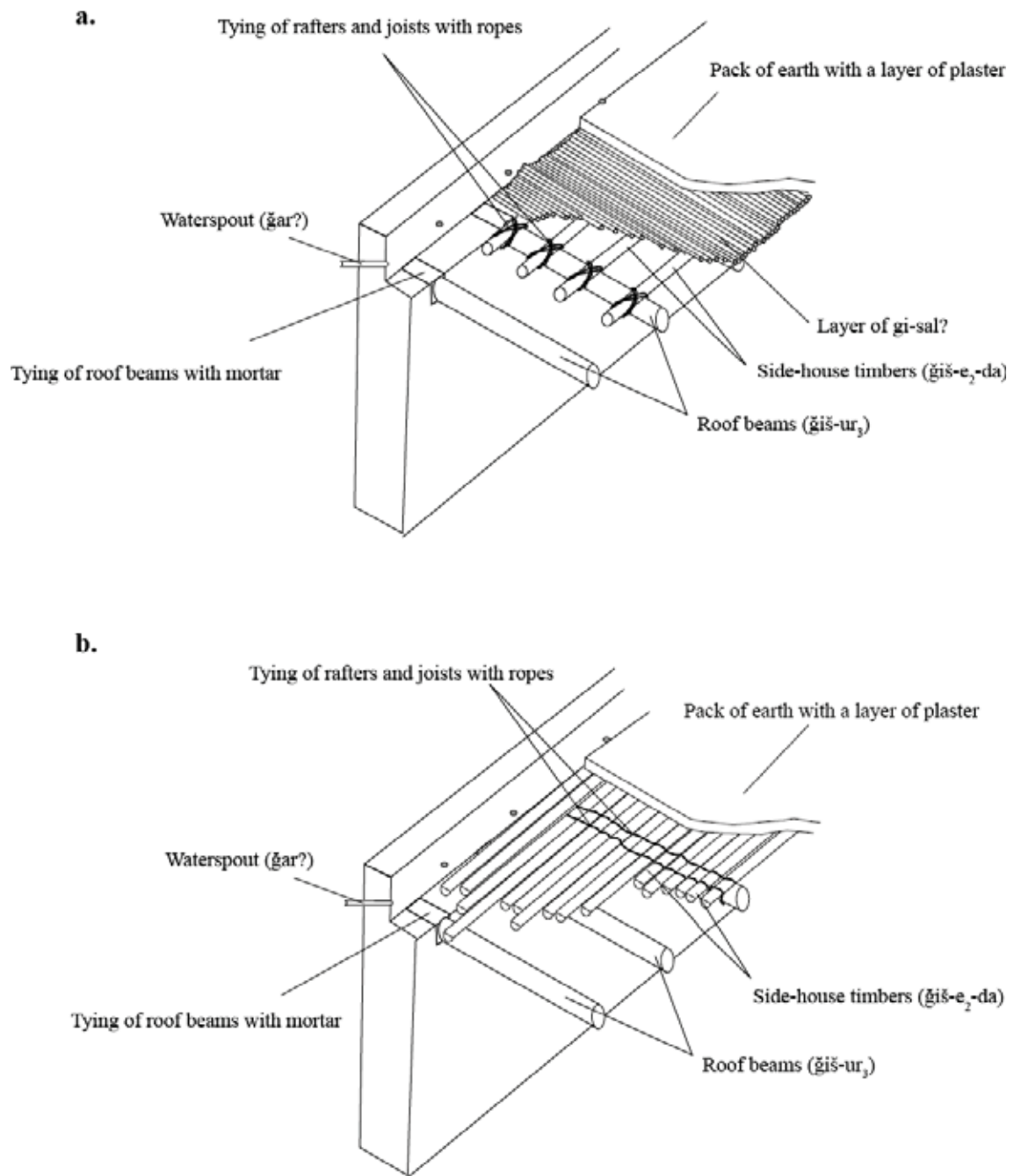


Fig. 6: Two different solutions for flat roofs at Garshana

PREVENTIVE CONSERVATION OF THE MONUMENTS IN MERV, TURKMENISTAN

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Theme 1: History of the earthen architecture in Asia and other related region

Sub theme 1.1: Archaeological sites and historical monuments

Key words: archaeology, preventive conservation, earthen architecture

Abstract

This article describes the various activities developed in Ancient Merv between 2001 and 2007 by the International center for Earth construction (CRAterre-ENSAG), in close collaboration with the National Department for the Protection, Study and Restoration of Historical and Cultural Monuments, Ministry of Culture of Turkmenistan (DPM) and the University College of London (UCL, Institute of Archaeology), to develop a preventive conservation strategy for this World Heritage Property.

The philosophy of this collaboration was to strengthen the capacities of the Turkmen specialists in the field of conservation for a better preservation of the unique monuments and precious archaeological remains. The working methodology integrated research & experimentation, capacity building, supply of equipment and improvement of conservation/management practices. This article comprises four main sections. The introduction presents the general context of the site, the second part explains the conservation principles adopted, the third part describes some interventions on the monuments and the last part presents the training activities undertaken.

1. CONTEXT

The Merv oasis, located at the intersection of the Murghab River and one of the major west-east trade routes to Bukhara and Samarkand, occupies a vast area of 1200 hectares on the flat landscape created by the alluvial delta fan of the Murghab River. A series of four adjacent walled cities of different periods testify of the importance of the oasis, founded in the 6th century BC, which became an imperial capital city during both the Abasid (8th century) and the Seljuk (11th -12th centuries) periods.

Important monuments, including the prestigious mausoleum of Sultan Sanjar (12th century), the greater and lesser Kiz Kalas as well as more than 1000 hectares of well preserved buried archaeological deposits contribute to the unique character and significance of the Park.

A year after the inscription of Ancient Merv on the World Heritage List of UNESCO, in 2000, important conservation problems were identified by the national and international community. The UNESCO World Heritage Centre set up a mechanism to respond to

these concerns. In the meantime, the World Monuments Watch inscribed the site on the world's 100 most endangered sites.

Between 2001 and 2007, CRAterre-ENSAG was regularly invited by UNESCO to work in close cooperation with the national and international partners² on conservation and management issues, with the view to better tackle the problems affecting earthen structures and strengthen capacities within the Turkmen team. This long period was a great opportunity to share experiences between various international and Turkmen teams, and allowed the gradual fine tuning of the conservation techniques in Merv, resulting in a range of innovative solutions based on a preventive approach.

2. PHILOSOPHY OF INTERVENTION

After assessing the efficiency of previous conservation campaigns and experimenting various conservation approaches with the Turkmen and English partners, it was recognized that only a slow process with long-term perspectives would be effective for the site. This option took into consideration the size of the protected area (1200 hectares) and the complex decay factors affecting the monuments and archaeological deposits, which include the raising of the water table (since the 1950s), when the Karakum canal was dug to increase cotton production in the region. The target was to gradually develop specific conservation techniques, adapted to the local context and according to the international conservation charters while emphasizing on capacity building amongst the Turkmen staff in charge of the site.

The key principles driving the conservation approach were the following:

Respecting values

The site conveys very important historical and archaeological values. Thus, all interventions, based on consistent scientific documentation, should result in a preserved archaeological resource respecting the state of conservation of the ruins.

Maximum understanding

The first step was to analyze the decay processes affecting the structures and the level of threat attached to each of them. Pathology surveys and comparative analysis with archival photographs helped to identify both environmental and human decay factors, and to measure their complex inter-related effects on the monuments. To confirm the hypothesis provided by the site observations, a monitoring system was launched to measure several parameters (physical, climatic, environmental, and human).

Additionally, a soil laboratory was established to analyze the characteristics of the different types of soils constituting the monuments and those supplied by the quarries around the site. For this purpose, UNESCO provided a new building with laboratory equipment, and two staff members were trained on soil analysis. Continuous field observations helped to evaluate the behavior of the soil mixtures selected and the efficiency of various preventive conservation techniques experimented.

² National partners: National Department for the Protection, Study and Restoration of Historical and Cultural Monuments, Ministry of Culture. The Ancient Merv Park. International partner: Institute of Archaeology, University College of London.

Adapting to the reality of the field

Priority was always given to solutions that could easily be applied by the Turkmen team with their own physical and human resources. This meant that conservation programmes had to make use of local materials and take advantage of technologies that could easily be applied by the Park staff with their available equipment.

Use of original materials

The applied interventions basically made use of soil only, to produce the same bricks and mortars as those found in the original structures. The only added material was geotextile, which was sometimes integrated to separate the original fabric from the conserved part, especially for the backfilling of excavated sites. The use of burnt bricks and cement mortars was abandoned.

Reversibility

The conservation activities carried out during the Soviet period and immediately after independence showed that heavy interventions are not effective in the long term, and could even be very destructive.

The conservation of earthen structures is a fast evolving field and the idea of reverting back to previous stages should always be kept in mind. Interventions should be removable without damaging the original structure. This criterion is closely linked to the others, and reduces the risk of uncontrolled decay processes taking place after the intervention. However, a long experimental phase is required to guarantee a safe application of this principle.

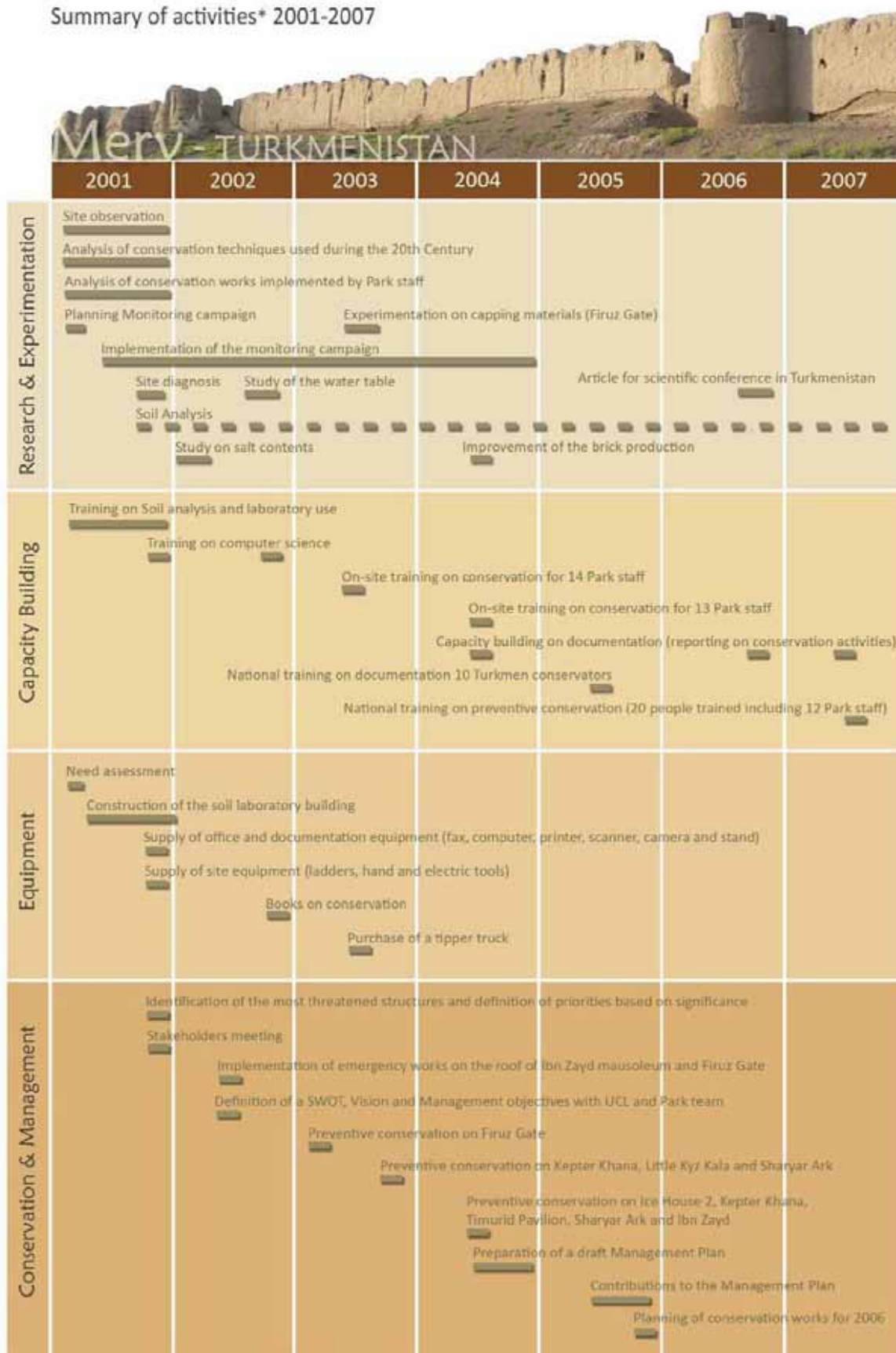
Avoiding confusion between original structures and contemporary interventions

While ensuring that interventions are reversible, they also have to be discrete, and added materials have to blend with the original ones. Additions or repairs have to be slightly distinct from the original fabric but not conspicuous, even if the physical properties of both materials are similar.

Minimum intervention

Several preventive techniques were explored and experimented. The first results show that minimal interventions can result in considerable savings if they are properly scheduled and implemented. Between 2000 and 2008, only the most threatened structures were treated with minimal interventions. Less critical interventions have been postponed until they can be handled in the future, to make sure that available resources are used to address, and reduce the list of threatened monuments. This has resulted in scattered and almost invisible interventions, as compared to the prestigious restorations that are sometimes implemented on isolated structures.

Summary of activities* 2001-2007



* Only activities involving CRAterre are inserted in the table. Many more results have been achieved during this period in Merv.

3. PREVENTIVE CONSERVATION WORKS EXPERIMENTED

The development of tailored conservation techniques for Merv is a slow and endless process. At the beginning of the programme, it was decided not to touch any of the prestigious monuments of the Park. Only the roof of Ibn Zayd received emergency repairs during the second year, to prevent its collapse. All conservation techniques tested in Merv had already given excellent results in other parts of the world where similar sites are found (Uzbekistan, Iran, Syria). Despite this guarantee, the first conservation interventions were implemented on elements that are not considered as prestigious or unique in Merv. For example, capping techniques were first tested on city walls for 2 years before being applied to standing monuments.

The following paragraphs describe the most efficient technique implemented:

Removing plants and vegetation:

Great effort was made to address the problems caused by vegetation growth all over the site, a feature that considerably accelerated the erosion processes. Vegetation affects the wall bases by changing a hard and dense material into a porous one, which can be easily washed away. It also reduces the drying process of the wall by retaining humidity in the ground. In addition, there are problems related to plants growing in the mortar joints. By simply removing vegetation from a monument and its immediate surroundings, it is possible to increase the life span of the structures by several decades. It is also possible to prevent further wearing away of gullies, holes and cracks or to prevent the collapse of arches by applying sacrificial mortar layers in such a way that the effect of erosion on the entire structure is better spread.



Fig. 1 - Ice House 2 – Removal of the plants on the building and its surroundings

Sacrificial mud renders:

To reduce the speed of erosion of fragile walls, domes or vaults, sacrificial layers of mud mixtures were applied on the most exposed surfaces. These mud renders endure the erosion instead of the original fabric. This method was first implemented in 2002 on the Ibn Zayd mausoleum where a traditional earth coating was applied to protect the domed roof, instead of the previous destructive cement coating which had led to serious humidity related destructions. In 2004, the tops of the walls of two other monuments - the Kepter Khana in Shahryar Ark and the Timurid pavilion - were treated in the same manner.



Fig. 2 - Applying sacrificial renders at the top of ruined walls to reduce the speed of erosion



Fig. 3 - Ibn Zayd mausoleum – Sacrificial layers of mud mixtures are applied to protect the domed roof instead of the previous destructive cement coating

Peripheral drainage

Gentle drainage slopes have been created along eroded walls where deep undercuts were observed. This was done to reduce humidity related problems due to the excessive humidity in the walls. Surface drainage channels have also been designed to divert water away from the sensitive structures.



Fig. 4 - Peripheral drainage along the walls of Ibn Zayd mausoleum and Shahryar Ark palace

Reintegration of masonry elements:

For walls presenting very deep undercuts, the bases were partially reconstructed to prevent their collapse. Special attention was also given to voids in monuments, which were likely to be the starting points of critical puncture erosion processes, generally leading to serious conservation problems for the whole building. This was the case on the “Timurid pavilion” and the “Ice House 2” where there was a real emergency situation and several holes had to be filled in order to prevent imminent collapse.



Fig. 5 - Reintegration of masonry at the corner of an eroded wall 2007

Reintegration was also carried out on damaged domes, including one dome on the Ibn Zayd mausoleum, and the dome of the Ice House 2. Masonry was reintegrated into the structure with the same bricks, following the same bonding patterns. The reintegration of masonry should not be seen as a straightforward masonry job. It is quite a difficult task because the added brickwork had to bond perfectly with the original structure. This was achieved by working slowly and carefully to prevent fast setting and shrinkage of the added brickwork.





Fig. 6 - Ice house 2 - Reintegration of the masonry on the damaged dome in 2004

Numerous other preventive conservation solutions have continuously been designed since the beginning of this programme. They are tested at small-scale, over a sufficiently long period of time, allowing for fine-tuning and adaptation to local conditions (materials, skills, weather ...) before being implemented at a large-scale.

4. TRAINING COMPONENTS

This methodological approach was designed with the Turkmen personnel of the Park who were involved in each activity: from the first site analysis to the experimentation of preventive conservation techniques. Two regional training courses were organized in Merv and a third one at the Kunya-Urgench World Heritage site, to enlarge the diffusion of the knowledge to the Turkmen professionals working on the eight historical and cultural national Parks. They have a better understanding of the conservation problems encountered on earthen heritage and are able to develop and implement their own ingenious conservation techniques. At Merv, a great number of interventions have been implemented by the Turkmen staff on various typologies of structures, including ruined city walls (Abdullah Khan Kala, Bairam Ali Khan Kala) and standing monuments (Great Kyz Kala, Ibn Zayd). The improvement of the conservation practices can also be observed on other sites such as Gonur Depe, Olug Depe, Nisa and Kunya Urgench.



Fig. 7 - On site training sessions comprised documentation, practical works, preparation of illustrated reports and theoretical classroom sessions



Fig. 8 - Participants to the regional training course in Merv, June 2007

5. CONCLUSION

This cooperation programme, involving a wide range of professionals from all over Turkmenistan and Europe, was an excellent opportunity to share experiences and move a step forward in developing adapted conservation responses for this challenging site. The joint team developed innovative links between archaeology and conservation, which did not exist before. The Turkmen professionals in charge of ancient Merv, as well as their colleagues working in other significant Turkmen sites, have become more effective and confident in their work as a result of the skills and equipment transfers. The previous inadequate conservation techniques, inherited from the conservation of burnt brick monuments have been totally abandoned. The physical and mechanical properties of earth are now better understood, and the Turkmen professionals and artisans make high quality bricks and mortars. Several rainy seasons will be necessary to assess the efficiency of the proposed protections, but the first trials are promising. Useful information on how to monitor the structures, how to document them for conservation, and how to select materials have been gathered by the trained professionals. It is now possible to embark on larger and more ambitious conservation projects for sensitive monuments, such as the two Kiz Kalas for which a project document has been established by the partners.

Merv offers a unique opportunity to work simultaneously on different types of structures and develop a variety of responses fitting each situation. Most of the conservation problems observed on the monuments and archaeological sites in Central Asia can be found in Merv, thus the experience developed here over the following years will certainly benefit other sites in the sub-region.

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Curriculum

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**3D VISUALIZATION OF HISTORIC EARTHEN STRUCTURES FOR THE
DOCUMENTATION OF THE DETERIORATION PROCESS AND THE
CONSERVATION WORK:
CASE STUDY OF THE ANCIENT BUDDHIST MONASTERY, AJINA TEPA,
TAJIKISTAN**

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Theme 1: History of earthen architecture in Asia and other regions of the world

Sub theme 1.1: Archeological sites and historical monuments

Keywords: Photogrammetry, Ajina Tapa, Buddhist monastery, earthen structure, Central Asia

Abstract:

The holistic approach to documentation, scientific research and practical work is indispensable for proper conservation of historic sites. Usually, every expertise is performed by a different specialist, so that the amalgamation among those different knowledges tends to be lost. In the project "Preservation of the Buddhist Monastery Ajina Tapa, Tajikistan", the authors tightly linked different expertises for achieving proper conservation. For the documentation, photogrammetry was selected for the 3D visualization of the site, but also for the monitoring of deterioration and the recording of conservation work. Furthermore, this method was used to clarify the deterioration mechanism and update the conservation plan. As for scientific research, the properties of historic construction material were studied through laboratory analysis. As salt weathering is the major agent of deterioration of the site, evaporation from walls was measured. By combining all results, a proper conservation plan was assembled and executed.

1. INTRODUCTION

The Buddhist Monastery of Ajina Tapa (E 068° 51' 15.0", N 037° 47' 53.1"), Tajikistan is located in a valley surrounded by hills that are part of the west foot of Pamir mountains and at about 100km south of the capital city Dushanbe, Tajikistan. The average elevation of the site is about 500m above sea level. Average annual precipitation measured during 1961-1990 at Kurgan tube city at about 15km west of the

site was 260mm/year and rain is usually observed in winter season. The minimum and maximum temperatures are -20 °C in winter and +40 °C in summer, respectively. It can be said that the climate condition around the site is severe.

The Ajina Tepa monastery was constructed along the ancient Silk Roads, and was archeologically excavated by Soviet archeologists led by Litvinskij during 1960-1975 (Litvinskij et al., 2004). On the basis of the archeological study, Ajina Tepa was defined as a typical combination of monastic and temple areas of 7th-8th Century AD. The site is entirely built with earth, partly mud brick and partly *pakhsa* (rammed earth). The study reveals that the entire site was composed of two distinct parts: the monastery (characterized by an open courtyard measuring 19x19m, with cellae facing four access elbow-shaped passages) and the temple (with similar arrangement of four iwan facing the cellae, but with a massive terraced Stupa in the courtyard).

After the excavation, no appropriate conservation work was carried out, and as a consequence, the site has deteriorated by weathering, erosion, collapse of walls and so forth under the extreme climate condition. For the conservation of the site, UNESCO/Japan Trust Fund Project "Preservation of the Buddhist Monastery Ajina Tepa, Tajikistan" was executed during 2005-2008. The present study was carried out as a part of this project which was successfully managed by the UNESCO Cluster Office in Almaty in close collaboration with the UNESCO World Heritage Center and it is a part of wider involvement of UNESCO/Japan Trust Fund in the conservation of the earthen archeological heritages of Central Asia (Fodde 2007a, Fodde 2007b). National implementation agencies include the Academy of Sciences of Tajikistan (Institute of History, Archeology and Ethnography, the National Museum of Antiquities), Ministry of Culture of Tajikistan and Tajik Technical University.

The conservation work was planned and executed on the basis of documentation such as the 3D visualization of the site, scientific researches, i.e. studies on the properties of the historic construction materials, researches on the mechanism of deterioration of walls/Stupa, etc. Although it has been pointed out that scientific research is very important for the actual conservation, proper methods on how to use the results for the benefit of practical conservation has not been clarified yet. In the project, the authors tried to tightly link those items to properly conserve the Ajina Tepa site. The conservation work linking tightly with documentation and scientific research is presented in the following sections.

2. DOCUMENTATION PROCEDURE AND SCIENTIFIC RESEARCHES

Figure.1 schematically illustrates the relation among conservation work, major documentation and scientific research in this conservation project. Documentation is important in the following three stages:

1. Initial stages: Before the conservation, initial geometry of the site and the damages of structures had to be well documented. The major items in the stage included in the stage are mapping, 3D visualization and assessment of damages on walls and the Stupa.
2. Monitoring stage: Deterioration of structures (walls and Stupa) during the preparatory phases and the execution of conservation work. The deterioration processes were well monitored and the initial conservation plan was modified on the basis of the monitoring results.
3. Final stage: The geometry of structures after conservation was documented. This documentation stage is very important for the maintenance works and/or additional conservation in future. Furthermore, it can provide basic information for further archeological excavation when it is planned.

In this study, photogrammetry was adopted as the basic technique for the mapping, 3D documentation, monitoring and the documentation of final geometry after conservation. As an alternative technique, the 3D geometry of the structure could be measured by using laser scan technique. However, when the monitoring of deterioration is considered, photogrammetry was thought to be more applicable and practical, because it is very effective to get image information simultaneously. Measurement precision is not so different between photogrammetry and laser scanning. From a pair of digital stereo-photographs, 3D graphics can be constructed by using photogrammetric software (Fujii et al., 2007, 2009, 2011). After 3D graphics of walls are constructed, the vertical and horizontal cross sections of walls can be easily made.

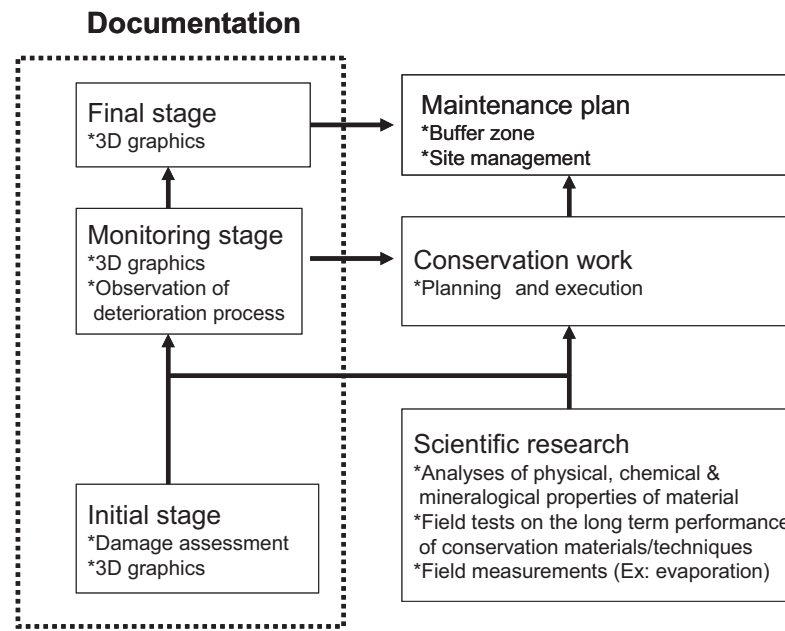


Fig.1: Relation among documentation, scientific research and conservation work

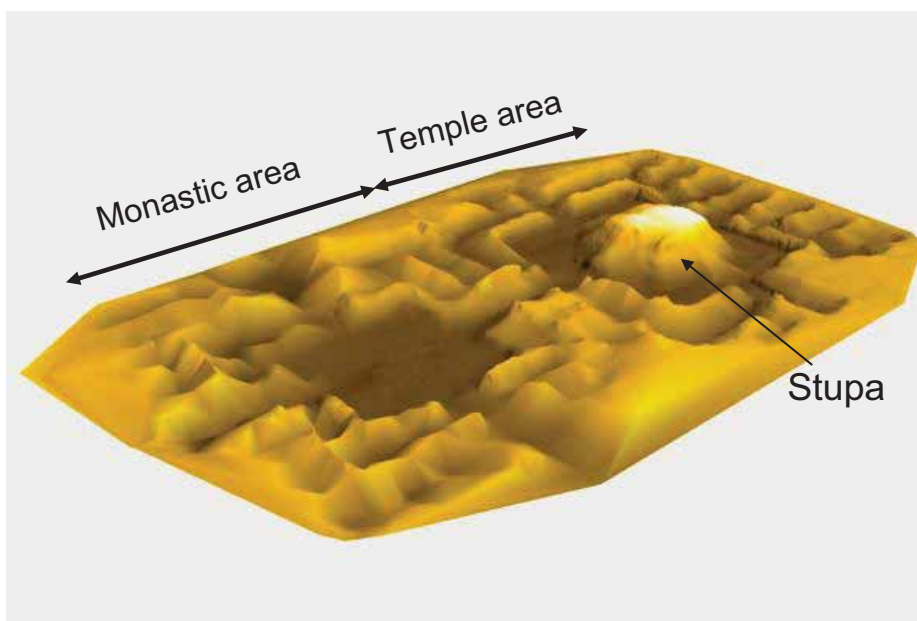


Fig.2: Perspective view of the site before conservation.

Figure 2 illustrates the perspective view of the site. It can be seen that Ajina Tepa is divided into two areas, monastic area and the temple area as above mentioned. A large Stupa and several walls can be observed in the site. Such structures were much deteriorated because exposed to the elements. Because the geometries of all walls/Stupa are thus documented, when a wall is collapsed at any location, the geometrical change can be detected. As the result of monitoring, it was found that the speed of the deterioration is rapid in the site. Small and large failures have been continuously occurring on some walls during the project period (Fujii et.al., 2009).

Scientific research is indispensable to document the mechanism of collapse and how to properly conserve the historic structures. As the first step, a photographic survey of all elevations, with name of structure, arrow for the north, and scale was carried out. Damage assessment was then undertaken with survey sheets before starting any conservation work. Condition reporting of the site was carried out regularly by documenting the elevations, and such documentation work is now available at the National Museum of Antiquities, Dushanbe. In order to have a general view of the main causes of deterioration, a survey was carried out in 2006 for every wall before the execution of actual conservation. This pointed out the most common symptoms of decay as being : collection of debris at base of wall (92.3%), soft crust of clay (91.3%), grass with deep roots (82.7%), hard crust of clay (88.9%) grass growth (62.9%), coving (48.2%), hole by animals (48.1%) man made damage (40.7%) preferential channels (25.9%), salt crystallization (17.3%), crack (16%), hole made by insect (14.8%), wide portion of missing wall (12.3%), missing wall (7.4%). The total does not amount to 100% because most walls showed more than one symptom of decay. Also, as the salt crystallization cannot be easily observed by eye, the percentage of salt crystallization may be higher. Previous researchers (Goudie et al., 1997, Kuchitsu et al.1999) pointed out that the salt weathering is one of the important factors in deterioration process of earthen structures.

Fujii et al. (2009) pointed out the coving at the bottom of the wall that was formed by salt weathering causes the collapse. They also proposed a way to estimate the stability of every wall. Watanabe et al. (2009) measured the distribution of evaporation that accelerates the salt weathering and found that the evaporation is large at the foot of the walls (Watanabe et al., 2008).

Physical, chemical and mineralogical compositions of historical materials were studied. In order to have a representative number of samples, 20 specimens of mud brick and 20 of *pakhsa* were collected. Their analysis was compared to that of the repair material following the method explained in Fodde (2007c). A summary of the main findings of such laboratory work is available in Fodde et al. (2008a, 2008b, 2010) where a new method for the requirement of sacrificial interventions was developed using a simple field laboratory. Analysis include: granulometry and grain size distribution of soils, Atterberg limits, soluble salts, carbonates content, erosion test, wetting and drying. Figure 3 shows the granulometry curves of an historic mud brick and a sample of *pakhsa*.

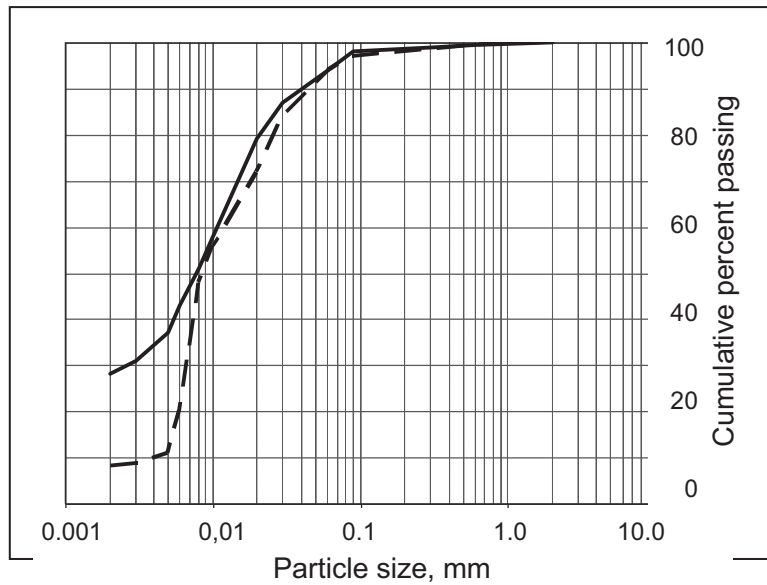


Fig.3: Diagram showing comparative analysis between grain size distributions of historic mud brick and *pakhsa* (dotted line)

Watanabe et al. (2011) reported that the mineral compositions of historic mud brick and *pakhsa* are almost identical and containing quartz, calcite, plagioclase, chlorite and mica mineral. On the other hand, salt that generated by weathering includes much amount of halite (sodium chloride) that was not found in the historic materials. The possible source of sodium chloride is thought as groundwater. Those facts are very important for conservation plan and for the selection of new material, mud brick and plaster, used in conservation.

3. CONSERVATION PLAN

As the deterioration speed has been very rapid in the site, the technique to cover the historic structures with thick mud brick and plaster layers (shelter coating) was selected. Figure 4 illustrates the procedure of the conservation. Some walls were structurally unstable and showed large fractures. Buttresses were constructed for supporting those unstable walls (Fig. 4(a')). Then, the walls were covered with mud brick shelter coats (Fig.4(b)). The thickness of the mud brick shelter coats were 50-80cm. Finally, the mud brick layer was covered with plaster layer of 5-10cm thick (Fig.4(c)). As above mentioned, the foot of the shelter coat may be weathered and eroded mainly by salt weathering. And from the mineral composition of the salt, it was found that the upward motion of moisture from the ground accelerate the salt weathering. To decrease the salt weathering, impervious sheet were installed at the lower part of some selected shelter coats (Fig.4(c')). It was found that the impervious sheet can considerably decrease the salt weathering. However, the moisture flow may not be completely stopped by impervious sheet because moisture can also infiltrate through original wall and flows towards the shelter coat. It is felt here that lowering of groundwater table around the site is better solution for preventing the salt weathering. A wide buffer zone is recommended to keep the groundwater table in lower depth.

The construction of the shelter coat was performed by local labors without precise measurement and record of its geometry such as the thickness distribution. As those information is important in the maintenance work, the geometry of walls after conservation should be precisely documented.

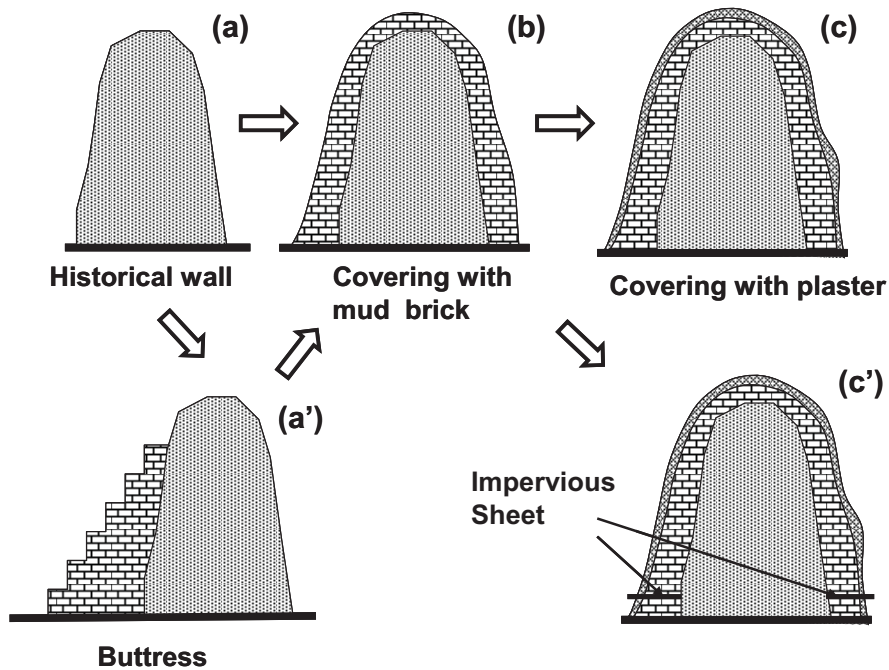


Fig.4: Basic concept of conservation adopted for the Ajina Tepa site

4. DOCUMENTATION BY PHOTOGRAMMETRY

Figure 5 displays three vertical cross sections of a wall that cut at the same vertical plane. The geometrical change in the initial stage, monitoring stage and final stage can be compared. As shown in the figure, the structure is characterized by coving effect at the bottom of the wall in the initial stage. During the monitoring stage, the upper part of the wall was slid down. As a conservation measure (final stage) the thickness of shelter coat was 70-120cm in this section.

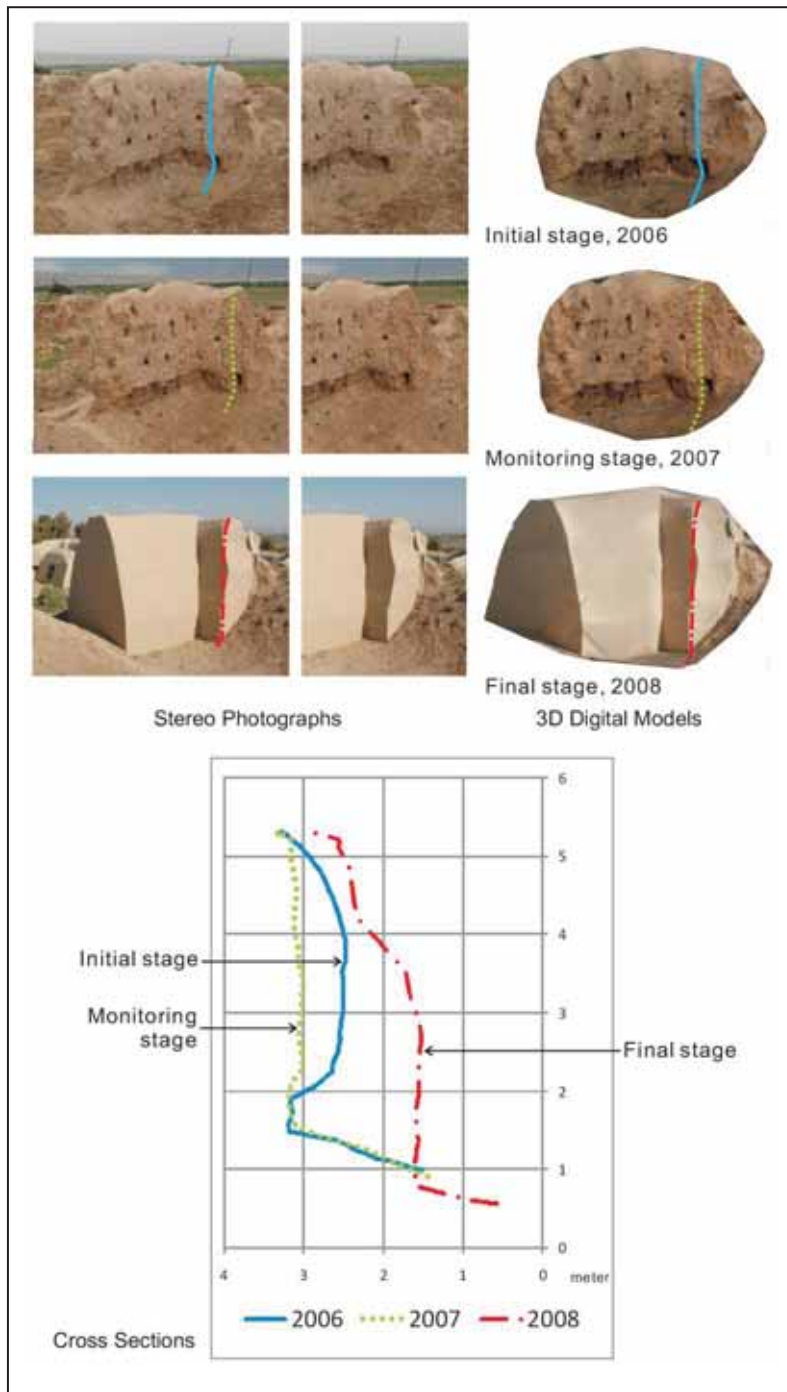
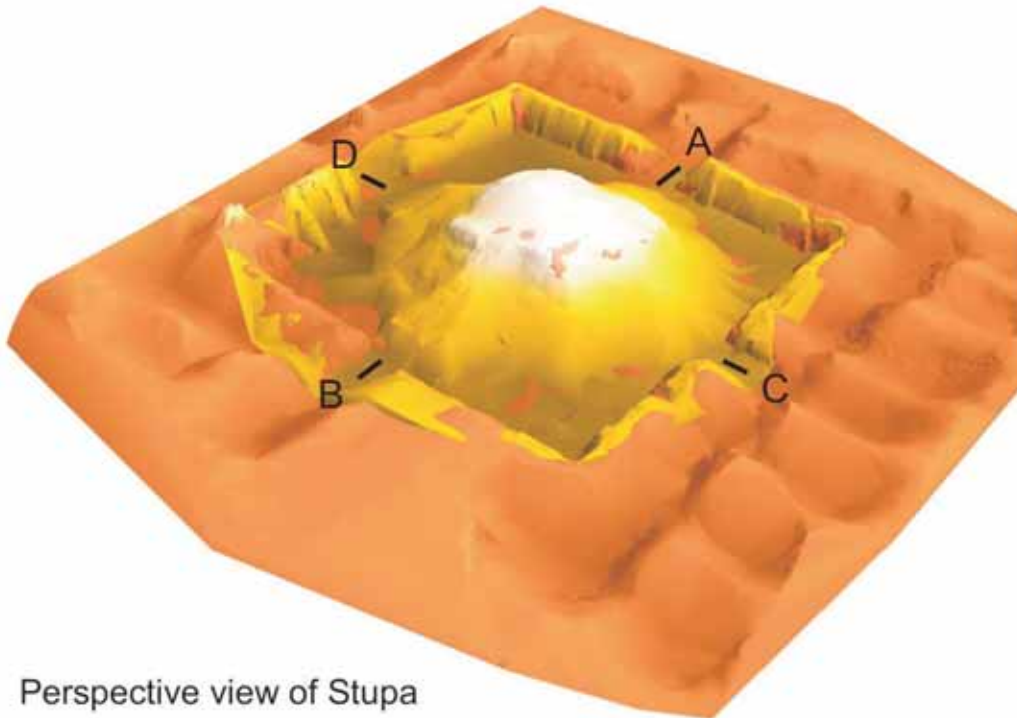
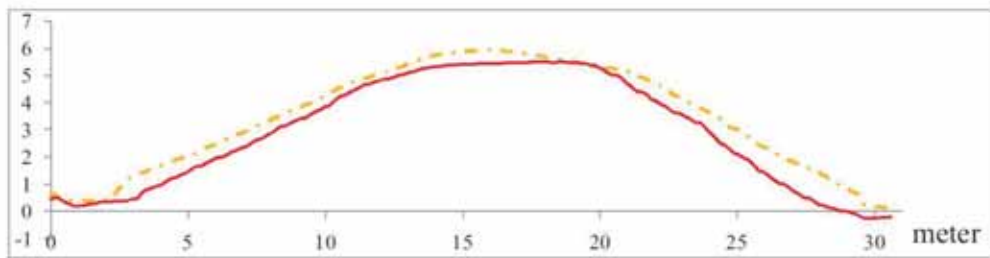


Fig. 5: Comparison of vertical cross sections of a wall in initial, monitoring and final stages. The pair of photographs 3D digital model and cross sections are displayed. A large scale collapse was occurred in monitoring stage.

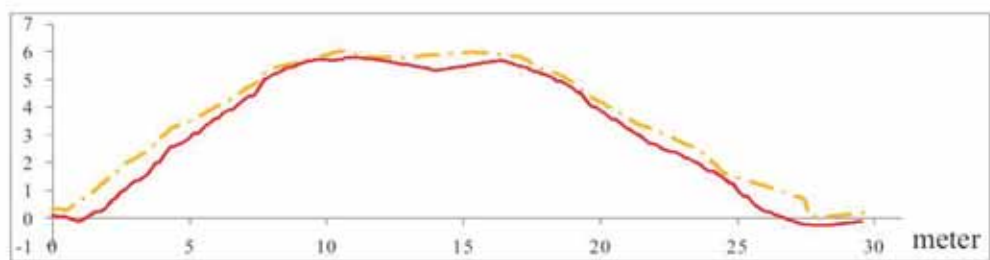


Perspective view of Stupa



A

B



C

D

Cross Sections of Stupa

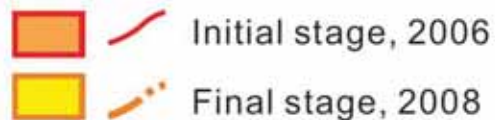


Fig.6: Shelter coat on Stupa. Geometries of Stupa in initial and final stages can be compared.

Figure 6 illustrates the geometrical change of Stupa between the initial and the final stage. It is observed that the Stupa was totally covered with shelter coat made of new mud brick and mud plaster and the geometry of the shelter coat such as the thickness

distribution is presented. In the cross sections A-B and C-D, it is observed that the average thickness of shelter coat is about 40-50cm.

5. CONCLUSION

The holistic approach to documentation, scientific research, planning and actual work is indispensable for the proper conservation of historical site. In the project for the conservation of Ajina Tepa, Tajikistan, all those activities are tightly linked and properly performed with following results:

1. Photogrammetry was an adequate technique for documenting wide archeological site.
2. Photogrammetry can be used successfully for the monitoring of deterioration
3. Documentation of the shelter coat geometry provides key information for planning proper maintenance work.
4. Scientific research on the damage assessment and material properties is indispensable for planning conservation work.
5. Evaporation measurement and mineralogical composition analysis is an effective method for evaluating salt weathering

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THE CHARACTERISTICS AND CONSTRUCTION TECHNOLOGY OF TRADITIONAL EARTHEN MATERIALS BY RESEARCHING *UIGWE* (THE OFFICIAL RECORDS OF COURTS EVENTS) OF JOSEON DYNASTY

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Theme 1: History of earthen architecture in Asia and other regions of the world

Sub theme 1.2. (ST2.1.): Vernacular architecture and traditional building cultures

Keywords: Traditional earthen material, *Uigwe*, Construction technology, Craftsman, Tool

Abstract:

The purpose of this study is to provide the basic information on Korean traditional earthen architecture for a database system by analyzing *Uigwe* which are the official records of court events of the Joseon Dynasty. For accurate analysis of *Uigwe*, current construction methods were investigated and interviews with craftsmen were performed. The contents of Korean traditional earthen architecture in *Uigwe* could be classified into five categories: building materials, production organization, construction methods, craftsmen, and construction tools. Next, research sheets including this information were created for use as the fundamental data of Korean traditional earthen materials in the architecture industry.

1. INTRODUCTION

Earth was the most widely used building material in Korea until the 20th century. The development of building technology and modern materials such as concrete and steel caused a decrease in the use of earth in building construction. Recently, however, concerns over earth architecture have been increasing since architecture made by earth is economical, energy conservation, environmentally friendly, and sustainable. Haneol Research Institute of Cultural Heritage, therefore, began to study Korean traditional earthen architecture in 2007. The purpose is to provide a database for the application of earthen materials in the architecture field. This study focuses on understanding the material types and construction methods described in *Uigwe*. The data obtained in this study will be used for the improvement of the guidelines for preserving historical architecture and also as the fundamental information for the development of construction technology in modern earthen architecture.

2. UIGWE : THE OFFICIAL RECORDS OF COURTS EVENTS

Uigwe (儀軌) are the official records of the royal protocols of the Joseon Dynasty in Korea. They describe and illustrate important ceremonies of the royal family such as ancestral rites, reception of guests, celebrations, declarations of war, and state funerals. *Uigwe* were also published after national events by Dogam, which was the temporary department for national events.



Fig. 1 - Contents of *Uigwe* (text, stylized illustrations)

The *Uigwe* we can access were written after the 17th century. *Uigwe* before that time were lost during the Imjin war (1592~1598). *Uigwe* were published continually since the 17th century and their publication became increased and diversified in about the 18th century. *Uigwe* consisted of various types of records and a total of 700 volumes. In this study, only the records of architectural constructions, *Yeonggeon-Uigwe* (營建儀軌) and *Sanreung-Uigwe* (山陵儀軌), were analyzed: the former are the construction records of royal buildings of which we investigated 33 volumes and the latter is the construction

records of a royal tombs of which we investigated 26 volumes (Table 1).

No.	Yeonggeon-Uigwe(營建儀軌)	Year published	Year researched
1	Changgyeonggung Suriso Uigwe (昌慶宮修所儀軌)	1633(Injo11)	2008
2	Changdeokgung Suri Dogam Uigwe (昌德宮修理都監儀軌)	1647(Injo25)	2008
3	Jeoseungjun Uigwe (儲承殿儀軌)	1648(Injo26)	2008
4	Changdeokgung Changgyeonggung Suri Dogam Uigwe (昌德宮昌慶宮修理都監儀軌)	1652(Hyojong3)	2008
5	Changdeokgung Mansojeon Suri Dogam Uigwe (昌德宮萬壽殿修理都監儀軌)	1656(Hyojong7)	2008
6	Yeongnyunjeon Sugae Dogam Uigwe (永寧殿修改都監儀軌)	1667(Hyeonjong8)	2008
7	Jipsangjeon Sugae Dogam Uigwe (集祥殿修改都監儀軌)	1667(Hyeonjong8)	2010
8	Nambyuljeon Joonguncheong Uigwe (南別殿重建廳儀軌)	1677(Sookjong3)	2008
9	Gyeongdukung Soorisoo Uigwe (慶德宮修理所儀軌)	1693(Sookjong19)	2008
10	Jongmyo Gaesu Dogam Uigwe (宗廟改修都監儀軌上,下)	1725(Yeongjo1)	2008
11	Jireung Jungjagak Gaegun Uigwe (智陵丁字閣改建儀軌)	1732(Yeongjo8)	2010
12	Jinjeon Joongsu Dogam Uigwe (眞殿重修都監儀軌)	1748(Yeongjo24)	2008
13	Uisomyo Yeonggeon cheong Uigwe (懿昭廟營建廳儀軌)	1752(Yeongjo28)	2008
14	Geonwonneung Jungjagak Joongsu Dogam Uigwe (健元陵丁字閣重修都監儀軌)	1764(Yeongjo40)	2008
15	Soeunmyo Yeonggeon cheong Uigwe (垂恩廟營建廳儀軌)	1764(Yeongjo40)	2008
16	Jinjeon Joongsu Yeonggeon cheong Uigwe (眞殿重修營建廳儀軌)	1772(Yeongjo48)	2011
17	Gyeongmogung Gaegun Dogam Uigwe (景慕宮改建都監儀軌)	1776(Yeongjo52)	2008-2010
18	Moonhimyo Yeonggeon cheong Deungrok (文禧廟營建廳騰錄)	1789(Jeongjo13)	2008
19	Hwasung sungyeok Uigwe (華城城役儀軌)	1801(Soonjo1)	2007
20	Injeongjeong Yeonggeon Dogam Uigwe (仁政殿營建都監儀軌)	1805(Soonjo5)	2008
21	Hyunsagung Byulmyo Yeonggeon Dogam Uigwe (顯思別廟營建都監儀軌)	1824(Soonjo24)	2008
22	Seogwol Yeonggeon Dogam Uigwe (西關營建都監儀軌)	1832(Soonjo32)	2008
23	Changgyeonggung Yeonggeon Dogam Uigwe (昌慶宮營建都監儀軌)	1834(Soonjo34)	2008
24	Changdeokgung Yeonggeon Dogam Uigwe (昌德宮營建都監儀軌)	1834(Soonjo34)	2008
25	Jongmyo Yeongnyunjeon Joongsu Dogam Uigwe (宗廟永寧殿增修都監儀軌)	1836(Heonjong2)	2008
26	Injeongjeong Joongsu Uigwe (仁政殿重修儀軌)	1857(Cheoljong8)	2008
27	Namjeon Joongeon Dogam Uigwe (南殿增建都監儀軌)	1858(Cheoljong9)	2008
28	Jokjungdan Joonkyung Yeongkyungmyo Uigwe (肇慶壇齋慶永慶墓儀軌)	1899(Kwangmoo3)	2011
29	Yeongheejeon Yeonggeon Dogam Uigwe (營禧殿營建都監儀軌)	1900(Kwangmoo4)	2008
30	Gyeongbok gung Changdeokgung Joongeon Dogam Uigwe (景福宮昌德宮增建都監儀軌)	1900(Kwangmoo4)	2010
31	Jinjeon Joongeon Dogam Uigwe (眞殿重建都監儀軌)	1901(Kwangmoo5)	2008-2010
32	Joonghwajeon Yeonggeon Dogam Uigwe (中和殿營建都監儀軌)	1904(Kwangmoo8)	2008
33	Kyungwoogun Joongeon Dogam Uigwe (慶運宮重建都監儀軌)	1906(Kwangmoo10)	2008
No.	Sanreung-Uigwe(山陵儀軌)	Year published	Year researched
1	Uiinwanghoo Sanreung Dogam Uigwe (懿仁王后山陵都監儀軌)	1601(sunjo34)	2009
2	Mokreung Sugae Uigwe (穆陵修改儀軌)	1609(Kwanghae1)	2010
3	Wonjong Yejong Dogam Uigwe (元宗禮葬都監儀軌)	1627(Injo5)	2011
4	Seonjo Mokreung Chunreung Dogam Uigwe (宣祖穆陵遷陵都監儀軌)	1630(Injo 8)	2009
5	Inmokwanghoo Sanreung Dogam Uigwe (仁穆王后山陵都監儀軌)	1632(Injo10)	2010
6	Sohyeonseja Myoso Dogam Uigwe (昭顯世子墓所都監儀軌)	1645(Injo23)	2009
7	Injo Jangreung Sanreung Dogam Uigwe (仁祖長陵山陵都監儀軌)	1649(Hyojong1)	2009
8	Yeongreung Gaesu Dogam Uigwe (寧陵改修都監儀軌)	1660(Hyunjong1)	2009
9	Hureung Sugae Dogam Uigwe (厚陵修改都監儀軌)	1667(Hyunjong8)	2011
10	Hyojong Yeongreung Chunreung Dogam Uigwe (孝宗寧陵遷陵都監儀軌)	1674(Hyunjong15)	2009
11	Hyunjong Soongreung Sanreung Dogam Uigwe (顯宗崇陵山陵都監儀軌)	1674(Sookjong0)	2009

First, terminology regarding the five categories was defined and then, research sheets with the information of the five categories were created. Each *Uigwe* has approximately 10 to 40 sheets. Between 2007 and 2010, approximately 1,550 sheets were created (Table 2).

3.2. Analysis of five categories

3.2.1. Earthen Material

Construction materials found in *Uigwe* are gravel, sand, clay, and lime. Gravel and sand were usually used as raw aggregates. Clay and lime were used after mixing, plastic deformation or drying. Lime plaster (三物灰) which is composed of lime, fine sand, and yellow clay was used for soil stabilization in buildings and royal family tombs.

■ Raw Earthen Material		■ Worked Earthen Material
Soil(土)	White Soil(白土), Yellow Soil(黃土), Clay Soil(真土), Lime Soil(灰土), Mud Soil(泥土), Mud(泥)	Roof Tiles(瓦) Walls(壁) Floor Tiles(甃)
Sand(沙)	Fine Sand(細沙), White Sand(白沙)	
Gravel(石)	Rubble(雜石)	
Lime(灰)	Lime(石灰), Good Lime(正灰), Leftover Lime(滓灰), Original Lime(元灰), Aggregate Lime(骨灰), Quick Lime(強灰)	Plastered Lime(泥灰) Oil mixed Lime(油灰) Water mixed Lime(水灰) Fine Lime(熟灰) / White Lime(白灰) Lime Plaster(三物灰) Aggregate Lime Plaster(滓三物灰)

Table 3 - Earthen Materials

3.2.2. Production Organization

Production organization served as both a manufacturing facility and an administration office. It has the responsibilities of the supply, transportation, and management of materials. Roof tiles, antefixes, and bricks were however provided by Waseo (瓦署) which is the facility to make tiles.

■ Production Organizations
A facility to make tiles(瓦署, 別瓦署, 燔瓦所), A facility to handle and carry the lime plaster(三物所), A facility to burn limes(燔灰處), A facility to fill with earth(補土處)

Table 4 - Production Organizations

3.2.3. Construction Method

Uigwe describe and illustrate the construction methods of constructing the foundation, finishing and plastering. The laying a foundation(開基, 地正) is the first step of the foundation construction. Spreading lime plaster and ramming(鋪灰杵築), it were conducted for finishing. This also has the effect of waterproofing.

■ Construction Methods	
Foundation & Ground finishing	Laying a foundation(開基, 地正) Leveling ground after burial(平土), Digging ground(破土, 掘土) Spreading ground(鋪灰土), Filling charcoal dust(炭末築) Ramming after filling plastering lime(三物築), Ramming after filling coal(炭築)

	Filling soil(土築), Filling yellow soil(黃土築), Filling leftover lime(滓灰平築) Ramming earth construction(杵築, 達古築, 踏杵築) Ramming plastering lime(三物杵築), Ramming plastering lime strongly(三物堅築) Ramming&filling by turns(交築), Spreading lime plaster and ramming(鋪灰杵築), Spreading soil and ramming(鋪土杵築), Flattening soil and ramming(平鋪杵築) Covering ground(補土), Cutting ground(刈土) Filling oil mixed lime(築油灰), Filling plastering lime(築灰, 築石灰), Spreading lime(鋪灰), Covering lime(補灰)
Finishing	Lime stopping around the coffin(灰隔, 隔灰), Lime stopping and ramming around the coffin(灰隔杵築), Lime finishing around the coffin(傍灰), Lime finishing on the coffin(天灰) Lime finishing on the ground of the coffin(地灰) Sand coat(沙壁), Roofing with tiles(盖瓦) Laying the floor tiles(鋪方磚), Laying with fine sand(鋪細沙) Mud plastered on the ceiling(仰壁)
Plastering	Plastering on the ridge of a roof(樑上塗灰), Plastering Oil mixed Lime(塗油灰) Mud plastering(塗泥), Soil plastering(塗土), Plastering a wall with loam(塗墍)

Table.5 - Construction methods

Craftsman

Craftsmen belonged to different production organizations according to their jobs. Craftsmen dealing with earthen materials include plasterers, roofers, and masonries. A plasterer was a craftsman who plastered wall, ceilings and fences. He also laid soil before tiling on the roof and plastered the ridge of the roof. A roofer specialized in roofing and decorating the roof. He laid soil before tiling with plaster.

■ Craftsmen

Plasterer(泥匠), Brick masonry, Brick burner(瓦壁匠), Gravedigger(沙土匠),
 Roofer(盖匠, 盖瓦匠, 瓦匠), Antefix roofer(鸞頭匠)

Table 6 - Craftsmen

Tool

Terminology of tools in *Uigwe* is similar with the term used in present days. The shape illustrated in *Hwasungungyeok-Uigwe* (華城城役儀軌) is also similar to the shape of modern tools. A spade (加羅) and earth were used for laying the foundation. Three to five workers laid the ground with spades in a circle. An earth pounder (杵, 達古) was used for ramming the ground.

■ Tools

Earth pounder(杵, 達古, 圓達古), Stone earth pounder(石杵)
 String(馬古遶), Small shovel(小鍤), hoe(鏝伊, 衝鏝伊), Shovel(鍤, 平鍤)
 Wooden spade(木加羅), Round Shovel(曲鍤), Wide hoe(廣鏝伊)
 Sieve(篩, 馬尾篩, 竹篩)

Table 7 - Tools

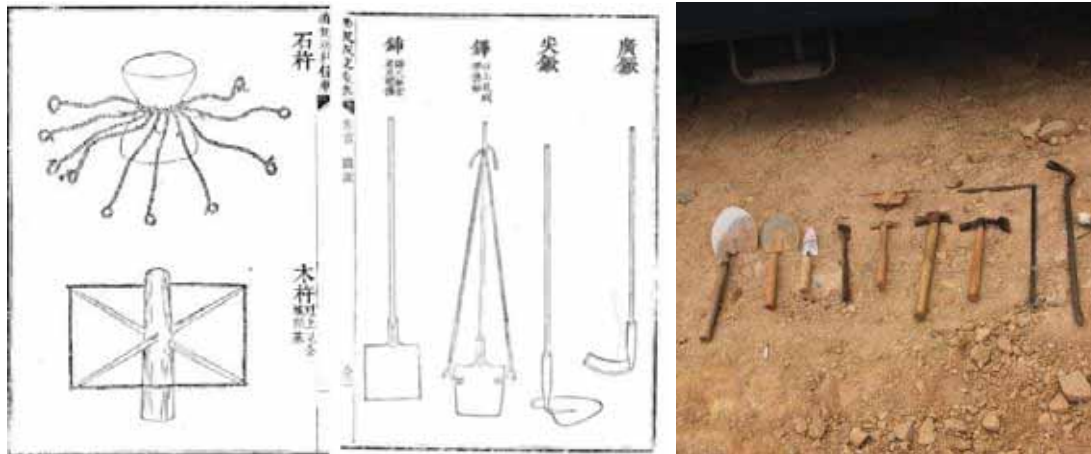


Fig.2 - The tools (left, middle) (*Hwasungsungyeok-Uigwe*) and the current tools (right)

4. CONCLUSION

Yeonggeon-Uigwe and *Sanreung-Uigwe* are the most important literature to understand the construction technology of the Joseon Dynasty. From analysis of these *Uigwe*, information on the type and mixing method of earthen material, production organization, construction method, craftsman, and tool was obtained. The database was constructed and updated continually by the laboratory members of Professor Sandong Lee of Mokpo University. The data will be provided via the internet.

This study provides information on the mixing methods and construction methods of earthen materials from analysis of the terminology described in *Uigwe*. The meaning of some terms, however, was not understood clearly in this research. Differences also exist between the construction methods described and illustrated in *Uigwe* and the methods performed at the current historical preservation job sites. Future research therefore, is required to accurately understand the construction methods described in *Uigwe*. Such research will help in the development of the guidelines for preserving historic buildings and will provide fundamental data for the technology development of earthen architecture.



Fig. 3 - Investigation of earthworks of traditional buildings (plastering, roof tiling,)



Fig. 4 - The database system of traditional earth materials

Endnote:

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TOBACCO CURING BARNs IN GOSAN-RI: AN EXAMPLE OF VERNACULAR EARTHEN ARCHITECTURE IN KOREA

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T1: History of earthen architecture in Asia and other regions of the world

ST1.2: vernacular architecture and traditional building cultures

Keywords: vernacular architecture, earthen architecture, tobacco curing barns

Abstract:

Since the birth of human civilization, vernacular architectures have appeared in every corner of the world. In remaining outside of the history of architecture, vernacular architectures reflect their respective local environments. In Korea, as well, there are many tobacco curing barns, typical of such architectures. After the 1970's, however, during the National Land Development Planning initiative, most of them disappeared without being handed down to the next generation. This study will focus on Korean tobacco curing barns - a type of vernacular architecture, and, in view of earthen architecture, this article will deal with typology analysis, construction materials and techniques, and an architectural diagnosis of the barns. The features of this kind of construction can be described as follows: simplicity of function and form, which is derived from earth, a local material; integration of function and form; and preservation of the quality of vernacular architectures in Korea.

1. INTRODUCTION

1.1. Content and objective

Vernacular architecture, which first appeared in the beginnings in human societies, exists in parallel with the history of architecture and is characterized by function, economy, and environment. As a result of shared practices that constitute daily life for inhabitants of the same environments and cultures, this type of architecture is in harmony with the environment and often displays simplicity in function and form. A typical example of this architecture is the tobacco curing barn, which spread throughout rural Korea. This type of building was built after tobacco was imported; those which are still standing were built in the 1960's and 1970's. The main building material is earth, as it allows for efficient drying and natural ventilation. Earthen materials enable solid architectural structure and are resistant to high temperatures during the drying process. The ease with which a material can be gathered locally is a decisive factor in choosing building materials. The objective of this thesis is to examine earthen vernacular architecture through a case study of three tobacco curing barns present in a village, in particular, their role, location, structure, the building materials employed, and the evolution of their function.

1.2. Methodology and delimitation

We chose a village, named Gosan-ri that has three tobacco curing barns; the case studies were carried out on-site and explored the size, structure, and materials. We then analyzed the evolution of the building materials in relation to the morphology of the village and the role of the tobacco curing barns on economic and symbolic levels. Finally, part of the study is devoted to damage assessment; exposing the state of deterioration is a way to raise awareness about the plight of these buildings.

2. BACKGROUND

2.1. The history of tobacco in Korea

Originally grown in the America, tobacco was introduced to Europe by Christopher Columbus following the discovery of the New World (1492). The introduction of tobacco to Korea cannot be precisely dated; however, it was imported from Japan around 1600³. This first tobacco was a native variety, grown mostly in Japan, where it was offered as a gift to the nobility, the *shogunate*, and the royal family. In Korea too, tobacco long remained a precious commodity reserved for nobility.

This native variety was grown only in mountainous areas of Korea. A new variety of tobacco, named flue-cured tobacco, was introduced to Korea at the beginning of the 20th century. This flue-cured tobacco was first grown in the United States, then introduced to Japan in 1902 for the first tentative attempts at production, and then to Korea, probably by via Japanese. Korea began producing flue-cured tobacco under the control of the Japanese government during the colonial occupation (1910-1945). As flue-cured tobacco is not grown exclusively in mountainous areas but grows also in the plains, it expanded to all parts of Korea after its introduction.

Tobacco production decreased during the Korean War in 1950, but picked up again from 1960, after the war. In 1970, the Korean government initiated the *Saemaeul*⁴ Movement. This movement, which was especially aimed at improving rural living conditions, provoked deep changes throughout all of the provinces. For example, the government distributed 300 bags of cement to each village so that the villagers could renovate their slate roofs, render their walls, or build annexes. In order to improve agricultural activities and prevent damage caused by floods, the villagers built cement dikes, irrigation canals, bridges, and alleyways. Without a doubt, these developments contributed to improving the quality of life. This climate of change was favorable to mechanizing agriculture, including the tobacco growing industry, which as a result went through a profound transformation. The introduction of drying machines at the end of the 1970's sparked the gradual move away from tobacco curing barns. The number of tobacco growers declined significantly in Korea because of trade monopolies, tax increases, and cheaper tobacco imports from developing countries.

2.2. Tobacco's geographical distribution and the evolution of tobacco curing barns

Until the end of the 19th century, there was only one native variety of tobacco found in mountainous areas and Kangwon-Do. This variety, popular with the nobility and royal families, all but disappeared after the abolition of the aristocracy and the decline of the royal family. These days, two varieties of tobacco exist: flue-cured and burley. Flue-cured tobacco is grown essentially in Chungcheongbuk-Do and Gyeongsangbuk-Do, and burley is grown mostly in Chungcheongnam-Do, Chollanam-Do and Chollabuk-Do. Burley tobacco was discovered in the middle of the 19th century in the United States

³ The history of Kyeonggi-Do, v.2, p.604-605.

⁴ This means "new village."

and was introduced in Korea after 1933⁵, later than flue-cured tobacco. Burley tobacco is air-dried at room temperature, as it loses its quality if it is dried with heat. It is a difficult variety to dry, as it is sensitive to a hot and humid climate. It is frequently dried in plastic greenhouses. Flue-cured tobacco is artificially dried with heaters. It requires a drying house that is hermetically sealed from the air outside. These tobacco curing barns can be found mostly in Chungcheongbuk-Do and Gyeongsangbuk-Do, and parts of Kangwon-Do, Kyeonggi-Do and Gyeongsangnam-Do.

During the Korean War in 1950, most tobacco curing barns were burnt down, and those that remain standing today were built between 1960 and 1970. They were progressively abandoned when drying machines were introduced at the end of the 1970's. When tobacco curing barns were no longer needed, these buildings became agricultural warehouses or were simply left empty. Today, most tobacco curing barns are abandoned and at risk of disappearing completely from the Korean landscape.

3. ANALYSIS OF TOBACCO CURING BARNs IN GOSAN-RI

3.1. The village's history and location

Gosan-ri village is located 50 km from the city of Andong in Gyeongsangbuk-Do. It stands in an area of plains at the foot of two small mountains and facing a lake. Gosan-ri is accessible by road and is served by a full range of infrastructure: drinking water, electricity, and a telephone network. The village was established 300 years ago, at the beginning of the 18th century during the *Cho-sun*⁶ dynasty. At that time, the village was named "water mountains" due to its location near the lake with its clean water and the surrounding mountains. There were around 100 families remaining in 1970, but the number of residents continues to drop, and today only 29 families, for a total of 80 residents, remain; they subsist mainly with agricultural activities, as is the case with most Korean villages.

3.2. The village's earthen architecture

Four types of architecture, based on the building materials used for the walls, can be found in the village: earthen architecture makes up 51%, stone and earth mortar 3%, cement 30% and steel 15%. Some of the earthen structures have bare earth walls, while others have been partially or completely rendered with cement. All of the roofs were redone in slate or sheet metal during the *Saemaeul* movement, when the introduction of materials such as cement was encouraged. The original roofs, predating the movement, were in all likelihood thatched. The occupation statistics for earthen architecture are as follows. 51% of the buildings with bare earth walls are used as warehouses or as shelter for cattle, and 11% are abandoned. For cement-rendered buildings, the percentages are respectively 3% and 2%. 27% of buildings that have been partially renovated or extended with a cement structure are used as homes; 4% are used as warehouses and for keeping cattle.

⁵ Burley tobacco was also introduced to Japan in 1933.

⁶ According to a plaque on the statue across from the village retirement home.




Village :		Gosan-Ri		
Chart				
Types of Earthen Construction	Construction with Earthen Walls	Construction Covered with Cement	Part of Construction Rehabilitated or Added with Cement	
Occupancy :				
Used as Residence	0%	0%	27%	
Used as Depot, Cattle	51%	3%	4%	
Abandoned	11%	2%	0%	

Fig. 1 - Occupation rates for earthen architecture within the village

In brief, the majority of bare-earth-walled buildings are used as warehouses and shelter for cattle, and most cement-rendered buildings are used as living quarters.



Fig. 2 - Inventory of the village's buildings: State of preservation and materials used

3.3. Architectural typology of the village's tobacco curing barns

Each variety of tobacco necessitates a drying technique, which in turn decides the shape of the building. Flue-cured tobacco requires a strong source of heat in order to dry quickly; this is best achieved with tobacco curing barns that are hermetically closed and that maintain a constant level of heat during the drying process. In this configuration, there is only one entrance and small, sealed windows for monitoring. The size of these curing barns is smaller than those for the native variety⁷ for more efficient drying. The three tobacco curing barns in Gosan-ri were built between 1960 and 1970. All three were built on a slope to facilitate water drainage, and their dimensions are smaller⁸ than those of neighboring areas. Several reasons can explain the location, shape, and size of these curing barns:

- Geographical location: the village is located on a hill at the foot of the mountains; as a result, there is insufficient space to build large tobacco curing barns.
- Field surface: in general, a 6 m x 4 m tobacco curing barn is capable of drying the leaves that are regularly harvested from a 4,900 m² field. The farmers in this village, however, cultivate smaller surfaces.

The village's tobacco curing barns are close to the farmers' homes for accessibility; farmers watch over the fire for five days and nights during each drying session. The small furnace is always on the side the farthest away from habitations to limit the spread of flames to farmers' houses in the event of a fire.

3.4. Construction materials and techniques for the tobacco curing barn

The tobacco curing barns follow a construction method called *pum-assi*.⁹ The barns are usually built with adobe consisting of earth and a type of straw called *sot-ku-dae*, which is often used to make traditional brooms. The adobe is molded with a metal press or a wooden mold.

3.4.1. The wall base and the floor

The wall base is made of stones bound by earth mortar and is about 50 cm high. The flooring of tobacco curing barns is made of packed earth. An *ondol* heating system is installed under the floor. This *ondol* system uses wood and, more recently, industrial coal and fuel oil. A metal tube with a diameter of 25 cm passes under the ground so that the heat derived from the smoke can circulate and dry the tobacco leaves efficiently. This structure prevents the flames from reaching the leaves during the drying process. The flooring is constructed with a slope to ease the circulation of heat to all parts of the ground. During the rainy season and typhoons, this slope helps to evacuate rain water.

3.4.2. The walls and the structure

In mountainous areas, thanks to the abundance of wood, walls are sometimes made of

⁷ The drying time for flue-cured tobacco is approximately five days, as opposed to three weeks for the native variety.

⁸ The widths and lengths are between 3m x 3.5m and 3.9m x 4.3m, and the heights are between 5.2m and 5.4m.

⁹ In rural areas, "puma" means "work"; "assay" means "to return," "to help," or "to work collaboratively."

a wooden framework and are filled with earth. However, as Gosan-ri is located in the plains, the most common material used is adobe. The 30-cm-thick by 1.5-m-high walls are built on top of the wall base, and then the thickness decreases to 20 cm up to the gables [Fig. 3]. The size of the adobe bricks is 30 cm x 15 cm x 15 cm. Wooden elements pierce the walls and are fixed with long pieces of timber. These wooden elements support the load of the beams together with shelves when large quantities of tobacco leaves are being dried. These drying shelves are 1.8m from the ground and spaced at 50-cm intervals vertically. The earth plasters contain more straw on the north façade to fight against rain and wind damage.

3.4.3. The roof

There are two types of roofs that allow the smoke to evacuate: roofs with a chimney, and roofs without, which are open at the gables. During the drying process, the temperature is maintained at a constant level by covering the chimney or the gable's opening with a straw mat. A ladder up against the outside wall of the building is used to readjust this mat in order to adjust the temperature. Tobacco curing barns' roofs are gables, and rafters are set at a distance of 45 to 55 cm. The rafters are maintained by wooden pole plates fixed into the lateral walls. A lattice is affixed to the rafters, which is, in turn, covered with plant stems and earth; slate is finally fixed onto the lattice.

3.4.4. The opening

The heating system needs a hermetically closed space in order to intensify the thermic isolation effect, which is needed to obtain a constant temperature for better drying; tobacco curing barns are well sealed, except for the openings used for monitoring, the chimney, and the entrance. Several 15 cm x 20 cm sealed glass windows allow the fire and drying process to be monitored for four or five days and nights. Monitoring can also be carried out through the roof, via the chimney or the opening in the gables. The entrance doors are made of wood.



Fig. 3 - Construction technique for tobacco curing barns: Lateral walls, roof, and section

3.5. Diagnosis of three tobacco curing barns

Two of the three curing barns studied are in fairly good condition despite no longer

being used for their original purpose. However, the third curing barn is abandoned, exhibits severe structural deformities, and is in danger of collapse.




Village :	Gosan-Ri		
Photos			
Tobacco Curing Barn	108	114	123-1
Construction date	End of 1960's	About 1970	End of 1960's
Degree of Occupation	Occupied	Occupied	Abandoned
State of Conservation	Renovation required ^⓪	Renovation required ^⓪	in Degradation / in Danger to Collapse
Restoration	no	no	no
Renovation	no	no	no
Current Use	Depot	Depot	None

Fig. 4 - The village's tobacco curing barns

This paragraph offers a diagnosis for each tobacco curing barn. The condition of each curing barn varies greatly; some are on the brink of ruin, such as curing barn 123-1 (fig. 5). The damage analysis shows the following:

- Large vertical cracks where gable walls and lateral walls meet. Two causes are possible: either stagnating water at the ground level and a wall base with insufficient height, or water leaks in the roof that have caused dampness and then the deterioration of the roof's wooden structure.

- Partially collapsed roofs and walls: this is the result of water leaks in the roof that have led to dampness and the deterioration of the roof's wooden structure.

Denomination			
Village :	Gosan-Ri	Code N° :	108



Large vertical crack where the west gable joins the north façade
Wall angle has deteriorated

Damage

1) Water stagnating at ground level
2) Wall base with insufficient height

Causes of damage

Denomination			
Village :	Gosan-Ri	Code N° :	114



Cracks in the cement plaster at the corner of the small furnace
Evidence of humidity and mould on the earth wall of the east façade

Damage

1) Water infiltration between the earthen structure and the cement plaster on the east façade

Causes of damage

Large crack in the earth wall of the north façade

1) Stagnating water in front of the north façade

Causes of damage

Denomination			
Village :	Gosan-Ri	Code N° :	123-1



Deteriorated rafters; roof and walls partially collapsed (east, west and north façades): north, east and west façades (from left to right)

Damage

1) Water leaks in the roof which have resulted in dampness and the deterioration of the wooden roof structure

Causes of damage



Large cracks in the gables (north and south façades) where they meet the walls: north and south façades (from left to right); the roof covering the fireplace in the corner has collapsed (north façade)

Damage

(north façade) Water leaks in the roof which have resulted in dampness and the deterioration of the wooden roof structure
(south façade) Stagnating water at ground level and Wall base with insufficient height

Causes of damage

Fig. 5 - Diagnosis: Photos and drawings

4. CONCLUSION

Tobacco curing barns are typical earthen constructions found in rural areas in South Korea. We chose a village where three tobacco curing barns were present. The typological study of the materials used in the village showed that most buildings with original bare earth walls were being used as warehouses and for cattle and those that were renovated with cement were being used as living quarters. This trend also exists in other Korean villages. We have summarized the characteristics common to the three curing barns are as follows:

- The floorings of the tobacco curing barns are packed earth and are fitted with an *ondol* heating system.
- The walls of these three curing barns are made completely of adobe. They were built collectively and following traditional methods.
- Stalks of vegetation are fixed to the rafters under the roof and are then filled with earth.

These buildings are examples of Korean earthen architecture that preserve the rural way of life in Korea. However, the damage assessment showed that despite having been reassigned to other purposes, the deterioration is critical; the third barn is at risk of being demolished soon. Abandonment and demolition are common practices in rural areas, threatening to erase the history of rural life and knowledge of earthen architecture building techniques. This conclusion is, of course, limited to South Korean tobacco curing barns; however, this thesis suggests the importance of identifying vernacular architecture and the necessity to concentrate efforts on protecting this endangered cultural heritage.

Endnote:

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Curriculum

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A REGIONAL STUDY ON EARTHEN BUILDINGS IN BANGLADESH

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Theme 1: History of earthen architecture in Asia and

Sub theme 1.2: Vernacular architecture and traditional building cultures

Keywords: Construction techniques, earthen buildings, natural materials, rural architecture, sustainability

Abstract:

Earth structures house a significant proportion of humanity, globally. Earthen structures adopt time-tested building techniques, are affordable, easily procurable and most responsive to local environments. In our current pursuit of sustainable development; earthen buildings have tremendous potential in providing solutions for energy efficiency, human comfort, eco-architecture and cost-effectiveness.

Different civilizations have produced earthen buildings with their own architectural styles based on the local conditions. Bangladesh is predominantly a rural country, where earthen buildings are especially significant in traditional peasant communities. These houses are constructed using locally available materials like wood, cane, bamboo, stone, mud, jute, lime and represent unique examples towards sustainable building design. This housing is well adapted to a natural environment and supports people's direct involvement in the construction of their dwellings. This paper attempts to reveal the secrets applied in such affordable, durable, compatible and eco-efficient buildings in rural Bangladesh.

The dwellings of rural Bangladesh demonstrate an economical use of local building resources, and respond to climatic conditions using low-energy design principles that provide human comfort. These design principles are consistent with the form, orientation and materiality of the buildings. A good number of solar passive features are available in most of these houses in relation to temperature control and enhancing natural ventilation. Based on all these parameters, functional diagrams of the building plans have been formulated that satisfies the socio-economic and socio-cultural setup of the region.

Architecture and buildings today are not climatically responsive and use exotic energy intensive building materials. Not only are modern building materials and techniques unsuited to local demands of climate and cultures, they place heavy demands on energy required to maintain required comfort levels. Earth buildings in the study area offers many advantages, including opportunity to use locally available affordable materials, low environmental impact, improved occupant health, reuse and recyclable capabilities, and a favorable building environmental performance. The study of these dwellings, on the one hand helps to better understand their development, and on the other, provides examples of a sustainable building tradition, from which many lessons can be learned.

1. INTRODUCTION

Bangladesh is predominantly a rural country, where earthen buildings are especially significant in traditional pleasant communities. The indigenous style of house construction has hitherto received very little attention, and yet it is the most popular way of shelter production for the overwhelming majority of rural population in Bangladesh. Traditional earthen buildings in Bangladesh are largely based on the use of locally available resources as prime building materials, usually in a process of self-help construction undertaken by the community. These buildings are well adapted to a natural environment with widely available resources, and supports people's direct involvement in the construction of their dwellings. Throughout the past, local availability of natural building materials and their employment in building construction has sustained traditional architecture. However, during the last few decades, due to the advent of the cash economy, scarcity of natural resources and population pressure, traditional earthen houses are gradually disappearing. Owing to low income, employment and poverty that prevail in rural Bangladesh, the rural populace has little choice but to continue to stick to the indigenous materials, methods and designs not only because of their low costs but also because of their familiarity and acceptability. A very pertinent question in this context can be whether the indigenous materials, methods and designs have the potential to be improved and adapted to meet the growing needs of tomorrow. This paper discusses the question through a review and analysis of the traditional earthen buildings in terms of the form, materials, design and the techniques of construction which have evolved to their present state over centuries.

2. OBJECTIVES AND METHOD OF THE STUDY

The traditional practice of self-help house building is greatly declining and further compounded by the depletion of natural resources (Ahmed 1988 pp. 355-374). It may not be possible to revert to the former pattern, but policy action to reduce the damaging effects on society and environment may point in sustainable directions. The aim of the study is to delineate the features of earth construction and to analyze the sustainable parameters of this construction. The indigenous construction technologies can be improved further with some institutional assistance and by utilizing the local potential, which eventually can strengthen the vernacular architecture of this regional. However, no serious study has ever been made on the vernacular earthen buildings of this region as well as its sustainability issues.

The study was conducted in Barind tract of Bangladesh where the soil is very significant in comparison to that of the other parts of the country. Some part of greater Rajshahi, Dinajpur, Rangpur and Bogra District of Bangladesh and the Indian territorial Maldah District of West Bengal is geographically identified as Barind Tract. The upper stratum of soil in this region is of hard red clayey type and especially helpful to construct earthen houses. This study was carried out to find out the influence of different features such as climatic conditions, building forms, construction materials and passive design features in the vernacular buildings of the region. In order to address these issues, a survey of 30 houses (i.e., 10 houses in 3 districts) was carried out. Houses that were more than 50 years old and still in use were selected for the study. Measurements of illumination levels inside the rooms, external wall thickness, inter-room partition thickness, false ceiling height and dimensions of doors and windows were taken. Collection of photographic evidence of various solar passive features available in these houses and extensive interaction with the inhabitants of these houses were also part of the study. The significant features related to the climatic

adaptation features, construction materials, architectural features and environmental performance were then assessed.

3. LOCATION, NATURE AND CLIMATE

Climate, socio-cultural setup, economy, materials and technology availability are the main factors that greatly influence building architecture and its sustainability. Since climate varies from place to place, favorable architectural solutions for the built environment are also region specific. Vernacular architecture constructed by the people reflects their needs and socio-cultural values. The buildings that are constructed using locally available materials show a greater respect to the existing environment and also take into account the constraints imposed by the climate. Of the various factors that affect architectural design, climate control is of prime importance for maintaining comfortable conditions inside the buildings. Vernacular architecture sets an example of harmony between dwellings, dwellers and the physical environment.

Bangladesh is located in approximately between the 20°N to 27°N and the 88°E to 93°E longitudes the climate of the region is ward-humid (fig. 1). The Barind Tract is located in between 24°23' to 25°15' North latitude and 88°2' to 88°57' East longitude. A typical dry climate with comparatively high temperature (Maximum 44°C) prevails in Barind area except for the wet season. In the winter months from November to February, the mean minimum temperature remains 12°C to 15°C. The rainy reason begins with the advent of the Monsoon in June and lasts until October. More than 70% of the annual rainfall is received during this period and rainfall in this area varies from about 1500 to 2000 mm. Out of the total cultivable land, 84% are single cropped, 13% are double cropped and the rest are triple cropped. House building in rural Bangladesh is a seasonal event which is usually completed before the onset of the Monsoon and carried out in periods of low agricultural activities usually after harvest and rice planting.



Fig. 1 - Main bioclimatic zones of the world

4. FORMS AND ELEMENTS OF EARTHEN BUILDINGS

A traditional earthen house in its basic form is a cluster of small *ghor* around a central yard (fig.2), locally called *Uthan*. The word *ghor* literally means a room, with specific functions and not a total building. A *bari* comprised of several *ghors* around a courtyard is considered as a unit of home. The main *ghor* is usually well-built structure and the ancillary structures like kitchen, cowshed etc. (fig.3) are semi-permanent structure. As the family expands, people opt to move to peripheral sites and more dwelling units are added around the courtyard. The courtyard serves as main circulation space among the *ghors* arranged around it.



Fig. 2 - *Ghors* around the Central Yard



Fig. 3 - Ancillary structures around *Ghor*

Dwelling units flanking the courtyard often have shaded open verandahs (fig. 4), which provide cool outdoor spaces. In some cases verandahs are partially or fully enclosed by screen-type walls for shade and privacy. The verandah is a semi-private space and serves as a transition zone from the semi-public courtyard to the private house interior. Generally, the interior size of a *ghor* ranges from 2 meters by 3.5 meters to 4 meters by 7 meters. Face of all *ghors* should be towards the courtyard and they can be entered only through the courtyard. The shorter span of the earth building is often governed by the maximum usable size of a bamboo or palm tree, which can carry the roof load. The earth buildings have one, two or multiple rooms and are usually single-storied (fig. 5), although in many well-to-do earth building are two-storied (fig. 6) and are widely available in the study area.



Fig. 4 - Shaded Veranda



Fig. 5 - Single Storey Mud House



Fig. 6 - Double Storey Mud House

5. CONSTRUCTION MATERIAL OF EARTHEN BUILDINGS

This section will discuss the most predominant and widely used building materials used in earthen construction. Traditional mud houses are common all over the study area. Generally, the study areas have less rainfall, dry climate and possess clayey type soil. Lands, which are normally above the flood level; are more suitable for the construction of mud house. Bamboo, palm tree and thatching materials are the three common natural building materials. The results of a national survey in 1982 showed that more than 60% of total households in Bangladesh lived in houses that used bamboo as a main building material, and less than 5% of houses were built of manufactured materials such as brick and cement (BBS 1988). The main load bearing system consists of mud walls having 0.5 meter to 1 meter thicknesses and carry the loads from roof. Although clay tiles, straw/thatch and CI sheets are used as roofing materials; use of CI sheets are most prevalent due to its durability. Figure 7, 8 and 9 portraits the examples of these three roofing materials available in the study area. The application of these materials also depends on their availability and the affordability of the house owners.



Fig. 7 - Mud House with Straw Roof



Fig. 8 - Mud House with CI Sheet Roof



Fig. 9 - Mud House with Tile Roof

Bamboo and palm tree made rafters, purlins, tie beams and wall plate form the roofing frame. The same materials are also used in ceiling and extends up to cantilever balcony (fig. 10) which is often used as storing agricultural crops, household goods and firewood (fig. 3 and fig. 11). Ceiling materials vary according to availability of local materials. A typical ceiling is made of either jute sticks or bamboo mating. Split bamboo is also used (fig. 11). Floor is made of mixture of clay and cow dung where, straw and rice husk are mixed with clay for the construction of mud walls (fig. 12). The plinth of the house is usually raised 0.5 meter above the ground level and is built with compacted clay. When completed, it is a dry, mildly hard earth surface but vulnerable to cracks for earth pressure as well as moisture penetration. Routine maintenance is required for normal wear and tear caused by stress and strain due to live loads.



Fig. 10 - Palm tree in Ceiling & Balcony



Fig. 11 - Ceiling Materials



Fig. 12 - Mud Wall Construction

6. CONSTRUCTION TECHNIQUES

A typical morphological feature of the earthen house is the arrangement of a number of closely spaced single-storied or double-storied rectangular buildings around a courtyard. Most earthen houses are built with self-help effort and figure 14 portrays the pragmatic figure of a typical mud house construction process. Construction of a new house involves several established division of labor among men and women. The building process of an earthen house may be discussed with reference to the major elements namely floor, walls, doors, windows and roof.

Floor: The floor is the first element of an earthen house that is to be built. Floors in earth buildings are usually constructed on a raised plinth of compacted earth. At the onset of construction, a pond is excavated to obtain soil for raising the land up to the plinth level. This is usually done by digging a backyard pond with steps and bathing. People dig the earth, mix water and prepare the mud. Then the mud is placed in the allocated space for floor up to plinth level and the floor is left bare. The plinth varies from a height of about 15 centimeters in higher areas to 120 centimeters in low-lying areas. After raising; the floor is compacted, trimmed and leveled properly. After completion of beating the floor, damp proof course is the other most fundamental addition to local earthen building skills. The damp proof course is a double layer of locally available PE-film. This additional flood-proofing technique is ubiquitous throughout Bangladesh and is a characteristic feature of earth houses.

Walls: The monolithic and mud walls are constructed in different phases and in different layers. The load-bearing mud walls are often constructed using the technique similar to cob walling. A straw-earth mixture with a low straw content is manufactured with the help of cows and buffalos and then heaped on top of the foundation wall to a height of 65 cm per layer (fig. 12). Excess material extending beyond the width and height (i.e. 65 cm) of the wall is trimmed off using sharp spades after a few days. After a drying period of about a week the next layer of cob can be applied. In the third and fourth layers the door and window lintels and jambs are integrated as well as a ring beam made of thick bamboo canes as a wall plate for the ceiling.

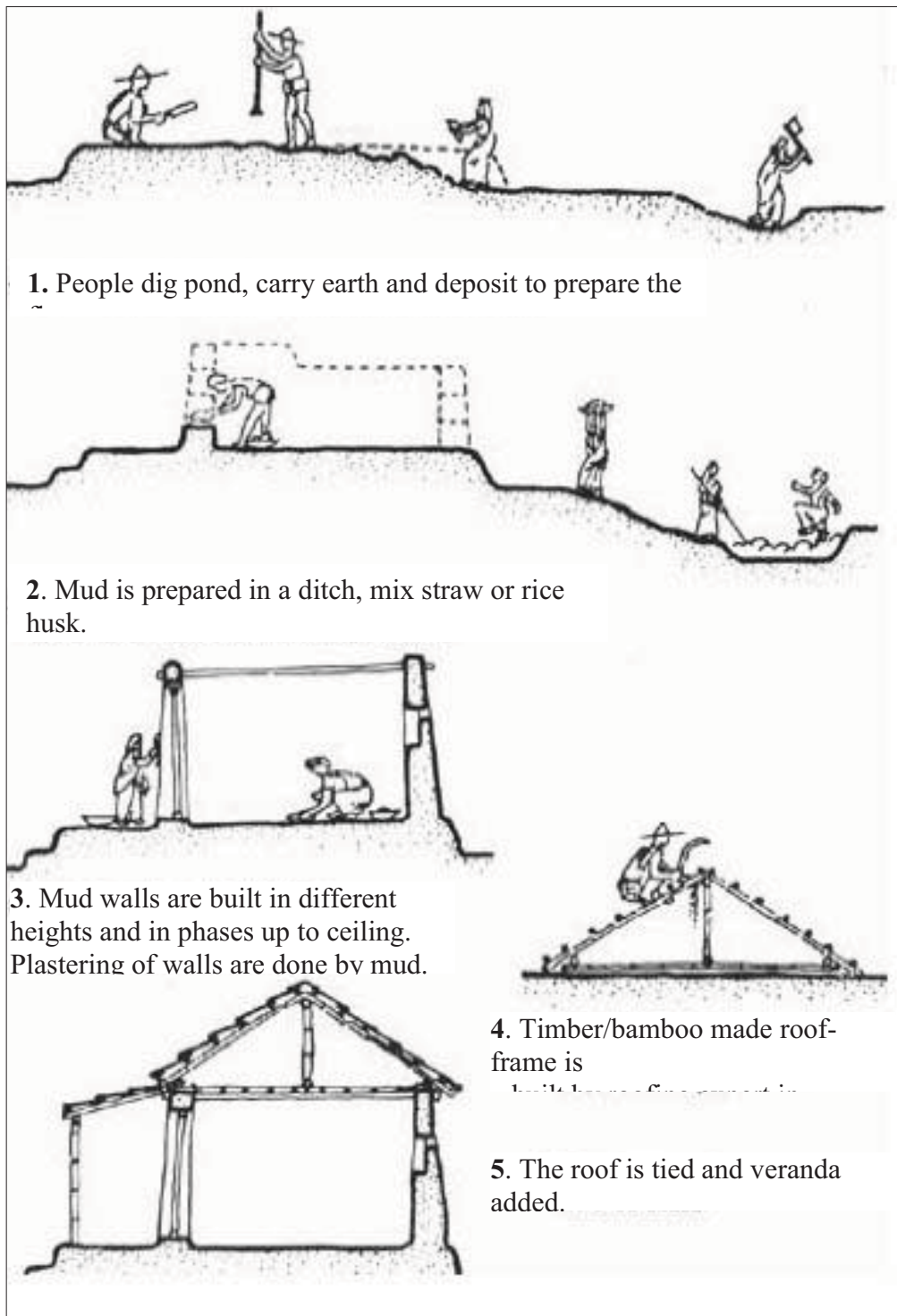


Fig. 13 - Typical mud house construction process in Barind Tract (Bangladesh)

Ceiling: The ceiling of the ground floor is a triple layer of bamboo canes with the central layer arranged perpendicular to the layers above and beneath to provide lateral stabilization and a connection between the supporting beams. A layer of planking made of split bamboo (fig. 11) canes is laid on the central layer and often filled with mud.

Roof: Pitched roofs are typical in earthen building, thatched with different types of grasses or straw but Corrugated Iron (CI) sheet is common in rural areas. A roofer, who is skilled in roof construction, is hired to make the roof frame and to cover it with thatch or tiles. The roof structure is framed in either by bamboo or palm trees depending on the availability. The roofing members being tied together with ropes or GI wires forming close rectangular or square grids. The roof slopes at an angle, usually on each of the four sides to facilitate the flow of rainwater and to reduce the risk of water leakage during monsoon. In some cases, to reduce cost of roofing, the roof is sloped only in two directions along shorter span. The roof frame is then covered on the surface with a thick layer of thatch woven or CI sheet carefully and skillfully. Accordingly, the basic form of the earthen house is completed which has all the ingredients of regional architecture.

The upper storey is a frame construction of four-layer bamboo or palm tree beams, vertical and diagonal members arranged at right angles to the building. The end of the frames at the short ends of the building and the stair also serve to stiffen the building. These are connected via additional structural members with the upper and lower sides of the main beams and equipped with additional wind bracing on the upper surface of the frame. A series of bamboo rafters at half the interval of the frame construction beneath provide support for the CI roof construction and are covered with timber paneling and adjusted in height to provide sufficient run-off.

Doors & Windows: The upper level of doors and windows are fitted in the mud walls at 7 ft height. When the doors and windows are provided, a wooden or bamboo plank (fig. 14) is provided over the opening, which is embedded up to 15 cm on both sides. Then the construction of the wall continued leaving the opening of the mud wall.



Fig. 14 - Settings of window (left), door (middle) and skylight (right)

7. ARCHITECTURAL FEATURES, CLIMATIC PERFORMANCE & ENVIRONMENTAL ASSESSMENT

A north-south orientation of a *bari* is preferred, with its long side along the courtyard facing south to benefit from the coolness of the prevailing southern breeze. *Ghors* built subsequently have to compromise their orientation in order to face the central rectangular courtyard, thus ostensibly also compromising their climatic performance.

However, several extensive protective cover by vegetation and the use of a courtyard reduces overall heat gain considerably. The courtyard draws in air and ventilates the buildings facing it, once again an example of how the earthen house here functions as a unit. The climatic performances of individual buildings are relegated to serve the overall collective performance of the building. Trees planted along the house boundary (fig. 15) and in the gaps between buildings together with the built structures form almost a continuous edge for the courtyard, thus defining its singularity and allowing its function of drawing in air. The courtyard functions as a bounded open-to-sky built indoor space.

There are many air leakages in these houses; the structure is suitable for humid and hot weather. In this warm climate, the courtyard is virtually an extension of indoor living and serves a variety of activities. In double storied mud house, the top floor is by contrast light and open. The openings in its walls offer sweeping views across the surroundings, its large interior providing space for movement. The view expands across the treetops and the village pond.

















Fig. 15 - Presence of vegetation (L), verandah & balcony (M) and shading device (R)

The success of a building's natural ventilation performance, particularly in the hot humid zones, is related to the thermal performance of the building's construction, materials and wind interactions around the building's façades. The earthen buildings in Barind tract ensure the use of natural construction materials, enhance natural ventilation and control solar heat gain. The houses are designed in such a way that they can capture the prevailing natural breezes and ensure that the location does not restrict the airflow to other buildings within the site or create wind shadows.

These climatic consequences indigenously control passive design features and achieve residential comfort standards. Nonetheless, these vernacular design also reduce energy demands through natural ventilation, introduce correct opening schedules, proper orientation and site selection, reduce solar gain (i.e. shading devices), thermally efficient construction (i.e., insulation and use of natural material with low U value), and improved use of daylight. Finally, trees and gardens that surround houses could also contribute to natural cooling. More environmental and sustainability indicators of earth buildings are presented in the Table 1.

Table 1: Multi-criterion Table of Evaluation on Sustainability Issues

Evaluated issues	Typical construction	Earth building construction
Materials		
Employment generation		
Construction technology		
Cost		
Codes and standards		
Embodied energy and energy of use		
Development in high levels		

8. CONCLUSION

It is particularly important to improve the quality of living in the rural areas in order to counteract the continuing population migration to the cities. The primary potential for developing earth building in the rural areas is the low labor cost and locally available resources such as earth, bamboo, palm trees and jute ropes etc. The study aims to acquire knowledge and skills of earthen buildings so that they can be further developed to the best possible use of available natural resources to meet the future demands.

Earth building is fast, economic, recyclable and needs little energy in order to achieve thermal comfort. Local materials are also advantageous from an economic point of view. They strengthen the local economy and create jobs by using local labor for both material sourcing and construction. Building costs can be lowered as the house owners can participate in the building process. The use of local materials is an ecological advantage.

There is no immediate panacea to the problems of promoting earth construction and the use of natural materials in a sustainable process, but enabling people to build better house for themselves through innovative solutions has the potential for promising results. It may offer a possible recovery from the decline of culturally rooted construction practices and degradation of the natural environment, and renew the power of people to be intimately involved in and control the process of creating dwelling for their own habitation. This paper demonstrates the possibilities of building with earth using simple methods as the continuation of a local rural building tradition and can serve as an example for future sustainable building development.

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INDIGENOUS KNOWLEDGE ON THE FORMATION AND PLANNING- DEVELOPMENT OF EARTHEN HISTORICAL VILLAGE OF KHOOR

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Theme 1: History of earthen architecture in Asia and other regions of the world

Sub theme 1.2: Vernacular architecture and traditional building cultures

Keywords: Earthen Architecture, indigenous knowledge, sustainable development, earthen historical village, South of Khorasan, Iran

Abstract:

Khoor is one of the villages of Khosof Dehestan, Khosof County in the town of Birjand located in South Khorasan Province. Khoor is situated by the Birjand-Kerman roadside at a distance of 86km after Birjand. Historical fabric of the village has taken its form under the influence of climatic and geographical condition of the environment. Earthen houses have been built in harmony with the regional climate. Architectural elements and patterns used in this fabric as well as its general structure have been formed during the reign of the Safavid dynasty. Therefore, considering the richness and bloom of the Persian architecture in this period, the historical fabric of Khoor village is regarded as one of the richest and most integrated architectural fabrics in the region. Among important points considered in the planning and designing of this human settlement are: setting, locating, its size and correct connection with environmental conditions with the help of the potential capacity of its place.

In the present article, not only architectural space and its parts are discussed and analyzed but also the manner of locality selection and formation of the human settlement are investigated. In addition, mention will be made of abundant experience and knowledge used in the complex about planning, designing, materials production and village construction. Introduction of Khoor represents the pattern for formation and development of earthen villages in south of Khorasan in Iran.

PREFACE

According to the latest census performed in 1385 SAH (2006), Khoor consists of 230 households with a total population of 888 of which 54% are male and 68.5% are literate. Most of the villagers are engaged in agricultural or animal husbandry activities but a few have service professions such as: administrative or educational jobs or are businessmen, tourism sector employees and workers. The majority of agricultural products are: wheat, barley, cotton and pistachio. Camel and goat husbandry is also significant due the desert climate of the village. (Kelvan consultant, 2009) Thus it can be said that Khoor is a living village with architectural and planning of a mud-brick village born at the heart of desert and during its development has become one of the first formation cores of mud-brick villages in the region. As a result, because of such

unique features, Khor has been nominated to be registered in the national monuments list. For this goal, the documentation and research process regarding such values are underway with the help of ICHHTO experts in South Khorasan Province. The following report is the result of those researches.

1. GEOGRAPHICAL AND HISTORICAL IDENTIFICATION

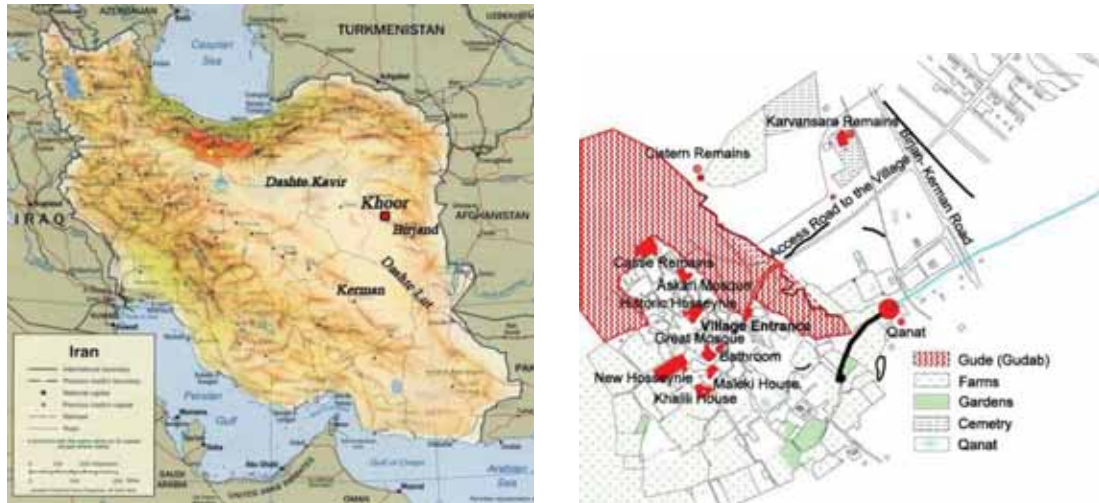


Fig. 1- Location of Khor - by author

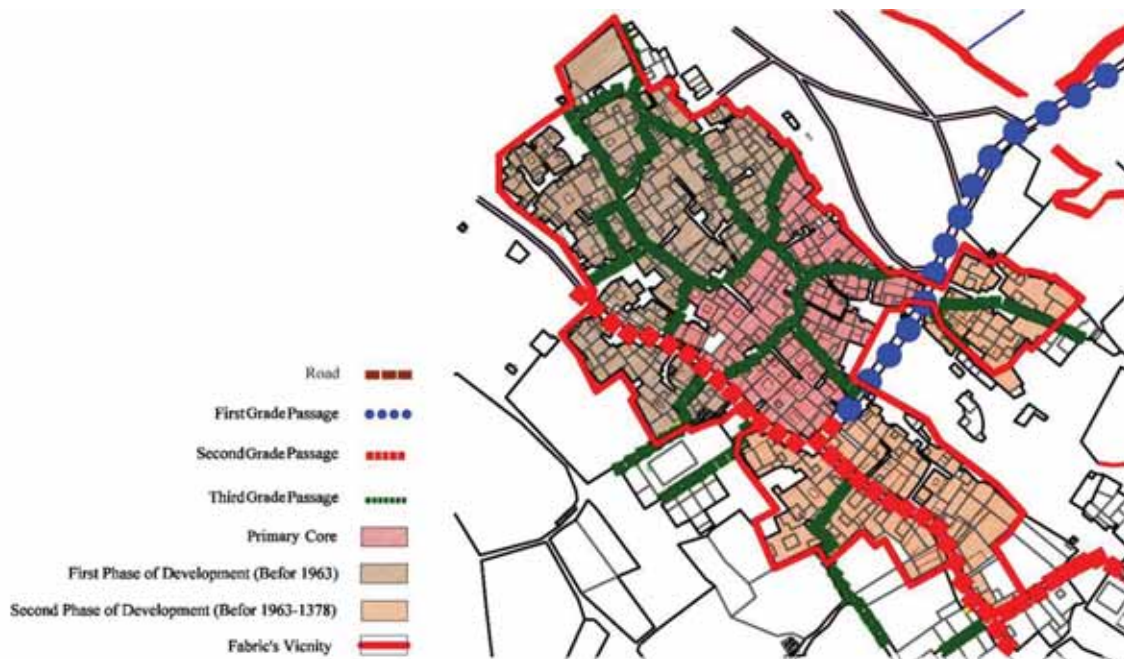


Fig. 2 - Khor's development process- CHHTO of South khorasan archive

1.1. Historical identification

Khoor rhyming with "moor" is an original Old Persian word with various meanings including: lowland, a sea branch, spillway of seawater, harbor, town and state, plain between two ups, etc... Also in its historical pronunciation, *khoor* has these meanings: sun, light, illumination, ray and several other meanings. This word has been mentioned in *Avesta* too and according to Zoroastrians, *khoor* was a holy word. This name has been given to many villages of Iran, Hejaz and Lebanon. It seems that the most famous of them were *Khoor-e-Biabanak* and *Khoor-e-Qahestan*. (Papeli, 2003) Historically, *Khoor* has been part of *Kuhestan* or *Qahestan* State in the greater *Khorasan* and most of Arab and Iranian travelers and geographers have mentioned its importance. Among one of the oldest ones is *Estakhri* who has described *Khoor*, its earthen structures, its scarce water, its geographical distance, routes connecting it to important town as well as its scale in relation to other villages such as *Tabas* in his renowned work called: *Almasalek va Almamalek*. (Rafiee, 2006)

Ibn-e-Hughel *Baghdadi* in his book *Sooratol arz* and *Mogaddasi*, the fourth century LAH geographer have also confirmed above statements. (Ayati, 1993)

Evidently, the *Safavid* era was the climax of *Khoor* development and boom. A written document belonging to this period still exists with an inscription on the occasion of construction of *Khoor* public baths showing that the village enjoyed relative prosperity in the *Safavid* era.

1.2. Identification of the geography effective on the formation of the mud-brick village of Khoor

Two important factors have influenced the formation of the village: the wind and the natural bed of the ground.

1.2.1. Wind

Location of the village on the margin of *Lut* desert as well as seasonal desert winds (from mid-Spring until early Autumn) which are almost always accompanied by sand particles and dust have given rise to a particular type of climatic condition. These winds usually blow in a south west to north east direction during hot days.

Therefore, in order to offset the negative influence of winds upon the village fabric, main passageways of it are in a south-east to north-west direction i.e. perpendicular to the path of hot, high desert winds. It is obvious that this initiative effectively prevents generation of wind tunnels. Subsidiary passageways have a winding design and are usually dead ends. At some points, *Sabbaths* have been erected in accordance with fabric pattern of Iranian deserts in order to make shadows which generate a cool environment for relaxation of pedestrians. This shows the role of structural elements for optimum usage of the ground. (fig. 3)

The one sided wind catchers appearing in the landscape and sky line of *Khoor* have been formed under the influence of these wind currents. These wind catchers stand opposite the unwanted desert winds so that only pleasant predominantly north winds can enter these wind catchers and rooms beneath them. It is interesting to note that the breeze blowing from north during the stifling heat of summer afternoons is known as *shomal* (meaning north in *Farsi*) among locals. Such proper orientation in the construction of wind catchers not only prevents the penetration of dust as well as hot,

high winds into residential spaces but also eases the entrance of cool *shomal* breeze into this space preparing appropriate condition for more comfort. Additionally, the entrance opening of the wind catchers is built with its back to the sun radiation so that during the day time the coolness of *shomal* increases. The wind catcher room has no direct connection to the outside space so its temperature is controlled in a natural manner. (Interview with Khood village residents, 2011)

1.2.2. Natural bed of the ground (Topography)

Unlike surrounding sandy fields, the ground bed of Khood is made of a kind of fatty clay called bentonite which under the influence of natural elements has gradually turned into irregular hard *caluts*. One of the significant properties of the soil is its very low water absorbance. (A dilute solution of bentonite and water is spilled upon the body of oil wells during excavation in order to prevent soil falling off the body) Khood village has been built upon a section made of natural *caluts*¹⁰ and considering the altitude of the village relative to grounds in its north, west and south west fronts, it can be said that a natural moat like pit encircles the village.¹¹



Fig. 3a - Natural moat (by author)



Fig. 3b - Narrow and curved alleys and *sabbaths* (by author)

¹⁰ Calut is a natural phenomenon which appears in layers after the erosion of mountain and ground by desert winds

¹¹ Locals call this natural moat: "*Goudeh*" meaning a water pit

Because the water accumulated in such natural moat is not absorbed by the earth, during rain seasons a huge amount of water is gathered inside the moat. The moat water is not only used for irrigation purposes but also prevents the movement of rolling sands toward the village by desert winds and creates a pleasant and cool microclimate in the desert environment (fig .3). Furthermore, farm lands and gardens located in the south, south west and south east directions of Khor significantly decrease the destructive effect of the wind upon the residential fabric.

As said before, gardens and agricultural lands outside the village not only make possible an optimal usage of natural assets and topographical conditions (such as directing *qanat* water toward farms and agricultural lands) but also create a pleasant atmosphere in the direction of the dominant wind for the comfort of villagers.

Architects of Khor were amazingly aware of the exact properties of its soil so that they rightfully used the fatty clay in their constructions. Location of the village shows the knowledge of its founders regarding earth layers, soil quality, natural assets and ground gradient.

2. CHARACTERISTICS OF THE MUD-BRICK VILLAGE OF KHOOR

The village has been built in a cohesive manner considering the geography of the environment so that its compact earthen houses have been constructed using specific architectural elements of desert such as: dome (*gonbad*) covers, a central yard (including a water basin and garden), wind catchers (*baad-geer*), *hashti* and corridors, thick walls. (fig. 4)

The compressed fabric of the village together with the organic order of road web and its encirclement by croplands and fruit gardens play a major role in the adjustment of environmental conditions to the specific desert climate. The surrounding space serves as a green belt in conserving the central fabric against desert winds, dust and dry air. It is noteworthy to consider the proportion and relation of the village size compared with the potentials of limited natural assets such as available water and land worthy of cultivation.

Regarding the architectural body, the village fabric can be considered consisted of structures or architectural units built and mixed in an exact order. Generally, Khor village can be viewed and analyzed as a complex consisted of: individual architectural elements, architectural sets, adjacent blocks, neighborhoods and the fabric as a whole.



Fig. 4 - Compressed fabric of the village (by author)

One of the prominent characteristics of its architecture is the compression of the village fabric aimed at preventing the penetration of intense heat and cold during summer and winter seasons respectively. Winding, indirect and occasionally roofed passageways of the village have made this possible. Moreover, such a property not only inhibits disturbing winds but also creates more shadows due to its depth. Also, the great difference between temperatures of sunshine and shade results in the shaded areas to become cooler so that a cool breeze constantly blows toward the sunlit parts. (Kelvan consultant, 2009)

Another thing worth noticing here is the one sided wind catchers which are observed in houses and other architectural units. Multiple domes and wind catchers seen atop most residential homes in particular the outstanding structures of neighborhood centers enjoy a rhythmic and harmonious state relative to each other making the village gain a special architectural character.

3. ARCHITECTURAL CHARACTERISTICS

General principles envisaged in the rural architecture of these complexes are aimed at confronting environmental harshness in order to bring more comfort to residents and pedestrians alike. Briefly, they are as follows:

Provision of a cool, pleasant air via a central yard: Within each residential home, there exists a central yard which makes possible the internal respiration of the compact fabric.

Air dryness and air cooling by water evaporation: For this purpose they used to build small yards in a north west to south east direction and in a central position. Most houses have double *Iwans* (portico) and are designed in the style of Safavid and early Qajar periods. In order to inhibit extreme wind exposure of the yards, building entrances have largely their backs to the wind and are connected to alleys or passageways via a *hashti* or a corridor. A small water basin is seen in the yard of most houses with a few trees planted around it which creates optimal microclimates at the heart of the house.

Optimal usage of sun temperature: For this purpose, the architectural plan is in such a manner that keeps safe the interior from unpleasant summer heat but during winter

times makes possible enjoying the pleasant sunshine. As a result, usage has been made of winter time and summer time chambers (which locals call toward sun and behind sun rooms respectively) as well as roofed *iwans* and a central yard for air circulation. All of these are among architectural characteristics of these houses. (Ghobadian, 2007)

Yet another advantage of this architecture genre is the usage of thick walls and curved mud-brick ceilings which are capable of heat accumulation as well as its gradual redirection. Therefore, they serve as a condenser in keeping the warmth or coolness within the room. Also doors and windows can only be opened quite minimally so that this property of materials is not hampered. Moreover, the curvature of the ceilings makes them higher thus adding the air volume which prevents rapid warming or cooling of the room and ultimately saves a lot of energy. (Kasmayi, 2004)

Desert people have learned from their ancestors that despite the harsh climate of desert (*Kavir*), it also has some merits such as cool and tranquil desert nights after a hot day. Thus they have considered the usage of rooftops during nights as an architectural principle. In this way they have made rooftops as their night time living and sleeping space while enjoying the unique desert landscape at the same time.

In addition, construction of cool and humid rooms under the ground significantly neutralizes the great daily and annual oscillation of temperature due to gradual absorbance of warmth and coolness and this is yet another architectural initiative of desert people. (Ghobadian, 2007)

3.1. Introduction to architectural elements

3.1.1. Sar-dar (portal) structure

This structure even in its most elementary shapes invites you inside. Its height is either equal or a little bit more than the earthen wall. The outer surface of the *sar-dar* is usually decorated with mud-bricks and engraved bricks. Moreover, it must be added that *sar-dar* together with the entrance corridor (*hashti*) create an intermediate space between the interior and the exterior of the house for a brief pause while observing the hierarchical order of entering the house. (fig. 5)

3.1.2. Yard

Yards in Khor houses are perfect examples of the introvert architecture of Iran. They also play a major role as the constituent of summer time and winter time chambers. Two kinds of yard utilization have been seen in the architecture of the village: houses with one yard and those with two yards consisted of the interior and the exterior. (fig. 5)

3.1.3. Room

Based on their function, rooms include: bedrooms, sitting rooms, seasonal drawing rooms with two or three doors, *korsi khaneh*¹² and kitchen. The latter was usually built near winter time chambers. Moreover, winter chambers were usually built at west and north fronts but summer chambers were built with their back to the sun. Rooms have a revolving and regular relation with the yard via the corridor. Illumination of rooms on the edge of the yard was done through windows and doors and sometimes via skylights. Such elements in their original form were inserted amid horizontal or perpendicular

¹² A room for winter times warming with a specific kind of fireplace

*tabesh-bands (Kharak-poosh)*¹³ and all of them ultimately were installed within a sort of frame. (fig. 5)

3.1.4. Basement

The most important household space during the stifling days of summer is the basement. In homes without any *godal-bagche*¹⁴, all or part of the spaces located beneath the ground floor were allocated to the basement which was connected to the ground floor by steps in the yard.

3.1.5. Wind catcher

Wind catchers that are used to provide natural ventilation in the building can be considered as one of the most significant elements of Khor architecture. Direction of their installation is toward north east. Khor wind catchers are one sided due to dusty desert winds so that they are located with their back toward the undesirable winds. Obviously, their opening was inserted toward the direction of the desirable wind. Unlike wind catchers of some desert areas in which a basin full of water beneath the canal was used to cool inner spaces, materials such as straws, mats, ceramics or brambles were used and by spilling water over them the cooling of the air increased. Another property of such wind catchers was general ventilation of the house so that at times when no wind blows, the warm air of inner spaces goes up due to its lightness and is directed outside of the building via the canal of the wind catcher.

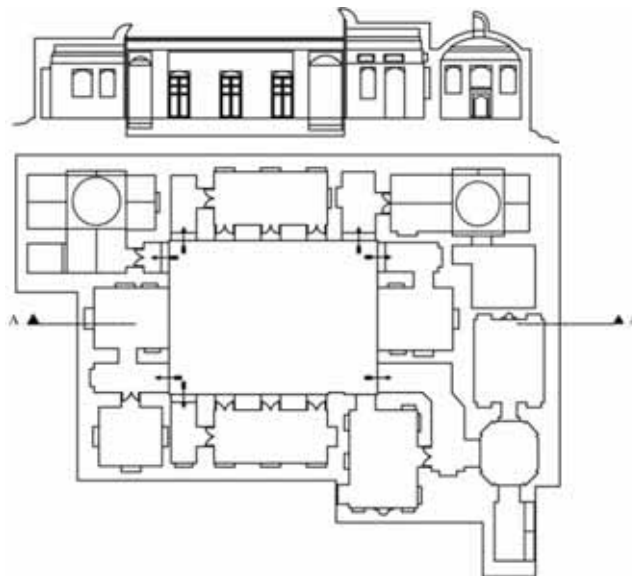


Fig. 5a - Khalili house. CHHTO, Birjand archive

¹³ A horizontal obstacle Prevents rooms from harsh sunshine

¹⁴ A yard under the ground level



Fig. 5b - House entrances (by author)



Fig. 5c - House yards (by author)



Fig. 5d - House yards (by author)

3.2. Structural system

Because during the construction of the village, it has been tried to use local materials with the least expenses possible, mud-bricks and soils are quite prevalent construction materials but certain methods and preparations have been used in order to strengthen the products. Among structural initiatives seen in Khor, mention can be made of *gonbad* covers as well as *taghs* with or without moulds.

Considering the great difference between daily and nightly, summer and winter or shade and sun temperatures, even if stone materials were at hand they would have minimal usage in the architecture due to their high thermal capacity, for example they are laid at the foot of the walls in order to prevent moisture penetration and to solidify the building. But soil remains the major construction material and is used in various forms such as: *chineh*, mud-brick, *kah-gel* and *sim-gel*.

Different methods of Arching (*tagh-zani*) and roof covering are seen in the architecture of the village depending on which sides the mud-bricks are connected together. Furthermore, various executive ways are utilized. Essentially, the difference seen in roofs is caused by various methods of layout which are either *dour-cheen* (*herreh*, *zarbi* or *chapileh*) or *rag-cheen*. (fig. 6). The choice between these two methods is based on the load bearing power of each as well as the materials and tools at hand.

Arches seen in the village are mostly: *Ahang*, *kolomboo*, *tagh* & *tavize* as well as *nim kar*. It must be noted that thick mud-brick walls and the connection amid adjacent homes is effective on the durance of this kind of structure. The following picture depicts examples of curved roof covers, *taghs* and moulds.

3.2.1. Materials

Constructors of Khor buildings were astonishingly aware of properties of the local soil and have decided to use the fatty ones in their constructions. The majority of materials used in the construction activities are mud-bricks in dimensions of: 5 x 20 x 20 cm or 8 x 25 x 25 cm. Ingredients of mud-bricks include: fatty clay, ordinary clay (to increase adhesiveness) and straw (to increase tensile strength). (fig. 6)

In some buildings, hardened blocks of the earth bed in the form of stones have been removed to be used in wall layouts. Considering the hardness and water impenetrability of the bed soil, constructions in Khor are performed without digging foundations or *korsi-cheeni* upon the natural terrain. Also because bentonite (*sarshooy* mud) is not permeable, damage due to moisture which usually threatens mud-brick structures is less prevalent in Khor. Aside mud mortars which have sufficient adhesiveness, *gatch* (gypsum) mortars are also used in *sar-dars*, curved and arched covers because they are hardened more rapidly. For interior facades, *gatch* plasters and for exterior facades of walls, clay and *kah-gel* plasters are applied. In entrance *sar-dars*, sun dried bricks in various dimensions are used for decoration. In more recent periods as well as during restorations, sun dried bricks have been used in floors and plinths (*Ezareh*).

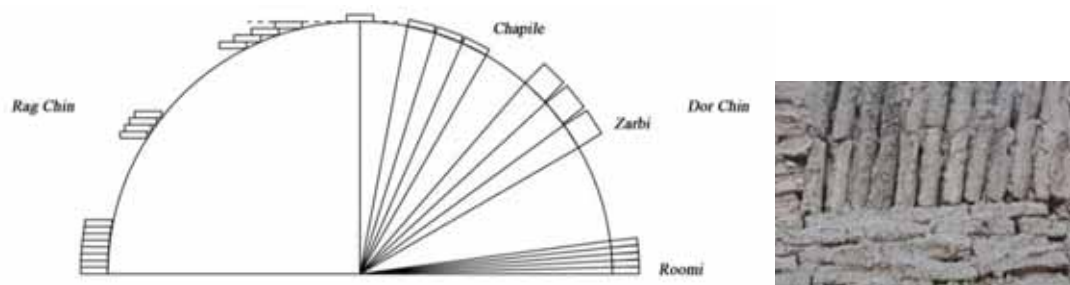


Fig. 6 - Sample of vaults (by author)

CONCLUSION

Due to constant water shortage, aggravation of natural conditions, gradual deterioration of the historical technical know-how and negligence of relevant organizations, conservation problems have intensified. Although recently, several projects concerning the documentation and identification of Khor Village as well as little local conservative activities have gone underway but it seems that the continued life of the village depends on conducting more research, restoration and conservation works as well as launching support projects. Fortunately, due to easy accessibility of Khor to Kerman and Khorasan roads as well as its huge potentials for tourism, agriculture, animal husbandry, handicrafts and mining it is hoped that sustainable development of the village is foreseeable in the future.

Of importance in this regard are: elevation of the awareness of local community concerning historical experiments, their constant training regarding optimal production of materials and mud-brick technology, systematic support of NGOs and ICHHTO as well as definition and initiation of interdisciplinary projects.

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DOMINANT ROLE OF EARTH BRICK IN SHAPING THE PHYSICAL ENVIRONMENT OF SHUSHTAR

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Theme 1: History of earthen architecture in Asia and other regions of the world

Sub theme 1.2: Vernacular architecture and traditional building cultures

Keywords: Historical/cultural background, history of brick, local materials and techniques, sustainable design, affordable housing

Abstract:

After the industrial revolution, historic cities faced the emergence of dominant international style towards their previous evolutionary growth using local materials and know-how. Nowadays, urban growth prompted central and local governments of developing countries to choose generally high-speed and affordable options to respond housing needs. This may lead to the application of an identical construction method in different areas with less consideration of climatic conditions and historical/cultural backgrounds. The present study analyzes the evolution of a simple material - brick - by examining its techniques of use and its environmental effects in the city of Shushtar during the different stages of its construction history.

Two recent development projects reveal two different approaches to providing new affordable housing for the growing population: Shushtar New Town in the last 70's and *Farhang Shahr* in the middle of 80s which will be developed by *Maskan-e Mehr* housing project. The analogy of these two forms of urban development according to old Shushtar's construction principles in terms of material choice and application may offer sustainable alternatives for future challenge of similar developing cities.

1. INTRODUCTION

Located in southwestern Iran, Shushtar is an ancient fortress city in the center of the Khuzestan province. It had an estimated population of 96,700 in 2006 (Shushtar's Master Plan, 2009). The name of Shushtar is derived from another ancient city, *Susa*, and means "superior (or better) than Susa" (Isfahani, 10th cent.). In Achaemenid era when Susa, former capital of the Elamite and Parthian empires, was being demolished, the new city of *Šurkutir*, Shushtar, was founded in a near place with a more pleasant environmental condition (Kasravi, 1934).

The earth architecture in this area goes back to the end of 5th millennium BC (Afshar,

1994). Some of the most remarkable examples of enameled bricks have remained from the ancient city of Susa (Moorey, 1999). One of the oldest existing ziggurats, Chogha Zanbil, was built of mud bricks about 1250 BC (Ghirshman, 1958). Today, Shushtar and its nearby city, Dezful, contain the very vast historic zones recognized by their brick architecture. Throughout the millenniums, they have maintained refined equilibrium between local resources, vernacular knowledge and natural environment, until the last years of the 20th century when this deep-rooted balance began to be forgotten due to the entrance of incompatible construction technologies in the process of increased urbanization. This circumstance brings up the following questions: How ancestral builders used earth architecture to face hot climatic condition? Why local construction materials/methods have disappeared in new urban developments? How to extract and reinterpret past construction knowledge into future sustainable development?

According to Shushtar's Master Plan report, the number of housing units is 15539 with the average surface of 211 sqm. The construction materials are classified in the following diagram:

Diversity of Construction Materials in the Housing Units of Shushtar								
Brick with wood structure	Brick with metal structure	Brick with concrete structure	Totally Brick with stone foundation	Steel structure	Cement blocks	Adobe and mud	Adobe and wood	Other
256	11459	315	1336	231	1397	346	19	5

The city of Shushtar constitutes three distinct urban fabrics:

- 1-The historic city;
- 2-The New Town in the North of the Old Town (1974-80);
- 3-The new urban developments, particularly two zones in the east of the New Town: *Farhang Shahr*, the neighborhood planned in the middle of 1980s, and *Maskan-e Mehr*, the collective housing under construction in the North of Farhang Shahr.

This paper deals with the construction materials/methods applied in the residential buildings of these three areas. By comparison of technical approaches throughout history, this study tries to reveal the importance of brick architecture in forming the adoptive built environment in hot semi-dry climate of Shushtar.

2. OLD TOWN OF SHUHSTAR

In the southwest of Zagros mountain range, where the plains of Khuzestan begin, there is a region with original climatic conditions. From one side, it is bound by the mountains and from the other side, by Khuzestan plain and Persian Gulf. Because of the noticeable distance from the Gulf (approximately 250 kilometers), the humidity decreases considerably in this territory.

Regarding the relative degree of heat and humidity, we can consider this zone as a special regional characteristic between the hot-dry central plains and the hot-humid Southern lands of Iran. Therefore, in the historic cities of Dezful and Shushtar, this hot and semi-dry climate gave birth to urban/architectural morphology halfway between the architectural styles of central regions (compact urban tissue and completely introvert constructions) and Southern territories (relatively open spaces/facades to promote air circulation).

The general urban characteristics are similar to cities around the central desert: very dense urban structure identified by fragmented popular spaces and labyrinths. Here also narrow and muddled streets connect adjacent buildings to minimize the direct impact of solar radiation and to optimize the use of shade. These passages engender dimensional and volumetric changes at the end to expose important local points. We can really feel harmony and variety in these coherent and human-scaled networks. Although these passages present a certain visual monotony in terms of colors and building materials, they can be distinguished from each other by different shapes, dimensions and construction methods.

Because of hostile heat and humidity during half of the year, the aeration in both directions of building is essential. Thus, the vernacular constructions are not completely introvert. Their openings take place on internal and external facades. Thereby, all the facades are equally beautiful and important. Generally, the length and the width of their central courtyards are bigger than the cases in the central regions of Iran and smaller than the courts of houses in the Southern areas. Also, the height of rooms is less than that of the Southern houses (Ghobadian, 1998).



Fig. 1 - Interior courtyard of Mostofi House in the historic city of Shushtar
Photo by Behrang Fakharian, 2010

Since wood is rare in hot and dry regions, and also we cannot find stones except in the mountainous regions and the edges of rivers, the only available material for the construction in these territories is soil. Therefore, the houses in the historic center of Shushtar are generally made by adobe and brick (sundried or baked). They are locally available in abundance and their price is cheap. Their thermal role is considerable because they warm slowly during the day and restore their heat in a progressive way during the night. This effect moderates the thermal change inside the building at any time (Tavassoli, 2000). The use of brick is also remarkable in the construction of most of the bridges and public buildings.



Fig. 2 - Photomontage of the facades of residential houses in the historic city of Shushtar
Photos by Behrang Fakharian, 2010

The architecture of the historic city is a continuation of ancient building traditions which evolved gradually through millenniums. Most of the existing constructions belong to the Qajar dynasty (1781-1925). However we can notice several houses built during the former periods, especially in the Safavid era (1501-1722) (Zista, 1986).

In the static point of view, the load-bearing elements of the buildings contain wide and voluminous walls realized by rubble stones and mortars. The dimensions of these walls were conceived so that the compression resistance is approximately the same as that of the traction. This structure prevents the collapse of walls because of buckling. For this reason, according to the diagram of the weights distribution, the profile of these supporting walls has a trapezoidal shape. Its biggest width facilitates the transfer of the weights to the foundation. The main mortar used in these walls contained a mixture of lime and ashes with the ratio of 4:1. Generally, this mixture used to cover the walls, particularly in basements. On the other hand, the mortar *Gach Chit*, the mixture of plaster and sand was applied for covering and restoring the facades. We can also notice that a mixture of cement and sand is used for the restoration of facades in the more recent times (Mashhoodi, 1999).

Rubble stones were used as well on the entrance of some houses. These stones represent carefully tailored pieces with fine and regular joints. Inscriptions or delicate

carving motifs are visible in some cases. This part of the wall is an aesthetic representation and has no supporting role. However the majority of the stone walls are load-bearing structures, which can also support the charge of the nearby arcs or porches. In the same way, they could sustain one or two brick-built floors over themselves. This kind of composition of stones and bricks in the supporting walls is a regional characteristic. It is necessary to consider that the thickness of a large number of these walls has never been calculated. But it is estimated that these walls bear a little more weight with regard to their thickness and capacity. This fact increases their thermal capacity; thus this phenomenon improves the thermal performance of these constructions in the hot climatic condition (Mashhoodi, 1999).

The interview of Bozorgnia with Mahjoobi, former *mimar* "master builder" of Shushtar, reveals some principles of Shushtar's vernacular constructions:

- Contrary to the profession of current architects, *mimars* of yesterday built their buildings without drawing any plan. It was enough to speak with their clients to understand their needs. Then, they the edifices up to the last internal details. Afterward, they drew the main structure of the building on the ground. Regarding the dimension of the area, first of all they founded the basement, *Shabestan*, and then established the main building over it.
- The foundation of buildings was usually made by mud. However in the majority of cases, after digging the ground, *mimars* perceived the former constructions over which the new buildings would have been based.
- The orientation of buildings was northward, toward the mountains. This attitude traditionally existed in this region since the pre-Islamic periods.
- For the realization of brick decorative motifs, the brick molds were modeled, and then, each brick would be measured and cut regarding to the desired format, and finally, be installed to shape the wanted motifs.
- Windows and doors were fabricated locally from woods of the groves nearby Shushtar.

The doors are usually made from lotus wood decorated with long and broad nails. The portals are decorated with brickworks called *Khovan Chini*. This method is particularly remarkable in old urban tissue of Shushtar and Dezful. The motifs are very variable. Although most of the existing buildings in the historic city were built between the 16th and 20th centuries, brickwork motifs, carvings and inscriptions used on the facades or over the entrances remind the classical antiquity, especially the Mithraism. The researches of Mohamad Salehi on the architectural heritage of Dezful (cnh.ir, 2009) show that these brickworks are the result of hot climate of this region. The large quantity of reliefs creates shadow between bricks so that most part of the dorsal facades, which is exposed to the sun, remains cool. As a result, less heat will enter the house. The static/aesthetic use of brick was widely developed in this region during the

Qadjar dynasty (1781-1925).

The later constructions were influenced by the technological and scientific evolutions, which entered the city at the beginning of the 20th century. The use of new building materials such as concrete and steel brought some changes. Nevertheless, these constructions still followed the principles of the local architecture. During the Pahlavi era, the use of stone in facades is almost disappeared. The only examples are limited to the regular blocks cut in fine and regular joints. On the other hand, most of the walls are made of brick whose manufacturing technology is principally evolved. These bricks still possessed considerable thickness representing a supporting element. Their application in the construction became simpler and less decorative. Indeed, the creativity and the variation of the brickworks were restricted to some particular motifs. Generally, these patterns were made with prefabricated bricks. The realization of these brickworks was similar to the art of ceramic.

Old Shushtar can be considered as one of the most coherent Iranian's urban tissue in terms of form, technology and materials. Half of the population of the city live and work in this largely dynamic habitat surrounded by water like an island. Due to the limited area of historic town, constructions have been developed in the same location throughout the years and centuries over old urban layers (Mashhoodi, 1999). According to this fact, the urbanization in others sides of the water remained stagnant till the appearance of New Town in 1978.

3. SHUSHTAR NEW TOWN (1974-80)

It is a city for workers and employees of the Karun Agro-industry situated in the north side of the river. The development of Shushtar New Town was intended to revitalize the historic city and to go along with the expansion caused by the industrial growth in the region during the last years of Mohamad Reza Shah era (1947-1979).



Fig. 3 - Brick in Shushtar New Town, Photos by Kamran Adl, 1980

The new town puts together the traditional values of regional society and the technology of its day. In this manner, it maintains a traditional continuity with the past.

The major design feature is a multi-faceted central east-west pedestrian boulevard. This consists of many gardens, paved squares, covered and shaded resting places, arcades, and bazaars. The neighborhoods are designed to encourage movement in the direction of this pedestrian boulevard. Major public activities occur along this spine, assuring its prominence. The treeless narrow streets have dead-end playgrounds or meeting places like the labyrinths of old cities (Diba, 1981). The automobile is segregated from internal community life. The traffic passes through an orthogonal network serving various parking areas concentrated collectively at strategic points. This network is connected with that of the historic city to unify the circulation in both urban units (Pontoizeau & Faghih, 1978).

The first neighborhood was designed as a total architectural unit, more like one building rather than loosely organized units within an urban structure. All units have a courtyard, which, in Shushtar weather, could be used, as a big-open-sky room. Considered for a local lifestyle, most of the houses possess one or two levels. Room sizes were generous, 5*5, 4*4 or 3*4 m², and connecting to the courtyard where we find a shaded corner at any time of the day. The roof terraces are accessible to enjoy the freshness at night. The possibility of expanding the house sizes would make the internal social transformation of the neighborhood easy and provide inborn dynamics for socio-economic mobility (Diba, 1981).

The yellow-ochre brick is the dominant material of this realization although concrete is used as structure and cement as finishing. At first, all the walls were conceived to be totally made by baked brick. But because of the lack of this material, the architects were obliged to compromise other solutions like cement surfaces (Diba, 2011). "Finally, it seems that the texture of the flat white surfaces prominently displays the brick composition and values it. The white walls are always inside; this solution is effective for the reverberation of the sun and makes the small courtyards clear and spacious. Nevertheless, dusts of sand transported by the wind may unify colors." (Emery, 1979)

Traditional construction methods were resumed by professional entrepreneurs. The supporting walls were constituted by locally produced bricks. They were laid on the reinforced concrete foundations. The roofs are framed with steel beams supported by walls or by engaged pillars. The ceilings are dressed in plaster. The floor finishing is stone on concrete patches. Otherwise, the terraces are supported by steel girders. The covering of interior is especially brick, but sometimes the cement is used in kitchens and bathrooms. The door and the window are framed by circular arcs of brick or girders.

Although educated in the West, Diba was strongly sensitive to the local and vernacular architecture of Iran. He tried to plan an urban tissue including residential, commercial and socio-cultural zones, in such a way that the rural upcoming population would not be shocked. Afsharnaderi writes: "while this project evokes the realizations of Hassan Fathi in Egypt, the construction process is [absolutely] different. Hassan Fathi applies "the local inhabitant" to build its housing environment with the simplest methods in a participative way while Shushtar New Town was acquired to the entrepreneurs using latest technologies of the day. However, both results represent practically comparable

form."

The architects planned to mix various architectural elements like forms, colors, and materials. This search of diversity is more important in this New Town as its population is socially and economically very homogeneous (Pontoizeau & Faghih, 1978). This housing typology is also intended to decrease the excessive heat and sunlight. It is characterized by the spatial distribution of houses, the various dimensions of streets and the different height of the constructions. This morphology is to provide maximum shade and shelter for the pedestrian against the direct sun radiation. However, the problem of non-intimate spaces is emerged in certain cases. Indeed, today's residents install air conditioners in their housing unit to face the excessive summer heat and lack of air circulation.

"Diba inspired by local patterns and motifs, made very good use of vernacular knowledge. Besides the main material used in New Shushtar which is brick, covered passageways' brick partitions, entrance frontispiece, elaborated ornamental brick works on facades, introverted architecture and subdivided neighborhood units are inspired by old traditional urban principles. Beautiful passageways and small local squares, serve to create a very strong local identity. What's more, is the excellent use of minor techniques like holes in partitions, walls, balcony edges in buildings and in passages which make possible air circulation." (Haeri, 2007)

The east-west streets are conceived to offer a north-south orientation to the housing units. It allows their residents to take advantage of the favorable wind of North. The creation of the small openwork bricks and the north-south orientation of buildings make a unique refreshing system for whole city.

4. NEW URBAN DEVELOPMENTS: FARHANG SHAHR & MASKAN-E MEHR

Every civilization has its culture and lifestyle, which form the environment of human. In Iran, urbanization and urban life are not recent phenomena but date to the farthest antiquity. They came from a long tradition with defined urban lifestyles; however, most of New Towns built recently in the country were conceived and realized without any consideration of past positive experiences. There is, on the contrary, an apparent gap between historic cities and new ones. These recent planned cities normally follow western models, hardly adapted to the climatic and socio-cultural conditions of the country. The project of Maskan-e Mehr is under construction in Shushtar. It is planned to accommodate 29 000 inhabitants in 220 hectares including urban equipments such as schools, hospital, mosque, official/commercial buildings, parks, and playgrounds. It is characterized by four-floor residential buildings conceived repeatedly from a typical plan. Each building includes 16 or 24 apartments (4 or 6 housing units in every floor). These buildings are founded on a ground floor, which serves as garage and stock rooms. This density enforces the use of elevator. The average surface of the housing unit is about 75m². In general, each one has three air conditioners depending on the number of rooms. In the majority of cases, all rooms of a single housing unit are

directed to one side of the building. This arrangement does not allow enough natural air circulation, contrary to the north-south orientation of transverse houses of the historic city and the New Town, which can take advantage of the favorable North wind.



Fig. 4 - Modeling of Maskan-e Mehr residential complex
Negar Shahr Memar Consulting Engineers, 2010

The construction technology is based on an industrial model typically spread everywhere in the country. The steel building structure whose iron is supplied comes from big cities like Ahvaz, the capital of Khuzestan province with a road distance of 93km, and Isfahan in the center of the country with a road distance of 675km. This realization will be completed by the following elements:

- Floors by prefabricated concrete on block joist system with terracotta or polystyrene blocks;
- Partitions in terra-cotta or light-concrete blocks;
- Double walls from 2*10cm of patch blocks with polystyrene in the center for sound and thermal insulation;
- PVC double glazed windows;
- Combination of thin clay bricks and stones for facade covering.

This project is situated in the North of Farhang Shahr, a residential neighborhood planned in the middle of 1980 at the West of New Town. It included the houses in one or two floors arranged on an orthogonal town planning. The large public places are not protected from the sun and the pedestrians are under extreme heat during the day.



Fig. 5 - Residential neighborhood of Farhang Shahr, Photos by Behrang Fakharian, 2010

This current architecture is influenced by an international style diffused all over the country due to the fast urbanization. In shushtar, this wave of construction began since the last years of Mohammad Reza Shah era and was multiplied after the 1979 revolution. These buildings do not present the rich values of regional architecture neither in their spaces nor in their building technology/materials. The housing units became smaller and are built by current industrial technology presenting recently in all geographic/climatic context. The wall thickness was reduced to the minimum possible thus the thermal exchange increases to the maximum. Because of this fact and also new materials used for building walls and partitions, the thermal resistance decreases considerably. In these conditions, it is impossible to live in most seasons of the year without air conditioner.

From the ecological point of view, the courtyard of contemporary houses and traditional ones is comparable. In the first case, we can notice the use of inappropriate materials such as mosaic or asphalt for the ground and iron bars for doors, windows and parapets. These materials absorb heat so fast that it would be too difficult to walk in barefoot on the ground or to touch bars and metallic doors during the afternoons or the hot summer days. On the other hand, traditional courtyards are covered with bricks with the less warm surface than mosaic or asphalt in the same climatic condition. Furthermore, during the evening, these bricks, which have already preserved the heat, prevent the fall of temperature of the courtyard. Moreover, the wood is often used for doors and windows and sometimes for balconies and beams (Ghobadian, 1998).

The study published in 1986 by *Zista Architecture & Urban Planning Consulting* shows that the extensive decrease of architectural quality in the city of Shushtar is mostly connected to the urban regulations. In fact, it is the result of the globalization of urban regulations and construction standards derived from *Teheran Master Plan* over all Iranian cities with different cultural/regional contexts. This may lead to the massive settlements of these environmentally incompatible building typologies.

5. CONCLUSION

The city of Shushtar owns an old technical culture of at least eighteen centuries. The successive technical evolutions translate the urge of a harmony between the natural and built environments.

The new urban developments of Shushtar such as Farhang Shahr and Maskan-e Mehr are the results of a national urbanization policy that rarely has regional consideration. Followed by a standard construction model in developing countries, these experiences show that:

- Their conception is based on the power of thermal machines instead of regional characteristics/resources/environmental conditions;
- The national/universal building industrialization mainly intended to reduce the necessary energy for the construction process, is actually one of the important factors of the loss of thermal efficiency during the life of these buildings.

One of the most important mutations in construction procedure during the last centuries is the role of designers. Contrary to the traditional master builders, today, architects and urban planners rarely have the direct experience of materials on the construction site. The other fact is that the former clients were the residents of their own building, while the modern costumers are generally the retail/major investors. Besides, the modern construction market has relatively reduced the time of design process. In consequence, the contemporary designers and their clients chose building materials/technologies according to economic criteria of construction market whereas the former master builders and owners were based on their same historical/cultural backgrounds and their lifelong local/environmental consciousness.

The range of the construction materials in the building industry during the 20th century is considerably developed. However, in hot (semi)-dry cities of developing countries, the earth architecture reflects all its interest in the reduced production/transport costs and also in the historic continuity. It still denotes a vital alternative solution with regard to imported/incorporated materials such as steel, aluminum and plaster.

Shushtar New Town avoids high residential buildings while reflecting the identity of horizontal compact cities. It is based on the cultural values of its region and maintains continuity with the past to find a regional expression. This example of urban planning is important as a planned city of large scale conceived and built by local craftsmen and competent promoters trying to satisfy the native lifestyles. This experience takes part of the contemporary movement that exploits and values the forgotten ancestral knowledge. This movement is more known in architecture than in urban design. Shushtar New Town is one of the rare examples of urban developments, giving rise to a "technological transfer in time". The study of this approach may bring sustainable answers for the environmental and socio-cultural questions of future housing projects.

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CURRICULUM

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THE ROLE OF ENVIRONMENTAL FACTORS IN THE FORMATION OF THE ARCHITECTURE OF EARTHEN CASTLES IN THE CENTRAL IRANIAN PLATEAU

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Theme 1: History of earthen architecture in Asia and other regions of the world.

Sub theme 1.2: Vernacular architecture and traditional building cultures.

Key words: Earthen architecture, mud brick castles, the central Iranian plateau

Abstract:

In accordance with the geographical location and natural characteristics of Iran, its inhabitants had to take specific measures in order to make secure their living and working environment against man made accidents. Since the pre historical and historical times, such measures were influenced by natural factors in particular regarding the creation of defensive architecture.

Investigating and interpreting the factors affecting the formation of the architecture of earthen castles reflects new important points, which have caught less attention in the past. Plain castles that in fact constituted the main core and center of historical towns served as the principal factor in providing security for city residents and played a defensive role in residential areas. Plain castles were a type of Iranian architecture constructed only around residential areas (whether urban or rural) and had different forms, dimensions, sizes, materials, designs and structures in accordance with effective factors of the monument environment.

In this article, not only the architectural structure and earthen materials of these castles is investigated but also they are compared and analyzed in relation to factors within the monument bed affecting the formation of architectural spaces of mud brick castles.

1. INTRODUCTION

The central plateau of Iran enjoys a distinct geographical identity because its area can be specified by surrounding highlands: Alborz Mountain ranges in its north and Zagros mountain chain in its south and south-west. Both have served like an impenetrable natural shield against the raid of aliens from the above-cited directions. However, this natural enclosure was incomplete resulting in numerous invasions from defenseless directions. Additionally, these mountains are largely in parallel to each other so that between them narrow or wide plains have appeared suitable for human habitation. As a result, Iran has actually acted like a bridge for immigrants and invaders in the course of its history. From old times, locals have built fortifications in mountain crossings to provide security.

The variety of climate in different areas has given rise to specific life styles. Based on economical, geographical, architectural, and military concerns, residents of different

areas resorted to unique methods in order to adapt themselves to their natural environs. Living in such undesirable and insecure conditions made people construct their homes like little fortresses. Therefore, all around this land, castles, ramparts, moats, gates and the like can be seen aimed at providing more security for inhabitants. The majority of military and historical fortifications in Iran consist of castles, which can generally be divided into plain castles and mountain castles. There exist similarities and differences between them regarding their forms, materials, and architecture.

Goals of the present article are: to provide a general classification of castles based on their setting, to study factors affecting the formation of plain castles in the Plateau of Iran and finally, to select a specific example (Aq-qaleh castle in Sabzevār) in order to express the architectural and environmental values and merits of such mud brick structures more clearly.

2. HISTORY OF BUILDING EARTHEN CASTLES IN THE CENTRAL IRANIAN PLATEAU.

During the process of human settlement and subsequent development of agriculture and business, a type of social organization appeared as evidenced by the construction of public buildings including defensive castles. After local governments were set up, population and immigration increased resulting in more conflicts among communities. That is, the necessity to build castles and defensive and military walls in order to remain immune from consequences of such skirmishes was felt. During the process of castles development, their enclosures initially lacked any defensive towers but later such feature was added to them in order to safeguard trading activities. Gradually about three thousand years BC, human settlements were formed in the Plateau of Iran such as Bloor-abad of Qare Ziaoldeen village in west Azerbaijan Province. Defensive enclosures did exist during the raids of Elamites and Assyrians but have since been largely destructed. The process of castle construction expanded during the reign of Achaemenid (e.g. Tal-e-takht in Pasargadae) Parthian and Sassanid dynasties (e.g. Qaleh Dokhtar in Firuzabab) until the Al-e Buyed era during which important castles as well as strong enclosures were built around major cities such as: Isfahan and Rages. Seljuk kings continued such trend. But perhaps it is fair to claim that the most flourishing period of castle construction in Iran dates back to the 200 –year rule of the Ismaelids. Later, castle building and dwelling boomed at the time of Ilkhanids and Timurids and especially Safavids and continued even until the rule of Qajars and Pahlavis but with the progress of technology, the tradition was gradually forgotten.

3. CLASSIFICATION CASTLES BASED ON THEIR SETTING

Due to the significant effect of geographical situation and natural topography upon castle design, castles can be classified into two groups concerning their settings:

A- Mountain castles

B- Plain castles

Both types will be described here regarding their design and structure.

3.1. Mountain castles

Natural geography is the most effective factor in the formation of these castles. Due to the irregular form of cliffs, enclosure designs of mountain castles were usually non-

geometrical. Materials used were mostly rubble stones or occasionally scraped and chipped stones, which are abundant in highlands. These were bond with a mortar of lime, mud or *Sarooj*¹ and sometimes were arranged by *Khoshke-chineen*² method. In some cases, even sun dried or mud bricks have been used. The roof and ceiling structural forms in these castles are flat types such as *Tir-poosh*³ and curve types such as *Tagh o Gonbad (Vault & dome)*.

The architecture of interior spaces lacked any specific design or plan and it was really the topography of the slope or cliff that determined the location of facilities and their settings. Interior spaces had a wide variety regarding their number, size, and details. They usually consisted of barracks, supply rooms and the commander's or ruler's residence.

In major castles, there existed several other structures with various functions such as: mosque, *Kushk*, manufacturing workshops, and prison. The commander's seat or *Hakem-neshin* was located at the highest and the most inaccessible section of the castle and depending on the scale and significance of the castle; it enjoyed the most architectural variety.

One of the challenges confronted in the mountain castle construction was the issue of water supplying. Based on investigating the remains of castles, the problem was resolved in different manners. In some castles like Alamut, stream or fountain waters flowing in higher elevations were redirected toward the castle by digging underground canals and using *Tanbooshehs* (terra-cotta water pipes). But some castles enjoyed water streams running through or nearby them. Still in some other ones, an underground duct was dug from the castle as far as the riverside so as to allow access to castle dwellers e.g. Lambsar Castle. Digging deep wells and gathering rainwater was yet another method of water supplying in mountain castles. Examples of Iranian mountain castles are: *Izad-khast* and *Qaleh-dokhtar* in *Firooz-abad*. (fig. 1)

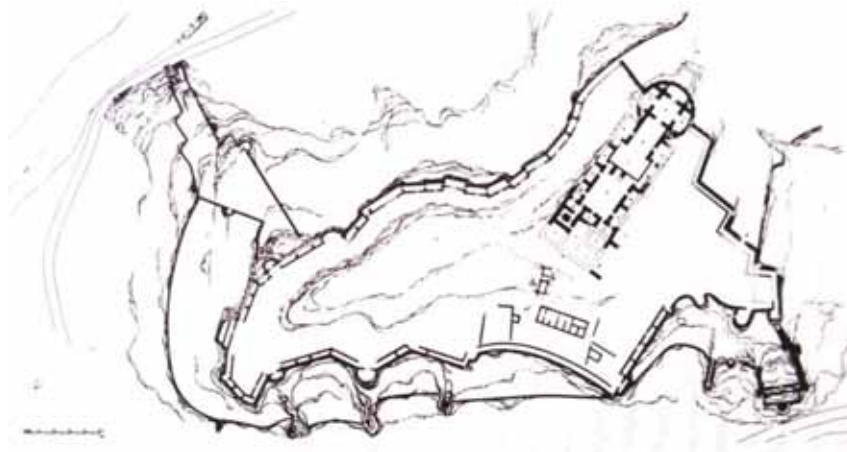


Fig. 1 - *Qaleh-dokhtar* mountain castle plan

3.2. Earthen plain castles

Despite their solidity and impenetrability, mountain castles are not efficient on low lands which require the construction of another type of castles. So, plain castles developed. This kind of castle was usually built upon natural or manmade hills or elevations in

order to overlook the surrounding areas and to increase the defensive potential. But in those places in which this was not possible, the simple method of building a wall all around the settlement was an old solution. Unlike mountain castles, plain castles were built based on pre-designed and had a geometrical form. They were characterized by their rampart(s). Form, number, and materials of these ramparts depended on not only the significance and size of the castle but also on the natural and social condition of the area and among their similarities are their high, thick, and long walls. Some defensive elements of these castles are their polygonal or cylindrical towers, their encircling moat, and at least one gate. Plain castles usually formed the primary kernel of towns and were built beside Caravan routes, along the sides of major rivers, near springs at the foot of mountains or at a *Qanat* opening.

Plain castles belonging to early or middle Islamic period can be classified into the following types based on their setting, function as well as their architectural design:

3.2.1. Function

- 1- *Hakem-neshin* (governor's dwelling place) castles were mostly built within important population centers and had exclusive quarters for the residence of the ruler. This type of castles is considered as the most perfect regarding its architectural spaces because they occupy a large area and consist of: ramparts, moat, several gates, *Rabaz*⁴, *Sharestan* and the governor's dwelling place. Examples are: Aq-qaleh of Sabzevār, Sahl-ābād Castle in Zavareh, Bampur Castle in Iranshahr, Pachenar Castle in Semnan and Esfarayen Castle.
- 2- Rural castles, which enjoy a uniform fabric. They are without *Hakem-neshin* but have public spaces for their residents. Farmlands belonging to castle dwellers are seen around these castles and they usually have only one gate e.g. Saryazd Castle.
- 3- Those castles that belong to a local ruler or tribe and are smaller than their counterparts such as *Qurtan* Castle of Isfahan and *Dezak* Castle in *Sārāvān*.
- 4- The so called *Rah-dāri* (road protection castles) which had tall towers and were built beside major caravan routes such as: Allah-abad Castle in Tabas, Jandagh Castle of Isfahan, Dolat-abad Castle of Damghan and Zafaraniyeh Castle in Sabzevār.
- 5- Shelter castles which were built near residential areas in order to be used during hard times such as the old castle of Jājarm town in Khorasan Province, Gogad Castle of Golpayegan and Sam or Sar castle in Zabol.
- 6- Military or border line castles which were engaged in safekeeping and providing security for the country like Vali Castle of Ilam.
- 7- Castles frequented by political or religious minorities or the central government's opposition groups such as: Hassan-abad Castle of Isfahan used by Ismaeeliyeh followers.
- 8- Castles frequented by highwaymen, insurgents, and criminals. The number of these castles increased during the Qajar era and an example of them is Mokoshom Castle in Semnan.

3.2.2. Architectural forms

Plain castles have a variety of forms depending on their settings, scales and dwellers' needs. Generally, they can be classified as follows:

- 1- Those with rectangular or square plans such as: Gogad Castle of Golpayegan, Aq-qaleh and Mohammad-abad in Daregaz.
- 2- Those with polygonal plans such as: Qooshchi Castle, Mohammad Khan Dashti and Jalaleddeen Castle of Jājarm.
- 3- Those with non-geometrical plans, which follow the contours of the terrain such as: Bampur Castle, Khandan Castle of Gorgan and Jolian Castle in Abdanan.

4. COMMON ARCHITECTURAL ELEMENTS IN PLAIN CASTLES.

Despite obvious differences regarding form, dimensions, size, design and materials, the design concept of plain castles is almost the same due to the kind of relationships governing the life of dwellers. Such relationships accompanied by regional geography and natural factors played a key role in the formation of various parts of castles. In the following, a brief description is presented:

4.1. Ramparts

These are high walls without any orifice encircling the castle in order to inhibit possible raids and invasions. A mixture of towers and ramparts not only added to the solidity of the ramparts walls but also served as a proper place for positioning guards. Enclosures often had a geometrical layout and atop them there existed regular openings and notches for defensive and observation purposes. Some castles were encircled by several rows of ramparts and occasionally because of castle expansion; new ramparts were built around the new residential area. (fig. 2)

4.2. Towers

Towers usually reinforced enclosures and were erected at specific intervals particularly in corners. Often they had multi tiered spaces inside as well as a stairway providing access to upper floors. Most towers had cylindered shapes with the diameter of walls the same as ramparts. The number of towers depends on the length and scale of the castle as a whole. Usually, towers located in corners had a perfect shape but those in the middle were imperfect. (fig. 2)

4.3. Gates

Factors determining the number of required gates included the scale, size, function and location of *Kohan-Dej* or *Hakem-neshin* as well as main routes existing outside it. Thus, the number of gates in plain castles varies. For example, in Aq-qaleh the position of *Kohan-Dej* south of the castle has led to the installation of three gates on north, east and west sides of its enclosure. However, in Zafaranih Castle which is a *Rah-dāri* (*Road protection castle*) or road guarding castle, there exists only one gate on the north side which is the nearest to the main road.

On the either side of gates, stood towers with their guard rooms positioned inside, behind or above the gates. These rooms had openings through which the traffic into and outside the castle was monitored. In moat castles, a movable or fixed bridge provided access to the gate by passing above the moat. (fig. 2)

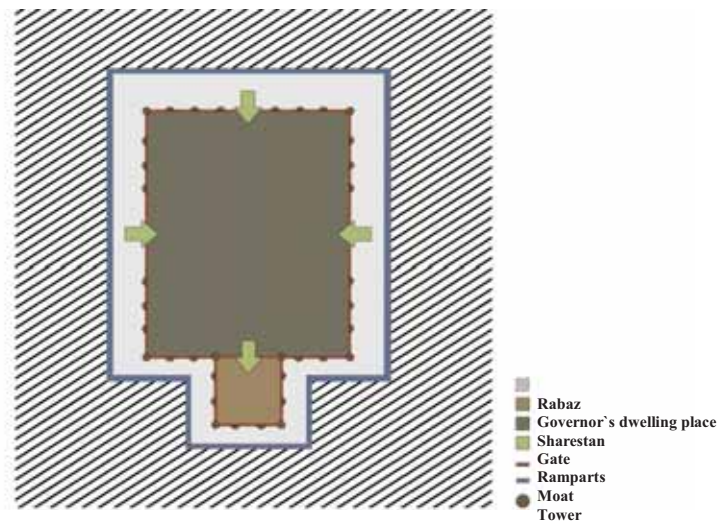


Fig. 2 - Common architectural elements in plain castles

4.4. Sharestan

During the pre Islamic times, this section of the castle that was made of special quarters and was allocated to the upper class was called the middle Shar. But during the Islamic era, it was usually called *Sharestan* or the public dwelling place which consisted of residential areas or public places such as: mosques, Bazar, cistern, Qanat, Hamam, various workshops and of course homes belonging to castle dwellers. From an urban planning and living point of view, *Sharestan* was a perfect compound fulfilling many needs of the society. (fig. 2)

4.5 Hakem-Neshin (Governor's dwelling place)

This part was usually built at the highest point of the town or castle atop a natural or artificial hill or was located at the end of the castle and served as the residence of the ruler. Structures of this part differed from other parts on account of materials, dimensions, size and beauty and were generally, more solid, more extensive and more luxurious.

Actually, *Hakem-neshins* were considered as independent and exclusive spaces within the castle and town enclosure. They not only had exterior ramparts and enclosures but also were equipped with special fortifications and were separated from other parts of the castle. Thus during invasions into the town, the last resistance took place in this spot. (fig. 2)

4.6. Rabaz

Before the advent of Islam, *Rabaz* was called the outer *Shar* that is the exterior area of ramparts including gardens, farmlands, mills, and a number of peasant homes, pasture for domestic animals of castle dwellers, and their graveyard.

During times of peace, residents of castles went out and started their regular activities such as farming within *Rabaz*. Occasionally enclosures were set up all around *Rabaz* but they were not as strong or large as the fortification of the castle. (fig. 2)

4.7. Moat

Moat was a long, narrow, and deep pit dug in the ground encircling castles so that the entrance of the enemy was interrupted. Moats were designed and built in a way that they were connected to the water supplies such as rain or river water and were filled with water if necessary so as to

inhibit foreign invasions even more. Moats were designed in various dimensions but were mostly 3-4 meters deep and a bit wider. Soil dug out of such holes were ordinarily used in castle construction. (fig. 2)

5. DEVELOPMENT AND FORMATION

The primary core and the most important part of plain castles were called *Kohan-dej* so that all other parts and elements of the castle such as: *Sharestan*, gate(s) and monitoring towers were positioned and organized in relation to this part. Locality of *Kohan-dej* depended on the function and location of castle. In places with natural uneven grounds such as hills, they were built atop them so as to overlook *Sharestan* and *Rabaz*. This not only emphasized the higher political and social status of *Kohan-dej* but also increased its security.



Fig. 3 - Development and Formation around Birjand Castle

After *Kohan-dej*, *Sharestan* or the public place came second regarding significance. As noted before, public buildings such as: markets, mosques, cisterns, schools, *hamam*, industrial and production workshops and private homes could be seen within this area. *Sharestan* has always been the most vulnerable part of any castle so that in times of war its residents left it and took refuge in *Kohan-dej*.

Despite its secondary place relative to *Kohan-dej*, *Sharestan* played a vital role in the expansion and alteration of the castle identity. Factors such as: population increase, disappearance of social ranks and change of life style affected its alterations and size. Gradually connection between *Rabaz* and *Sharestan* caused an increase in the number of buildings within *Rabaz* and led to the addition of a rampart around *Rabaz*. With the passage of time, this process continued and little by little, the border between *Sharestan* and *Rabaz* disappeared resulting in the formation of the rural or urban fabric in its present concept. (fig. 3)

6. CASE STUDY

6.1. AQ-QALEH OF SABZEVĀR

6.1.1. Brief History and Description

Located to the north west of Sabzevār town in Joveen Plain, there exists Aq-qaleh. Based on historical texts and archaeological excavations, it can generally be concluded that the compound was built during the later years of the Ilkhanid era in order to be the nucleus of a new town similar to Soltanieh plan. It had a moat as well as a rectangular shaped enclosure. In the middle of the enclosure, a mosque was built whose inscription dates back to the year 721 LAH, coinciding with the rule of *Ojaito* and one year before Soltanieh Town was completed. Then it had a relatively low population living in the area south of the mosque. Apparently, the town was deserted around this time until the Safavid era in which again at the south front of the castle, earthen or mud brick houses were built atop old Ilkhanid ruins resulting in its gradual population increase to a level higher than ever before. Seemingly, this new booming phase continued until mid Qajar era during which the insurgent Khan dwelling in Aq-qaleh surrendered to Fāthali Shah Qajar leading to the gradual destruction of the castle.

According to archaeological data, the northern part of the castle located above the road lacked any architectural monuments. To the south west of this part and opposite the west gate of the town, there exists the Islamic cemetery, which is buried under a pile of sand. Remains of the south *Iwan* of the mosque can be seen at the southern front (to the south of the road). In the middle section of the castle, architectural remains belonging to the Qajar era are seen on the surface but civilization layers dating back to the Safavid and Ilkhanid periods (8th century LAH) are deep under the ground.

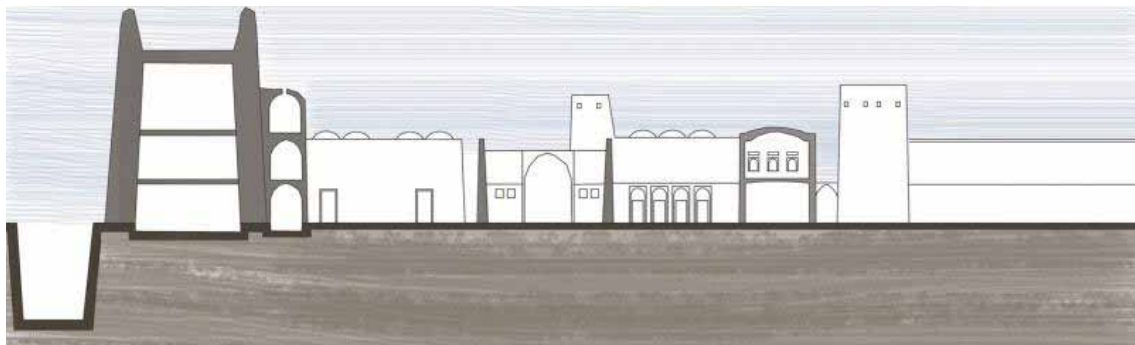


Fig.4 - *Aq-qaleh* Gate of *Kohan-dej* and schematic section

6.1.2. Architectural System

Both Aq-qaleh Castle and the Kohan dej to its south have a rectangular shaped plan encircled by a rampart with 28 towers. Based on its form, scale and location, the castle can be classified as a *Hakem-neshin* type. Prominent spaces of the castle are its: *Kohan dej*, *Sharestan*, *Rabaz*, *Qanat*, ramparts, moat and gate. The water of the compound is supplied from a *Qanat*. Until now, 31 *Qanat* opening have been identified in its *Sharestan* and the main well of *Qanat* exists in Joghtai mountains south of the ensemble. (Figure 4)

Historical documents show that the remains of buildings in *Sharestan* belong to a market, a public bath, a school as well as private homes. But now only part of the southern *Iwan* of the mosque still stands.

Kohan dej in the south of the castle had one entrance at its northern front. Based on the remains belonging to buildings around *Kohan-dej* rampart, they were in three floors but those at the middle part were shorter. The entrance to the castle had an octagonal form serving as a distribution space in order to make possible access into different parts. On northern and southern sides, structures are seen equipped with small rooms in three floors that served as barracks. The larger middle space was the most important part of the castle and the residence of the governor.

6.1.3. Structure System

According to geological and archaeological reports, the rampart of the castle was built upon a virgin piece of land. One of the most significant characteristics of the rampart was its large diameter (7-10m) as well as its layered (*Chineh*) condition but as its height increased, its thickness decreased. The soil used for *Chineh* (layer) was the same as found in the regional terrain and most probably was the soil dug out of the moat. In middle sections of *Kohan-dej* and in load bearing parts foundation with stones (*Korsi-chinee* in Farsi) can be seen but at most spots, *Chineh* walls have been erected upon virgin grounds. These walls have a 100-120 cm diameter. A mixture of local soil plus sand has been used to make *Chineh*, which has these dimensions: 5 x 25 x 25 cm.



Fig. 5 - One of the Rooms in South of *Kohan-dej* that shows the Mud Brick Structure

6.1.4. Construction Materials

Most of the materials used in this compound are: *Chineh* and mud brick, earthen mortar, *Kah-gel* and *Gatch* (Gypsum) plasters.







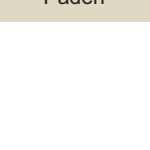
6.1.5. Climatic and Natural Factors Affecting the Architectural System





Weather has played a major role in the architectural composition of the mud brick castle of *Aq-qaleh*. Main problems compelling locals to construct this plain castle were the hot sun, intense heat; daily thermal variations especially during summer time, very warm summers followed by very cold winters, dry climate and shortage of rainfall as well as sand storms.

The compact composition of the compound, narrow passages between high buildings, construction of two or three floor structures in the perimeter, making shelters for

rooftops, usage of curved covers, thick walls, and finally *Kah-gel* plasters are among features used in the architectural structure of the castle in order to combat climatic challenges of the region. Many of the structures within the castle have collapsed due to its abandonment following civil wars (in particular during the rule of *Fāthali Shah* of Qajar), earthquakes, precipitations and the ever increasing urban expansion. Therefore, gradually a rural fabric took shape outside *Sharestan* and along the main road.

6.2. COMPARISON

Mud Brick Additives	Construction Materials	Variety in Architectural Spaces	Scale	Architectural Typology	Functional Typology	Factors affecting formation	Period	Castle Name & Aerial Photo	
Sand	<i>Chine</i> , Mud Brick (25×25×5) Brick	Tower Ramparts Moat Gates <i>Koham-dej</i> <i>Sharestan</i> <i>Rabaz</i>	Total Area: 585000m ² (900×650)	Rectangular Plan	Governor's Dwelling Place Castle	political, Social and Geographic conditions ,	Ilkhanid	Aq-qaleh 	1
Straw, Sand	<i>Chine</i> , Mud Brick (40×40×10)	Tower Ramparts Gates <i>Koham-dej</i> <i>Sharestan</i> <i>Rabaz</i>	Total Area: 14400m ² (120×120)	Squar Plan	Rural Castle	Economic, Social and Geographic conditions ,	Qajars	Dolat Ābād 	2
Sand	<i>Chine</i> , Mud Brick (30×30×8)	Tower Ramparts Gates <i>Kohan-dej</i> <i>Sharestan</i>	Total Area: 24000m ²	Non Geometrical Plans	Governor's Dwelling Place Castle	Defensive and Geographic conditions ,	Afsharids	Bampur 	3
Straw, Sand	<i>Chine</i> , Mud Brick (23×23×5)	Tower Ramparts Gates <i>Koham-dej</i> <i>Sharestan</i> <i>Rabaz</i>	Total Area: 5200m ² (16×20)	Rectangular Plan	Local Rural Castle	Defensive and Geographic conditions ,	Safavids	Mask 	4
Sand	<i>Chine</i> , Mud Brick (23×23×5)	Tower Ramparts Moat Gates <i>Koham-dej</i> <i>Sharestan</i> <i>Rabaz</i>	Total Area: 6300m ² (90×70)	Rectangular Plan	Rural Castle	Economic ,De fensive and Geographic conditions ,	Safavids	Saryazd 	5
Sand	<i>Chine</i> , Mud Brick (25×25×5)	Tower Ramparts Gates <i>Koham-dej</i> <i>Sharestan</i> <i>Rabaz</i>	Total Area: 3600m ² (60×60)	Rectangular Plan	Governor's Dwelling Place Castle	Governmental , Defensive and Geographic conditions ,	Safavids	Birjand 	6
Straw	<i>Chine</i> , Mud Brick		Total Area: 4800m ²	Non Geometrical	Rural Castle	Defensive and Geographic	Pre- Islamic	Padeh 	7

	(40×40×8)	Tower Ramparts Gates <i>Koham-dej Sharestan Rabaz</i>		Plans		conditions ,			
Straw, Sand	<i>Chine,</i> Mud Brick (35×35×10)	Tower Ramparts Moat Gates <i>Koham-dej Sharestan Rabaz</i>	Total Area: 5625m ² (75×75)	Squar Plan	Shelter Castle	Defensive and Geographic conditions	Seljuk	Nooshābad 	8
Straw, Sand	<i>Chine,</i> Mud Brick (25×25×8)	Tower Ramparts Moat Gates <i>Koham-dej Sharestan Rabaz</i>	Total Area: 600m ² (30×20)	Rectangular Plan	Road Protection Castle	Defensive , Commercial and Geographic conditions ,	Safavids	Zaferānie 	9
Sand	<i>Chine,</i> Mud Brick (30×30×8)	Tower Ramparts Gates <i>Kohan-dej Sharestan Rabaz</i>	Total Area: 6300m ² (70×90) Total Area: 4500m ² (80×50) Total Area: 3500m ² (70×50)	Rectangular Plan	Rural Castles	Security , and Geographic Conditions	Safavids	Māyān 	10

7. CONCLUSION

It can be noted that the following factors have contributed to a serious challenge regarding the life and conservation of mud brick castles of Iran: the wide distribution of mud brick castles in the Plateau of Iran, the scarcity of investigations conducted, abandonment of most of them, change of life style and gradual disappearance of technical and historical knowledge. For these reasons, the above mentioned structures which are considered as quite important components in Iranian mud brick architecture require more attention and conservation. Despite sparse attempts for recording and identifying them, it seems that much more purposeful projects concerning research, restoration, conservation and protection are urgently needed. Fortunately, due to their location in strategic spots or at central core of urban and rural fabrics as well as their historical significance and identity importance, they enjoy great potential capacities and values. It is hoped that optimal conservation and better management of these values, their introduction to various audiences as well as suitable utilization of them lead to their prolonged protection and continued vitality. In addition, micro and macro strategies, launching interdisciplinary projects, scientific and practical trainings, elevating the public knowledge and finally participation of the local community can also be beneficial.

Endnotes:

1. Plaster of lime plus ashes or sand
2. Use of stones without mortar
3. Made by wood timber-kahgel-bamboo

4. Suburb of *Sharestan*
5. Cultural Heritage, Handicrafts and Tourism Organization

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world

Sub theme 2.1.: Fundamental investigations on the material, research and development (R&D)

Sub theme 2.2.: Architectural design and sustainable development

During the last decades of the 20th Century and particularly since the beginning of the 21st Century, the international scientific community invested in research in the field of earthen architecture has carried out numerous activities. All this scientific commitment has resulted in more communication of the results of this growing specific research, thanks to articles that have been presented during successive international congresses gathering an ever increasing number of scientists and professionals in the field. On the other hand, specialised and very active national, regional or national networks are increasingly contributing to the dissemination of the scientific achievements. Despite this progress, we can still observe a duplication of research and laboratory experiments already carried out by others in distant countries or regions. This is the result of a lack of communication despite a real progress. Today, there is a need to address research in earthen materials and techniques, conservation, construction and architecture, in a joined-up way. This could bring decisive help to clearly defining the scientific priorities, and to save money and efforts.

Concerning investigations on the material, fundamental scientific research is making promising headway in the areas of mineralogy and crystallography, hydro transfer, organic composition, salinity and biological deterioration, mechanisms of cohesion and loss of cohesion, and stabilization of earthen materials with traditional physic and chemical treatment using cement or lime and even with bio-polymers. The better understanding of the role played by water at the macro cellular level is opening new directions for gradually mastering the possibility for pouring earth in forms or for realizing poured earth pavements. The prefabrication of earthen building elements as rammed earth panels is globally mastered and improves the productivity on the construction sites. Research and development on new building systems in wooden structure filled with earth and straw, or with earth bricks are proving their efficiency for improving the seismic resistance of the traditional wattle and daub construction. A new direction looking at hybrid building systems mixing earthen materials and other modern material as steel structures with projected earthen mortar is also being developed. With new standards for saving energy and developing a low energy consuming construction, research and development is carried to produce alternative solutions for insulating traditional earthen masonry, indoor and outdoor, with compatible natural material as cellulose wadding, wooden wool, wood shavings, hemp bricks or panels, earthen plasters on hempen cloth or panels of reeds which are confirming their efficiency for regulating the relative humidity and thus the living comfort. New building systems mixing insulating built envelope and thick earthen inside walls (in adobe or rammed earth) for increased thermal mass and inertia are also much more used by architects in the promotion of a new eco-housing.

Another important challenge is the necessity of promoting sustainable architecture and living environment at the core of which the use of natural building materials will play a decisive part. Among these, earthen building materials are both abundant and easily accessible, and together with the rich knowledge and know how related to them, offer a great potential. Obviously, there is a worldwide interest in sustainable development which has dramatically grown during the last decade in the face of the deepening

environmental. Asia is not escaping to this worldwide movement and more projects are being undertaken. But, although earthen architecture can be considered as a model of sustainability there is not enough connection between studies on earthen architecture for sustainable development and experimental research, or research and development (R&D), and a more obvious field production of sustainable earthen architecture that would demonstrate innovative design and building concepts for mass achievements. Research on economical and social parameters for solving actual decisive blocking against the expansion of a contemporaneous earthen architecture, is not sufficiently developed. In order to escape from isolated initiatives, from indecision between tradition and modernity, and facilitating the growing of an extended movement in favour of the revival of earthen architecture, more research and development, more education and awareness-raising have to be supported. It is clear that such evolution is also linked with the need to better understand what earthen architecture can offer to society, what are the values of this architecture for contributing to the true implementation of a sustainable development can be, at global and local scale. All scales of research, experimentation and application must be investigated, from the raw material to the building material, from the building systems and the architectural design to the implementation on the working sites, from the house to the human settlement, and to the territory. It could be argued that at the scale of "habitat" as it is based on the anthropological approach, and much more at the holistic scale of "eco-habitat".

If we try to raise some essential directions for taking forward fundamental research and R&D in the field, based on scientific literature review and on recent seminars¹, we can point out that there is a need for:

- more coordinated interdisciplinary research;
- additional research at the material level on topics such as stabilization with biopolymers, thermal behaviour, decay processes, vapour transmission rates, acoustic ambiances, air quality, compatibility between earth and other materials (natural and modern), durability to environmental exposure and impact of climatic change;
- greater exploration of building cultures and architectural heritage in Asian regions (and in other regions of the world);
- surveying all recent architectural projects revalorizing earth as main building material with hybrid building systems;
- exploring the relationship between social systems, living traditions and cultural landscapes;
- adaptation of existing building standards and codes for facilitating the development of a contemporaneous architecture; this would include numerical models for structural, thermal, acoustic, design principles;
- developing specific construction rules for earthen construction;
- values of earthen architecture for sustainable development;
- natural disaster management for improving human and built resilience with

¹ - Avrami, E., et al., (2009). Avrami, Erica, Guillaud, Hubert and Hardy, Mary, eds. *Research in Earthen Architecture: A Literature Review*. Los Angeles, The Getty Conservation Institute.

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- assessment of the impact of natural disaster such as flooding, earthquakes on traditional earthen architecture;
- assessing the actual knowledge on earthen architecture for sustainable development;
 - analysing the economic and social impacts and benefits of earthen construction in comparison to modern construction (concrete, steel,...);
 - life-cycle assessments;
 - analysis of performance based on reducing energy consumption, reusing and recycling;
 - adaptability to climate change;
 - more experimentation on full scale built prototypes exploring the relationship between high and low-tech innovative building systems;
 - low-cost housing and public facilities (schools, health centres) for disadvantaged people;
 - contribution of earthen architecture to poverty alleviation.

This second theme of the TerrAsia 2011 international conference, with its twin sub themes on fundamental investigations on the material, research and development (R&D), and on architectural design and sustainable development, contributes to highlighting a recent literature review on research trends for earthen construction and architecture at the international level while identifying priorities for their application to the southern Korean context. It presents a global summary on the recent development of new building materials, components and elements, and their architectural application in the country, outlines recent experiments on micro organisms and earth for stabilization, improvement of mechanical resistance adding lime to earth, explores traditional air conditioning systems that would be worth updating, presents experimental investigations on the anti seismic effectiveness of textile fibbers net applied on earthen masonry, and geotextile reinforcements, reviews recent architectural achievements in the Republic of Korea and in China, valorises the pertinence of underground contemporary buildings for reducing energy consumption in Portugal and Turkey. This second theme also reminds us of the pioneering ideas of the Egyptian architect Hassan Fathy and their concrete application to a modern avant-garde earthen architecture that could be a source of inspiration for new sustainable architectural achievements. Finally, the theme also rises the decisive importance of education for earthen architecture valorising recent achievements in the field in Germany, and in France. All authors having contributed to this second theme of the conference must be thanked for their provision to the knowledge and sharing of experience.

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MODERN USE TRENDS AND FORECAST OF EARTH MATERIALS IN KOREA

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world
Sub theme 2.1: Fundamental investigations on the material, research and development (R&D)

Keywords: Earth material, earthen architecture, modernisation

Abstract:

Earth has been used traditionally in Korea as a construction material, and it is still currently being used; however, due to rapid industrialization, earth has not been developed into a modern construction material. Since the 1990s, interest in earth materials has been growing, and the role of earth as a construction material has been expanding. In particular, earth material is perfectly sustainable and is a construction material with great hidden potential. To explore the value earth material, Mokpo University's Architecture Community of Terra (ACT) has engaged in many experiments to develop and expand modern uses of earth materials. The fact that many studies are being conducted with an interest in earth material is a positive indicator for the revitalization of the earth architecture area.

Going forward, Korea's research on earth material should not only expand modern uses but also guard against development only with a view to performance or economic efficiency. Balanced research should progress toward seeking the genuine value of earth material from spiritual and cultural perspectives.

1. INTRODUCTION

Korea has a long history of earth architecture and many of its traces remain to this day. Earth is a material with plentiful deposits which are easily acquired from our surroundings. Even today, earth architecture is one of the most preferred types of housing in Korea and interest in earth as a construction material is very high.

From the past, earth has had a very important position spiritually and culturally, and it was regarded as far more than a construction material. In primitive agricultural society, the maternal properties of earth which sustains the life and growth of seeds of plants were mysterious and awe-inspiring. To Koreans, earth was the origin of life and a place

to return after death. It was not merely a nearby construction material; rather, it was closely connected to our lives. Living on earth, living in a house made of earth, and living on grounds detached from earth were considered as a flow starting from being born out of earth and returning to it after death.

This is why Koreans have had a strong preference for architecture using earth materials. The advantages of earth material were well-known, and it was commonly known that it is especially beneficial to good health. Therefore, earth architecture is a sanctuary of the mind for Koreans, and many Koreans wish to live in such spaces at sometime during their lives.

In keeping with this tradition, systematic research into earth architecture in Korea is being led by Mokpo University's Architecture Community of Terra (ACT) established by Professor HWANG, Heyzoo. Since its establishment in 2000, Mokpo University's Architecture Community of Terra (ACT) has been the only university program in Korea carrying out earth architecture education, research, development, exhibition, social service, and so on. In particular, various activities are pursued through cooperation with other universities, institutes, companies, and governments. Therefore, looking at the Architecture Community of Terra (ACT)'s earth material studies can help determine recent, specific earth material technology trends in Korea.

This study examines the changing role of earth as a construction material in the modern transition from the 1900s to the present and analyzes the recent research carried out by Mokpo University's Architecture Community of Terra (ACT) to consider the earth material technology trend and to forecast future trends.

2. EARTH MATERIAL IN THE PROCESS OF MODERNIZATION

In the late 19th century, as Korea was reorganized as a product market for foreign countries imperialist economic goals, new construction materials (baked brick, glass, cement, iron) began being imported. During the Japanese Colonial Period between early 1900's and 1945, western architecture was introduced across the country. However, such housing types were not introduced due to necessity or requirement by life, so they were only adopted on a limited basis by a few of the upper class, and most of the general public continued to build using existing traditional materials, such as earth, wood, stone, and so on.

The Korean War (6.25) in 1950s destroyed many building structures, and it led to a sharp increase in the demand for housing. When truce talks were ongoing in 1953, the Korea National Housing Corporation began to build public housing, such as reconstructed housing, rehabilitated housing, hope housing, and so on, centered around Seoul. The public housing units supplied then were earth brick houses with a size of 30.7 m of cross-shaped flat plane. These earth brick house were generally small (less than 33 m with wooden floors, toilet, a conventional kitchen, and no bath. For reconstructed housing earth brick houses, many small rooms were arranged to reduce movement. Earth houses were built due to lack of construction materials such as wood and cement and lack of technical experts. For the purpose of refugee resettlement, 3000 units of earth houses were built and then no longer constructed.

In 1958, the Korean National Housing Corporation met a turning point in the housing business. Standardization and prefabrication of housing materials were pursued for quality improvement of public housing and cement blocks began being mass produced to gradually replace existing earth bricks.

As the rural population moved to cities from 1955 through the 1960s, the urban population rapidly increased which led to a housing shortage. To solve this problem, the government actively developed housing projects, and starting with the Seoul Mapo Apartments in 1962, public housing began being constructed. In line with housing market revitalization, modern construction materials and housing equipment were developed, and from that point onward, earth disappeared as construction material, or it was used sparingly.

After the 1970's, government-led policies, such as the *Saemaeul* Movement (new community [village] movement), the 'Housing Improvement Project', and so on, brought about major changes to Korean society overall. In the construction area, traditional architecture, especially that of rural private houses, was deemed to be unhygienic and inconvenient, requiring urgent improvement. As infrastructure was renovated, traditional architecture disappeared rapidly in both urban and rural areas. Together with this, traditional earth architecture, especially rammed earth houses, nearly disappeared. During the worldwide energy crisis in the 1970's, other countries turned to earth material as a construction material, while Korean earth architecture rapidly disappeared.

The 1980's were marked by a real estate/housing market boom due to economic growth, and in the 1990's, the construction industry rapidly grew due to government's affordable housing policy. In this era, Korean construction was totally dominated by industrialization's development rationale leading to the establishment of mass production systems for industrial materials, such as cement, iron, glass, and so on, while traditional materials such as earth were relegated to be used rarely due to personal preference. Thus, the role and meaning of earth gradually became lost in the process of modernization in Korea and was generally forgotten.

3. MODERN APPROACH TO EARTH MATERIAL

Earth has traditionally been used as a major construction material in Korea, and modern earth architecture began in the 1980's in Korea. Seoul University Professor Kim Moon-Han attempted modern earth brick production, and architect Chung Gu-Yon elucidated the meaning of earth architecture in the article '*Clay architecture-Lost spirit*' (Review of Architecture and Building Science of the Architecture Institute of Korea, 1992.5) and introduced earth architecture factors. In the mid-1990's, centered around Hwang Hyezoo research team, modern earth architecture material technology was developed to be recognized as a new national technology through the Jang Yeong-Sil award¹⁵, new construction technology, new domestic technology, and so on. The 'Earth Room Apartment' was introduced to bring popular interest in earth, and based on such

¹⁵ The award was established in 1991 to honor and encourage engineers who accomplished a prominent job in technologically innovative activities of private companies, the result of which was successfully commercialized into a new product or process during the previous two years.

developments, earth architecture began in earnest from a modern perspective. Afterwards, many earth architecture houses were built, and companies dealing with earth architecture materials such as earth brick, earth plaster, earth board, etc. were established. However, this trend did not last long. Earth architecture was approached commercially only highlighting the health benefit aspects, and due to the small scale of companies, it was dependent on traditional methods with lack of R&D, and high quality earth architecture was not provided due to a lack of trained personnel. Thus, during the Korean economic crisis in the late 1990's, many earth-architecture-related companies shut down their operations.

However, architect Chung Gu-Yon continued to build structures made of earth, and other architects became interested in attempting to build modern earth architecture. Hwang Hyezo's research team eliminated distrust in earth architecture through research of earth materials at Mokpo University and proposed new alternatives from a material aspect and continued experimental construction. This became an opportunity to bring new recognition to earth architecture, and together with the recent environment and energy problems, it has brought back interest in earth architecture.

4. DEVELOPMENT AND RESEARCH OF MODERN EARTH MATERIAL

4.1. High-performance earth block

A high-performance earth block is based on the three principles of non-cement/non-organic/non-plastic and is created by physical/chemical/mechanical methods from the response principle between traditional earth and pozzolan from lime. A high-performance earth block has greater than 30N/mm^2 compressive strength, 5N/mm^2 tensile strength, and has exceptional freezing and thawing resistance, chemical resistance, and durability.

4.2. Earth concrete

Instead of cement for cement concrete, earth concrete uses an earth composite consisting of earth and stabilization. The earth composite is based on the same response principle as the high-performance earth block and the concrete has high liquidity with a hardening speed similar to that of cement, allowing it to be poured like concrete. Earth concrete has greater than 21N/mm^2 compressive strength, 4N/mm^2 tensile strength, and exceptional durability.

4.3. Earth panel

A earth panel is created by extrusion molding by mixing an earth composite consisting of earth and stabilization with sand and natural fiber. The interior of the material is fine and firm, allowing it to be used as both an internal and external material for buildings.

4.4. Rammed earth construction method

Studies were conducted on methods to overcome the drawbacks of earth ramming construction methods and traditional methods. Studies were done to develop precast rammed earth, which is rammed-earth wall sections of a certain size that are produced

in advance and may be stacked one-by-one like blocks. Stabilized rammed earth is a mixture of earth with a solidification material to reduce ramming time and increase strength.

4.5. Earth plaster

Scientific and systematic research was performed for earth particles to create an earth plaster as a construction material with an even quality. Traditional earth plaster does not have a uniform quality depending on the type of earth having no cracks, and it has a drawback of requiring multiple plaster layers to achieve a homogeneous surface. To overcome this problem, particle size analysis of earth by region and XRD, SEM, and other types of analysis were performed to improve earth plaster materials.

4.6. Earth Paint

Earth paint is made by traditional methods, using clay and natural adhesive such as seaweed glue. This earth paint can be used as paint for buildings, brushed on for protection of earth plaster surfaces, and sprayed using a spray coating machine.

4.7. Egg packing box (EP) construction method

The EP construction method is a new architecture method that creates an earth wall using egg packing boxes and earth that can be found in our daily lives. Without formwork or machine equipment, egg packing boxes and earth are alternately stacked to complete the wall structure; thus, the method allows anyone to handle the task.

4.8. Bio technology

Study was performed for cementation of earth material using microorganisms. This study produced calcium carbonate between the earth particles for cementation of earth and applied the formation principle of sedimentary rock.



a) Precast rammed earth



b) Earth concrete



c) Earth concrete



d) EP construction method e) High-performance earth block f) Earth panel



g) Earth spray

h) Earth plaster

i) Earth plaster

Fig. 1 - Development and research of modern earth material

5. STUDY ON UTILIZING EARTH MATERIAL CHARACTERISTIC

5.1. Environment

A study was performed to check the effect of earth material in architectural space on people. For example, model houses were made out of earth and cement for mice to live in, and then they were subjected to various tests. As a result of the experiment, the mice living in the cement model house showed unstable movement as time passed, lost weight, and some mice even died. On the other hand, mice living in the earth model house gained weight normally and most maintained their health. Through this study, living space made of earth proved beneficial to living organisms, and earth materials were found to provide a suitable space for people. Also, spaces consisting of earth materials were found to have a positive effect on people's safety and comfort. This was verified by research done on environmental characteristics such as heat, sound, moisture, and so on felt by people in earth architectural spaces.

5.2. Energy

A study was performed to find the optimal method to reduce energy expenditure through the implementation of earth architecture. Earth material can reduce energy expenditure by using thermal characteristic such as thermal and time lag or by using other natural materials. For example, when earth plaster was applied to a normal building space, energy efficiency rose by 10%, and if material such as rice-sheaf was used with earth, it proved to be an excellent material to reduce energy expenditure of the building. The ultimate goal of this study was to improve the deficiency of earth material to find the optimal method to implement low-energy earth architecture.

5.3. Design

This study utilizes the earth material technology in the previous study to propose a modern earth architecture model. Currently, to correspond to and comprehensively consider future architecture's key word of 'sustainable development,' new earth architecture models are constantly being attempted.

6. EVALUATION OF EARTH MATERIAL RESEARCH

In the previous section, Mokpo University's Earth Architecture Community of Terra (ACT)'s main study details were reported. Research on earth material is taking place on an extensive scale. From studies verifying the essential value of earth material to studies seeking suitable modern uses, various research attempts are being made. Regardless of achieving the purposes as intended by all completed studies, they hold various meanings and values.

High-performance earth blocks and earth concrete have been jointly developed with companies to be applied in real-life settings, and earth panels have been test produced in a factory. Newly developed solidification materials have been used to enhance the performance of earth materials, and studies have shown the hidden potential of earth as a construction material able to complete with equal standing with existing industrial materials in terms of color, design, economic efficiency, and so on. In particular, earth blocks are used not only as masonry bricks of inner and outer walls of buildings but also as floor blocks in sidewalks and roads. They can also be applied in all areas where embankment blocks, anchor-blocks, and secondary cement concretes are used. Also, earth concrete has been applied in test cases in actual buildings and is actively used in road pavements.

Earth plaster with stable quality is being produced and sold to companies, and while earth paint remains at a research stage, it is showing potential as a construction material. Also, traditional rammed earth construction methods are increasing in both interest and usage by architects and the general public. Although precast rammed earth and stabilized rammed earth have not been commercialized, it is research that can be expanded in application. The EP construction method, which has begun to be researched relatively recently, has been applied excellently in several housing projects, and bio technology using microorganisms is in the initial research stage.

The Architecture Community of Terra (ACT) is continuously engaging in various studies from energy, environment, and design perspectives to expand the use of earth materials. These studies aim to find advantages of earth as a construction material and to discover new functions to further raise the value of earth. Through comprehensive thinking, such study is a process of finding the optimal method for utilizing earth material, and instead of ceasing at the research level, application in real-life sites is attempted whenever possible.

Although many earth material studies are being executed, it is not enough when taking into consideration the entire construction area. For earth material to be used universally like cement concrete and to be accepted as a general construction material, more participation by researchers is required to carry out various studies.

7. FORECAST OF EARTH MATERIAL AS MODERN CONSTRUCTION MATERIAL

Currently, even though earth material has many advantages, it is yet unclear whether modern society will accept it. There is not only materialistic aspect but also people's

awareness, economic rationale, social value, coexistence issue with existing materials, etc. and various factors are complexly inter-related.

However, earth material is facing the greatest opportunity from a periodic standpoint. Already, all areas of society are striving for sustainable development, and earth material perfectly possesses all characteristics of sustainability. However, no matter how beneficial earth material is, it is useless if no one uses it. From this perspective, a modern interpretation of earth material is required, and earth material study is absolutely necessary to meet current needs and revitalize the earth architecture area.

Also, the fact that earth material study is continuing, even if the results are not being adopted immediately, should act as positive factors in the revitalization of the earth architecture area in the future.

8. CONCLUSION

As in other regions in the world, earth material has been replaced by other industrial materials through the industrialization process in Korea. In particular, intense development which was more rapid than in many other industrial countries and the government's affordable housing policy led to a more rapid demise of earth material.

However, in midst of the industrialization process, Korean sentiment and expectation for earth material have once again demanded earth to serve as construction material.

The opportune rise in interest in developing a sustainable society has increased interest in earth material. As a part of this wider societal trend, Mokpo University's Architecture Community of Terra (ACT) is making great effort to develop new earth material technology suitable for sustainable society and presenting various practical applications. This earth material study is not just stopping at research but is applying new developments on-site through commercialization. However, for earth material to be universally accepted as a modern construction material, more studies are necessary.

In addition, earth material contains our construction cultural identity including our spiritual and cultural values passed down from the past. Therefore, going forward, Korea's research on earth material should not only expand modern uses but also guard against development which narrowly focuses on performance or economic efficiency. Balanced research should progress toward seeking the genuine value of earth material from spiritual and cultural perspectives.

Endnote:

This study, which forms a part of the project, has been achieved with the support of national R&D project, which has been hosted by National Research Institute of Cultural Heritage of Cultural Heritage Administration. We express our gratitude to it.

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Curriculum

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BASIC EXPERIMENT BY USING MICROORGANISM AND EARTH MATERIAL

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world

Sub theme 2.1: Fundamental investigations on the material, research and development (R&D)

Keyword: Microorganism, sporosarcina pasteurii, architecture materials

Abstract:

Recently, eco-friendly ideas have come to be considered as an important global issue, and as one way of promoting an eco-friendly outlook, various applications that utilize earth as a building material are being studied and are moving into commercialization in these days. However, there are limitations in the strength and durability of earth, and so materials that use such processes as the pozzolan reaction, like cement and lime, are being commercialized to improve the strength and durability of earth. However, to approach a solution that considers the problems of the earth's environment, via reducing CO₂, etc., there have been efforts to reduce the use of that. Especially, various experiments have been conducted that use microorganisms in complexation studies. However, studies conducted using earth and microorganisms have been very rare and only a few countries have performed such studies. Thus, this study is a basic study that will look at strength revelation using earth, microorganisms and lime; our purpose herein is to inquire about the effects of microorganisms on the strength of earth binding materials and to consider the change of strength according to a variety of composition conditions. Especially, it seems that to apply earth in various uses as a secure construction material, it will be necessary to ensure the economic feasibility by not only reducing the energy consumption and the impact on the environment but also by using this experiment's results to decrease carbon emissions.

1. INTRODUCTION

Activities to build living spaces for people, such as apartments and houses, and to build social infrastructure such as roads, are called the construction industry. Construction materials indicate the materials required for vitalizing the construction industry. The domestic construction industry makes up 18% of the Korean economy, although the actual impact is higher when including the industry's indirect effects. This construction industry area's final energy usage rate is 21.2% of the nation's total energy usage, while the amount of CO₂ created by construction materials is 13% of the nation's output, and can even be higher when including other construction industries. In particular, with the view of a low-carbon, green-growth policy, interest in construction materials that allow for carbon reduction is increasing in Korea and there is high interest in future environmentally-friendly construction materials. Given such interest, and because the usage of environment-friendly materials is mandatory not only according to recent national policy but also for construction-related practitioners, research is being concentrated in related areas. In these areas, interest in earth as a building material is growing higher by the day, and experiments that consider earth as a building material have been conducted recently; however, the commercialization level is still not that high. In particular, even though earth-based construction materials are low-carbon materials, the general public considers this material inefficient in the actual usage aspect due to the field's high wages and high time expenditure. To counter these problems it is necessary to increase the strength of existing earth-based building materials and to improve the lime aspect. As a result, some countries have been engaging in various research studies to commercialize the use of microorganisms to increase the utilization value of earth-based building materials in many ways, especially by merging with other industry areas.

To analyze earth's compressive strength, this study uses earth, lime, and a microorganism that can conserve resources and energy. SEM, XRD, etc., are used to examine the interactive reaction in order to validate each material's potential as a construction material. Also, based on this study, basic data is provided for commercialization in the construction field.

2. MORTAR TEST USING EARTH, LIME AND MICROORGANISM

2.1 Test Plan

This study mixed earth, lime, and microorganism to examine the reactions between earth powder and microorganisms, micro-filled earth and microorganisms, sand and microorganisms, earth and lime and microorganisms, and earth and high-performance lime and microorganisms. Depending on the ratio of each, the compressive strength, and SEM, and XRD data are used to explore the material characteristics.

Test Variables	Level	Remarks
Earth	Earth powder, earth, sand	Earth: Clay Max Co., Ltd.
Lime	Hydrated lime, high-performance lime	High-performance lime: Clay Max Co., Ltd.
Microorganism Culture Fluid	Sporosarcina pasteurii	Purchased from KBRC

Table 1 - Test variables and level

2.2 Test Material

2.2.1 Microorganism (*Sporosarcina pasteurii*)

The microorganisms used in the test were purchased from the Korea Biological Resource Center (KBRC) located in Daejeon; samples had a badge number of 285, badge name of Bacillus Pasteurii Medium, bacteria stated name of Sporosarcina pasteurii with cultivation temperature of 30°C and lot type of Plate state. To cultivate this microorganism, the following conditions were used: 10 g trypticase, 5 g yeast extract, 4.5 g tricine, 5 g (NH₄)₂SO₄, 2 g glutamic acid and 10 g urea liter⁻¹, all of which were filter-sterilized. For the solid medium, a final concentration of 1.6% agar autoclaved separately was added later. Growth conditions of broth cultures for calcite precipitation in Urea-CaCl₂ medium were the same as those described earlier. All cultures were grown at 30°C.

2.2.2 Earth powder

Clay produced in Korea and earth powder consisting of more than 90% silt ingredients in an overdry state was used.

Particle size (μm)	150	75	31	2	0.007
Cumulative Residual Rate (%)	0	10	33.5	90	100

Table 2 - Test variables and level

2.2.3 Earth

Earth plaster produced by Clay Max Co., Ltd. was used.

2.2.4 Sand

Sea sand with water content of 2% collected from the Mokpo region was used.

2.2.5 Hydrated Lime

As hydrated lime (200~325mesh) suitable for grade 1 KSL 9501 industrial standard, quicklime was stirred with water and then ground before using.

2.2.6 High-performance lime

The lime complex used in this experiment was a mix manufactured by company C from Korea; the relative weight was 2.74, the fineness was 5969 cm^2/g , and the ignition loss was 2.5%.

Category	SiO ₂	Al ₂ O ₃	CaO	MgO	SO ₃	LOI
Content (%)	26.10	13.31	45.51	6.13	6.71	2.24
Type					HPL	
Specific gravity (g/cm^3)					2.74	
Blain fineness (cm^2/g)					3,483	
Ignition loss (%)					0.09	
Initial setting time (min)					209	
Final setting time (min)					609	
Compressive Strength (MPa)	7 D				11.1	
	14 D				21.9	
	28 D				36.6	

Table 3 - Properties of high-performance lime

3. TEST RESULTS

3.1 Compressive Strength from Earth, Lime, and Microorganism Reaction

As to the results for compressive strength, in the case of earth powder, the powder was not molded correctly in the initial stages and so the strength was not measured or compared to mixtures with water and microorganism; as a result, it was confirmed that there was no special characteristic from a strength aspect. Also, in the case of general earth, no reaction was observed when the microorganism was added; there seemed to be an increase in compressive strength when lime was added. When sand was added, there was almost no reaction with the microorganism. Consequently, the earth and microorganism did not show a large reaction when mixed independently. Also, in the case in which lime was added, adding the microorganism appeared to increase the compressive strength slightly more than simply mixing with water. In particular, in the case in which high-performance lime was added, the microorganism reaction for 28-day concrete led to an increase of compressive strength of greater than 2MPa. The test results show that it is more effective from a strength aspect when lime is partially added to the earth instead of using an independent reaction between the microorganism and earth.

(Curing Room Temperature : 23±1 °C, Moisture : 60%)

Category	Earth Powder	Earth	Sand	Hydrated Lime	High-Performance Lime	Water	Culture Fluid	Compressive Strength (MPa)		
								3 Days	7 Days	28 Days
CW	100					50		-	1.2	1.8
CM	100						50	-	-	1.4
EW		100				40		0.8	1.2	1.3
EM		100					40	0.7	1.1	1.1
SW			100			10		0.2	0.3	0.5
SM			100				10	0.4	0.5	0.8
ELM		100		20			50	1.2	2.3	3.9
CLW	100			20		50		0.5	2.0	2.6 (Surface Crack)
CLM	100			20			50	1.3	2.6	3.2 (Surface Crack)
EHLW		100			20	50		6.2	10.8	13.5
EHLM		100			20		50	7.3	12.7	15.9

Table 4 - Compressive strength according to mixture ratio

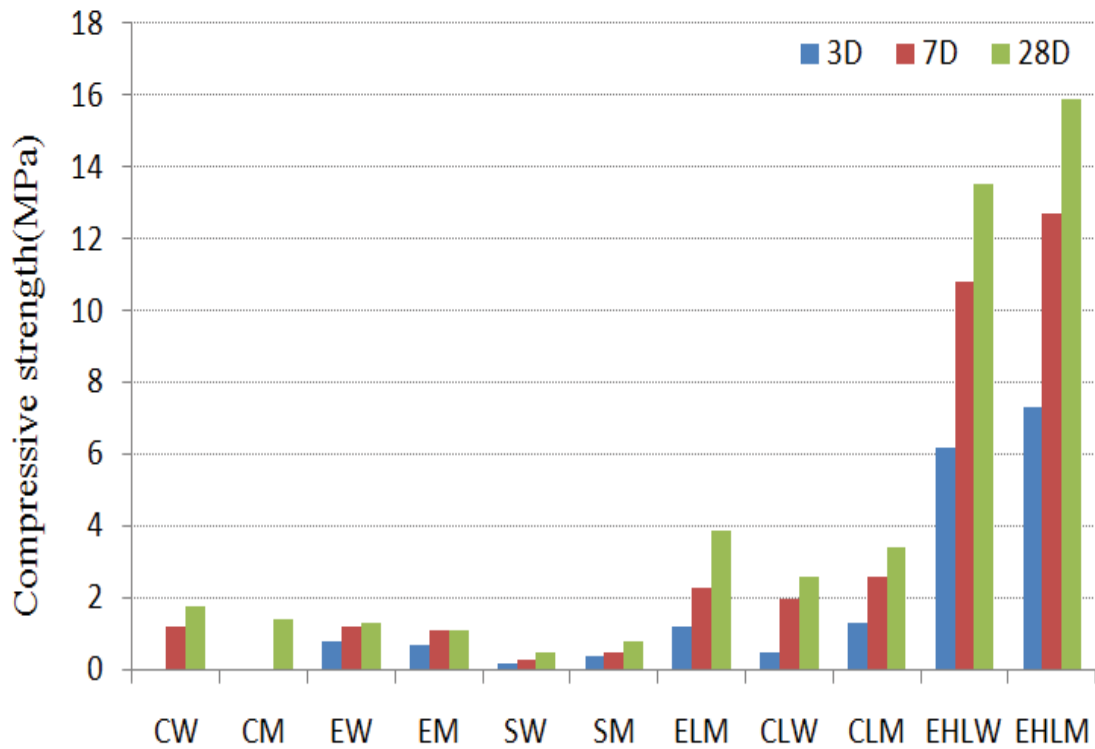


Fig. 1- Compressive strength according to mixture ratio

3.2 SEM Analysis

According to the SEM measurement results, when only earth and lime were added, needle-like or round, long-shaped material can be seen; however, when the microorganism was added, many round shapes could be seen attached to the earth surface. It cannot be verified that these shapes are microorganisms, but there is definitely a difference in this sample compared to the sample without the addition of microorganism.

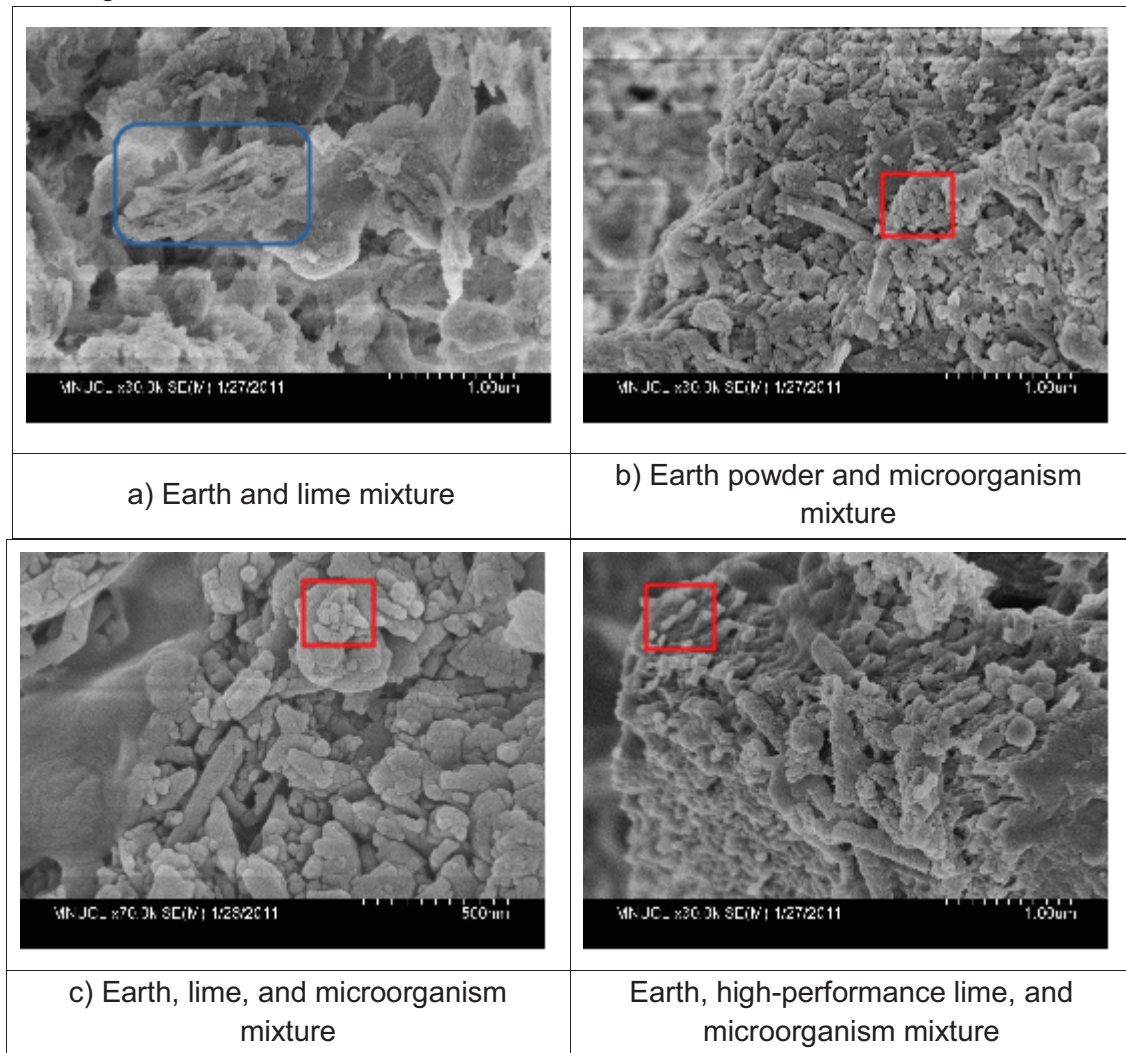


Fig. 2 - SEM measurement results

3.3 XRF Analysis

To examine the chemical compound created by the reaction between earth and the microorganism, XRD analysis was performed and showed that, compared to the case in which lime was added, the Al_2O_3 and SiO_2 ratios were relatively higher and CaCO_3 barely formed when only earth and the microorganism culture fluid were added. Also, compared to the case in which the microorganism was added, CaCO_3 was relatively

higher and Al₂O₃ and SiO₂ formed at a low level when earth powder and hydrated lime were mixed without adding microorganism. As a result of these tests, calcium carbonate was found not to form when just earth and water were mixed, and the low formation rate of CaCO₃ when hydrated lime was added seems to show that the relatively low rate was caused by the lime's high pH. In order for the microorganism to create calcium carbonate, the mix rate of lime has been determined to be important. Since XRD analysis requires the sample condition to be in powder form, this test was not used to test the earth, high-performance lime, or microorganism sample due to sample damage concerns.

Category	Earth Powder	Earth	Hydrated Lime	Culture Fluid	Water	CaCO ₃	MgO	Al ₂ O ₃	SiO ₂	K ₂ O	Fe ₂ O ₃
1	100		-	60		0.6	0.7	37.8	50.6	0.8	7.7
2	-	100	20	60		28.7	1.4	19.2	42.5	2.4	4.6
3	100	-	20	60	-	28.0	1.4	19.0	42.8	2.4	4.5
4	100	-	20	-	60	59.2	2.1	9.9	21.5	1.4	4.0

Table 5 - Earth, hydrated lime, and microorganism reaction by XRD

4. CONCLUSION

For the purpose of checking the potential of earth as a construction material, compressive strength, SEM, and XRD test results using earth, lime, and microorganism were used to derive the following conclusions.

(1) Through the results of compressive strength testing, it can be seen that the mixture of earth and microorganism did not show any special reaction. However, when lime was added, there was a slight effect from a strength aspect due to the microorganism. If future tests are performed by specifying the ratio of earth and lime, better results are expected.

(2) As a result of SEM analysis, it was determined that, unlike the case of samples in which microorganism was not added, round-shaped matter was attached to the particle surface in samples to which the microorganism was added.

(3) As a result of XRD analysis, it was determined that calcium carbonate did not form at all when earth powder was mixed with microorganism; however, when hydrated lime was added, calcium carbonate was found to form at a lower rate when the microorganism was added compared to when it was not added. This shows that the microorganism reacted partially to the earth due to calcium carbonate precipitation.

As a result of this study, no prominent strength increase was found to occur due to the addition of the microorganism; however, in the future, depending on the appropriate

mixture of earth, lime, and microorganism and the cultivation conditions of the microorganism, better research results are expected.

Endnote:

This study, which forms a part of the project, has been achieved with the support of national R&D project, which has been hosted by National Research Institute of Cultural Heritage of Cultural Heritage Administration. We express our gratitude to it.

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Curriculum

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STUDY ON HIGH STRENGTHENING OF AN EARTH WALL USING EARTH AND HIGH-PERFORMANCE LIME

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Theme 2: Current state and future prospects for earthen architecture in Asia and other regions of the world

Sub theme 2.1. (ST.2.1.) : Fundamental investigations on earthen materials and research and development (R&D);

Keywords: optimal micro-filler, High-performance Lime, Rammed Earth Construction Method, Earth Concrete Method

Abstract: This study seems to high strengthen an earth wall using an earth and lime composite. Earth collected from our surroundings was used while an optimum micro-filler effect reduced the content of particles lower than silt common in earth. To increase strength, high-performance lime was used and the rammed earth construction method and Earth Concrete method was applied. Test results showed that both construction methods produced a compressive strength of greater than 21 MPa. In particular, the Earth Concrete method secured liquidity and compressive strength sufficient for mechanized construction. Such results are expected to be used in the revitalization and modernization of earth architecture in Korea.

1. INTRODUCTION

Earth architecture activities decreased greatly before and after the Saemaeul Movement period in the 1970s in Korea. Due to the prevalence of cement, many earth buildings were replaced by buildings constructed from cement materials. Cement was perceived as a better material having higher strength, more convenience, and more durability compared to earth and rapidly spread as the preferred material. Therefore, in the past 30 years, earth architecture became a rare construction form found only in cultural assets or in rural areas. However, as a recent preference for environment-friendly construction materials increase, interest in earth architecture is rising. Unfortunately, many technologies for earth architecture that were passed down from past generations have been forgotten.

Currently, earth architecture in Korea is being used in various construction methods. The core wall construction method of traditional Korean houses, the rammed earth construction method, the 'almae' earth construction method, the earth bag construction method, and the earth plaster construction method are the main methods that are being used. Such construction methods use only earth or use lime or cement mixes. In the past, lime was used in limited areas where building foundations, castle walls, or graves required high strength in 'samhwato' or 'sammoolhoe' forms. However, achieving the necessary strength required a very long time, so there was a limit to its application in modern buildings. To be used as construction structure materials according to Korean architecture standards, strength must be secured within 7 or 28 days. Because of this limitation, its use is limited to small buildings or non-bearing walls. Therefore, as a basic investigation for the popularization of earth architecture, this study seeks to realize a high strength earth wall using earth, which can be easily acquired, and high-performance lime, which improves upon the lime used in the past. The progress of the study is detailed in the following table.

Table 1 - Progress of Study

Category	Details
Part 1	Analysis of High-Performance Lime Characteristics
Part 2	Earth Mixture Test by Applying High-Performance Lime to General Earth
Part 3	High Strength Earth Mixture Test Using the Optimum Micro-filler Effect and High-Performance Lime

2. TEST OF HIGH-PERFORMANCE LIME

Before using high-performance lime, its characteristics were reviewed. High-performance lime using the pozzolan reaction of lime where non-organic matter contributing to strength was added. It showed a higher strength than the hydrated lime or quicklime used generally in architecture. In this test, its physical and chemical properties were compared to commonly used binding material in cement.

2.1 Characteristic of high-performance lime

The results of the comparison of chemical properties between generally used Portland Cement produced by Korean company S and high-performance lime is presented in the following chart. SiO₂ content was similar at about 26% and 27%. Al₂O₃, MgO, and SO₃ content was very high for high-performance lime. CaO and Fe₂O₃ content was higher for Portland Cement.

Table 2 - Comparison of Chemical Properties

Category	SiO ₂	Al ₂ O ₃	CaO	MgO	Fe ₂ O ₃	SO ₃	LOI
Portland Cement	27.2	5.4	62.0	2.7	2.7	-	-
High-Performance Lime	26.10	13.31	45.51	6.13	0.6	6.71	1.64
Hydrated Lime	1.2	0.6	90.4	5.3	1.2	0.9	0.4

2.2 setting and hardening test

The setting and hardening test results showed that the setting time of the initial setting was 350 minutes, which was a slower reaction time than cement. In this case, there is an advantage of securing a longer work time after mixture. From the initial setting to the final setting, the time for high-performance lime was shorter at 150 minutes while it was 197 minutes for cement.

Table 3 - Setting / Hardening Test Results

Category	Cement	High-Performance Lime
Initial Setting (Minutes)	255	350
Final Setting (Minutes)	452	500

2.3 compressive strength by age

The compressive strength by age test results are shown in Table 4. According to the regulations for normal Portland Cement by the Korea Industrial Standard (KS), strengths required by cement by age are 3 days 12.5 MPa, 7 days 22.5 MPa, and 28 days 42.5 MPa. However, the lime mixture fell below the level of the KS standard. At an age of 3 days, 9.9 MPa was not too different from the KS but at an age of 7 days and 28 days, performance fell more than 50% below the standard.

Table 4 - Compressive Strength by Age

Category		Cement (Company S)	High-Performance Lime	KS First-Class
Compressive Strength by Age (N/mm ²)	3 Days	22	9.9	Above 12.5
	7 Days	33	11.2	Above 22.5
	28 Days	41	19.3	Above 42.5

2.4 SEM and XRD Fig s

The SEM measurement result showed crystallization that included partial needle-like structures for high-performance lime at an age of 7 days. In strength reaction of high-performance lime, a needle-like structure ettringite reaction formed and a pozzolan reaction occurred; thus, stable crystallization together with a need-like structure is considered to have occurred.

High-performance lime was made into a paste and the XRD pattern was measured at an age of 28 days. Measurement results showed that various chemical compounds were formed due to the reaction of Ca^{2+} ions in the lime. The major compound elements were Si and Al and were determined to have been formed by lime and pozzolan reaction.

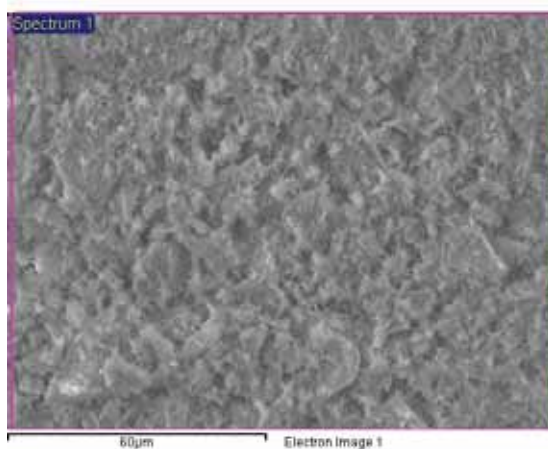


Fig. 1 - High-Performance Lime SEM

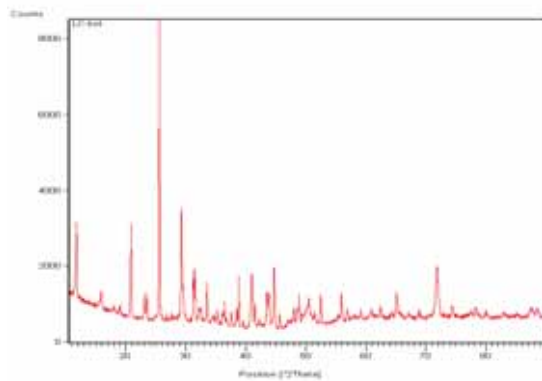


Fig. 2 - High-Performance Lime XRD Pattern

3. EARTH MIXTURE TEST APPLYING HIGH-PERFORMANCE LIME TO GENERAL EARTH

The test used two methods: the rammed earth construction method where liquidity was small and the Earth Concrete method where liquidity was large. In the rammed earth construction method the texture was hardened, similar to the normal rammed earth construction method but the liquidity was improved to ease ramming. In the Earth Concrete method the liquidity was similar to existing cement concrete and the goal was to form an integrated wall. Test variable and level used three levels for a unit binder weight of 250, 350, 450, two levels for a unit binder weight of 250 depending on the mix consistency of W/B, three levels for a unit binder weight of 350 and 450, and the admixture was set at one level of 2%.

Table 5 - Mixture Table

Category		W/B (%)	Unit Quantity	Unit Binder Weight	Earth	Air	Admixture	Category		W/B (%)	Unit Quantity	Unit Binder Weight	Earth	Air	Admixture
RH1	Mix proportion by volume (t)	120	300	91	579	30	2%	LH1	Mix proportion by volume (t)	190	475	91	404	30	2%
	Unit quantity (kg/m ³)			250	1441				Unit quantity (kg/m ³)			250	1005		
RH2	Mix proportion by volume (t)	130	325	91	554	30	2%	LH2	Mix proportion by volume (t)	200	500	91	379	30	2%
	Unit quantity (kg/m ³)			250	1379				Unit quantity (kg/m ³)			250	943		
RH3	Mix proportion by volume (t)	80	280	128	562	30	2%	LH3	Mix proportion by volume (t)	130	455	128	387	30	2%
	Unit quantity (kg/m ³)			350	1400				Unit quantity (kg/m ³)			350	964		
RH4	Mix proportion by volume (t)	90	315	128	527	30	2%	LH4	Mix proportion by volume (t)	140	490	128	352	30	2%
	Unit quantity (kg/m ³)			350	1313				Unit quantity (kg/m ³)			350	877		
RH5	Mix proportion by volume (t)	100	350	128	492	30	2%	LH5	Mix proportion by volume (t)	150	525	128	317	30	2%
	Unit quantity (kg/m ³)			350	1226				Unit quantity (kg/m ³)			350	790		
RH6	Mix proportion by volume (t)	60	270	164	536	30	2%	LH6	Mix proportion by volume (t)	100	450	164	356	30	2%
	Unit quantity (kg/m ³)			450	1334				Unit quantity (kg/m ³)			450	886		
RH7	Mix proportion by volume (t)	70	315	164	491	30	2%	LH7	Mix proportion by volume (t)	110	495	164	311	30	2%
	Unit quantity (kg/m ³)			450	1222				Unit quantity (kg/m ³)			450	774		
RH8	Mix proportion by volume (t)	80	360	164	446	30	2%	LH8	Mix proportion by volume (t)	120	540	164	266	30	2%
	Unit quantity (kg/m ³)			450	1110				Unit quantity (kg/m ³)			450	662		

3.1 Test Material

The composite used high-performance lime as reviewed in Chapter 2 and the earth was collected from a test subject area near Jeonnam Muan-gun Cheonggye-myun and was then filtered through an 8 mm sieve and dried to an air dry condition and its physical chemical properties are presented in Table 6. Since there are many particles smaller than silt, a large quantity of water is required for mixing, and as strength loss is expected after curing, a water-reducing agent is added and its physical properties are presented in Table 7.

Table 6 - Muan Earth's Physical Chemical Properties

Water Content (%)		Weight		Porosity (%)			Unit Dimensional Weight (kg/l)	
2.66		2.49		50.90			1.123	
SiO ₂	Al ₂ O ₃	Fe ₂ O ₃		CaO	MgO	K ₂ O	LOI	
43.26	13.23	5.86		8.41	6.5	2.15	18.16	
Category		clay			silt		sand	
Water Content (%)		5.1			51.32		43.58	

Table 7 - High-Performance Water-Reducing Agent's Physical Properties

Type of Admixture	Type	Color	Main Ingredient	Toxicity	PH	Weight
Naphthalene	Liquid	Dark Brown	Copolymer	None	8-10	1.05±0.02

3.2 Test Method

Different molding methods were used to make the test structures for the rammed earth and Earth Concrete methods.

Since the liquidity was low for the rammed earth construction method, an air compressor and rammer was used to ram and lessen the pore space. On the Ø10×20 concrete mold, an M-18 rammer was used to ram for 3 seconds with the strength of 0.5 MPa and ramming was divided into three levels. The ramming height was 3 cm for the lower part, 12 cm for the center part, and 5 cm for the upper part. For the Earth Concrete method, on the Ø10×20 concrete mold, a test structure was made according to the method of producing concrete samples in the KS F 2425 test laboratory. Curing was performed in a 2m×2m×1.8m space at a temperature of 23±2°C while maintaining a moisture of 70±2%.

For measurement of the test structures, the compressive strengths were measured by the KS F 2405 concrete Compressive Strength test method at age 1 day, 3 days, 7 days, 28 days, 56 days, and 98 days for both the rammed earth construction method and the Earth Concrete method. For the Earth Concrete method with good liquidity, the KS F 2402 slump test method was used to measure the liquidity and the air quantity was measured by a dry process method based on an air quantity method of KS F 2449 unhardened concrete measurement.

3.3 Test Result

As a result of measuring the compressive strength of the rammed earth construction method, the W/B had a bigger effect on the compressive strength than the unit binder weight. There was no big difference at unit binder weights of 350 and 450, but for unit binder weights of 250 and 450, the compressive strength differences were more significant depending on the W/B. Because a large quantity of mixture water is required when the mixture contains a large amount of powder, if the mixture water is small, the strength manifestation reaction does not occur sufficiently. In addition, when the unit binder weight increases, the powder amount increases in the mixture to make such a phenomenon more prominent.

For a compressive strength increase rate depending on age, with a unit binder weight of 250, the compressive strength increase rate was low, but as the unit binder weight grew and after an age of 28 days, the compressive strength increase rate generally decreased.

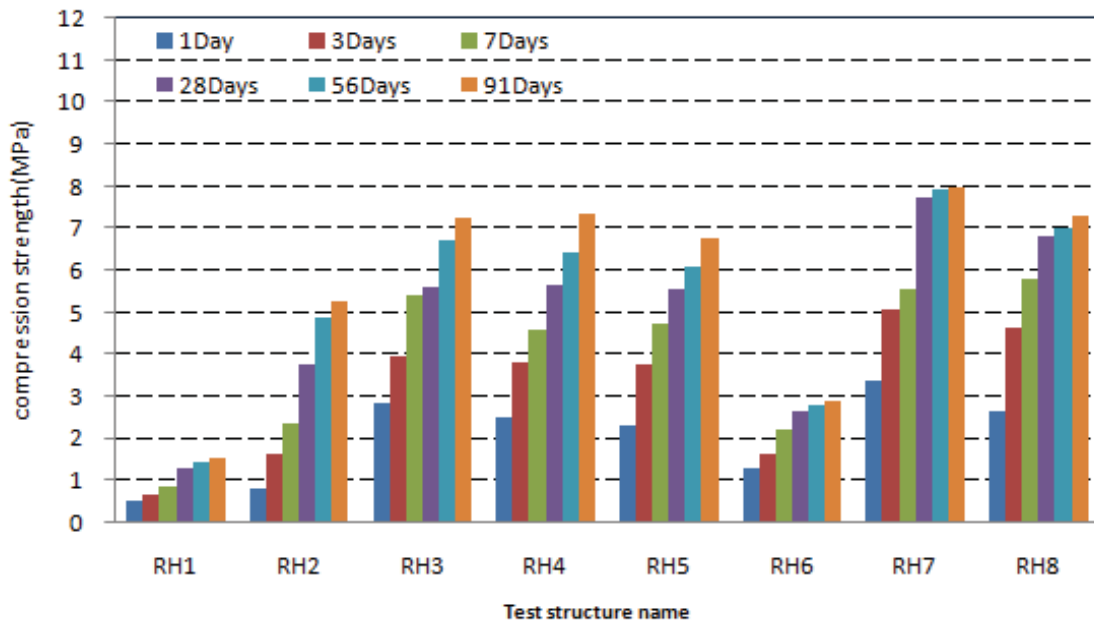


Fig. 3 - Compressive Strength Result for the Rammed Earth Construction Method

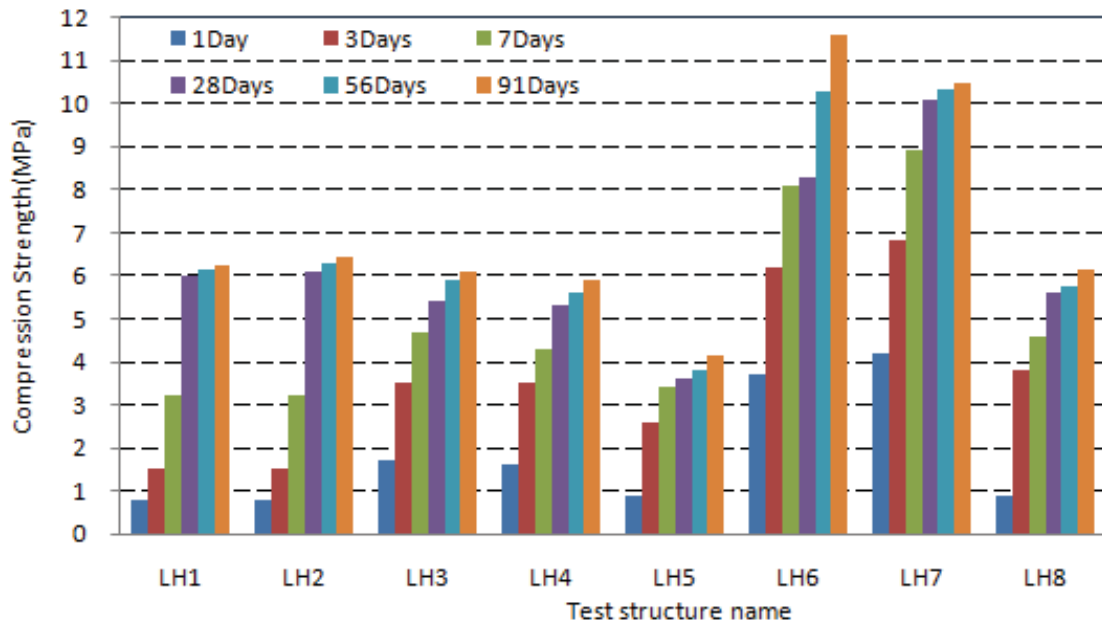


Fig. 4 - Compressive Strength by Age of Earth Concrete Method

The compressive strength measurement result for the Earth Concrete method is shown in Fig 4. A unit binder weight increase generally led to an increase of the compressive strength, but when the unit binder weight was 350, it did not have an appropriate amount of W/B and the strength was consequently low. At the greatest compressive strength was at age 28 days with a unit binder weight of 450 and W/B 110% with a result of 10.1 MPa and the slump value at this time was 127 mm to meet the appropriate liquidity, and the air quantity was 4% satisfying an appropriate level. However, the strongest strength of the test structure did not satisfy the required

strength for structures of Korean building construction. However, it was enough strength for earth houses being built currently and low-rise buildings.

For the rate of compressive strength development by age in the Earth Concrete method, in the case of unit binder weights of 350 and 450, at age 7 it was most developed, more than 80% strength, showing a faster development than in cement concrete. Excluding LH6, all the mixtures showed a low increase rate after the age of 28 days showing a different aspect than general lime.

Table 8 - Slump and Air Quantity Measurement Result of the Earth Concrete Method

Test Number	Unit Binder Weight (kg/m ³)	W/B (%)	Air Quantity (%)	Slump (mm)
LH1	250	190	8	0
LH2	250	200	5	45
LH3	350	130	7	0
LH4	350	140	6.3	84
LH5	350	150	5.5	292
LH6	450	100	5.5	0
LH7	450	110	4	127
LH8	450	120	1.15	255

The Earth Concrete method required more W/B than the rammed earth construction method for securing liquidity and lowering the unit binder weight, and a higher W/B was required. Change in the air quantity depending on an increase or decrease of W/B was small but the slump value change was very big. We expect that this was due to the fact that the earth used in the mixture contained a large number of particles smaller than silt.

3.4 Conclusion

As a result of mixing earth and high-performance lime and applying the rammed earth and Earth Concrete methods, both construction methods failed to provide enough compressive strength to satisfy the Korean usage standard for construction materials. However, it secured strength greater than the level that is being used in current earth architecture.

4. HIGH STRENGTH EARTH MIXTURE TEST USING OPTIMUM MICRO-FILLER EFFECT AND HIGH-PERFORMANCE LIME

In this test, the particle size of earth containing many powder particles smaller than silt was adjusted according to the optimum micro-filler effect and the mixture was mixed with high-performance lime to create a high strength earth mixture.

The rammed earth construction method and the Earth Concrete method were applied to the earth mixture and the production of the test structures were the same. Before mixing, an optimal micro-filler test was performed to determine the optimal micro-filler ratio of earth and sand. The optimal micro-filler ratio found was mixed with high-performance lime to perform high strength earth mixture test. The mixture used three

levels for unit binder weights of 250, 350, 450 and three levels for W/B depending on each unit binder weight. To reduce the unit quantity, a 2% admixture was added. For the high strength earth mixture measurement method, compressive strengths were measured by the age of 1 day, 3 days, 7 days, and 28 days and in the case of the Earth Concrete method, the air quantity and slump were measured.

Table 9 - Earth Wall Mixture Table Using High-Performance Lime

Category		W/B(%)	Unit Quantity	Unit Binder Weight	Earth	Sand	Air	Admixture	Category		W/B(%)	Unit Quantity	Unit Binder Weight	Earth	Sand	Air	Admixture
LO1	Mix proportion by volume (t)	100	250	92.6	107	521	30	2%	RO1	Mix proportion by volume (t)	60	150	92.6	129	629	30	2%
	Unit quantity (kg/m ³)			250	266	1354				Unit quantity (kg/m ³)			250	321	1634		
LO2	Mix proportion by volume (t)	105	263	92.6	105	510	30	2%	RO2	Mix proportion by volume (t)	70	175	92.6	125	608	30	2%
	Unit quantity (kg/m ³)			250	260	1327				Unit quantity (kg/m ³)			250	310	1581		
LO3	Mix proportion by volume (t)	110	275	92.6	102	500	30	2%	RO3	Mix proportion by volume (t)	80	200	92.6	120	587	30	2%
	Unit quantity (kg/m ³)			250	255	1300				Unit quantity (kg/m ³)			250	299	1527		
LO4	Mix proportion by volume (t)	50	175	129.6	113	552	30	2%	RO4	Mix proportion by volume (t)	40	140	129.6	124	606	30	2%
	Unit quantity (kg/m ³)			350	282	1436				Unit quantity (kg/m ³)			350	309	1576		
LO5	Mix proportion by volume (t)	55	193	129.6	110	538	30	2%	RO5	Mix proportion by volume (t)	50	175	129.6	118	577	30	2%
	Unit quantity (kg/m ³)			350	274	1398				Unit quantity (kg/m ³)			350	294	1500		
LO6	Mix proportion by volume (t)	60	210	129.6	107	523	30	2%	RO6	Mix proportion by volume (t)	60	210	129.6	112	548	30	2%
	Unit quantity (kg/m ³)			350	267	1360				Unit quantity (kg/m ³)			350	280	1425		
LO7	Mix proportion by volume (t)	55	248	166.7	95	461	30	2%	RO7	Mix proportion by volume (t)	30	135	166.7	119	580	30	2%
	Unit quantity (kg/m ³)			450	235	1199				Unit quantity (kg/m ³)			450	296	1507		
LO8	Mix proportion by volume (t)	60	270	166.7	91	443	30	2%	RO8	Mix proportion by volume (t)	40	180	166.7	111	542	30	2%
	Unit quantity (kg/m ³)			450	226	1151				Unit quantity (kg/m ³)			450	277	1410		
LO9	Mix proportion by volume (t)	65	293	166.7	87	405	30	2%	RO9	Mix proportion by volume (t)	50	225	166.7	103	505	30	2%
	Unit quantity (kg/m ³)			450	216	1102				Unit quantity (kg/m ³)			450	258	1313		

4.1 Test Material

The same materials as in the previous test, that is, earth, high-performance lime, and a high-performance water-reducing agent, were used, and the sand was sea sand collected from the sea in front of Incheon. The physical properties of the sand are presented in the Table 10.

Table 10 - Physical Properties of Sand

Maximum Particle Diameter (mm)	Weight	Fineness Modulus (FM)	Absorption Rate (%)	Solid Volume Percentage (%)	Unit Volume Weight (kg/m ³)
5	2.6	2.47	0.22	57.7	1.5

4.2 Test Method

The optimal micro-filler test mixed earth dried to an air dry condition and sand by volume ratio, and each weight was mixed to be packed and put in 30 L containers 3 times. Each mixture weight was measured and the heaviest mixture was selected as the optimal micro-filler mixture with the smallest pore space. Since particles are clustered in earth, it was broken down finely using a rubber hammer before the test. The compressive strength, slump, and air quantity measurements were carried out in the same way as in the previous test.

4.3 Test Result

As a result of the optimal micro-filler test, the optimal micro-filler ratio of earth and sand was found to be earth : sand = 17:83. Fig. 5 shows the particle size distribution curve of the earth, sand, and optimal micro-filler mixture before and after optimal micro-filling. In the optimal micro-filler mixture, particles smaller than silt were 10.35% of the total weight and it decreased about 40% compared to when only using earth.

Fig. 6 shows the analysis and comparison of the earth rammed aggregate particle size range; cement concrete small aggregate range, and optimal micro-filler mixture particles.

In this test, earth from the optimal micro-filler mixture was tested by the rammed earth construction method and the Earth Concrete method, and it was compared to the rammed earth aggregate particle size range, which was the base of the earth architecture and cement concrete small aggregate particle size range.

The optimal micro-filler mixture showed a very low number of particles below 0.002 mm compared to the rammed earth standard, and for silt and sand particles, it did not deviate from the minimum standard of rammed earth. In earth architecture, lime is used instead of insufficient clay but a lime composite was used in this experiment. When compared with cement small aggregate particles, it satisfied the standard particle range for particles greater than 0.015 mm, and for particles under 0.074 mm, it was not used in cement and appeared about 10% higher. We expect that a relatively higher W/B may be required to secure liquidity.

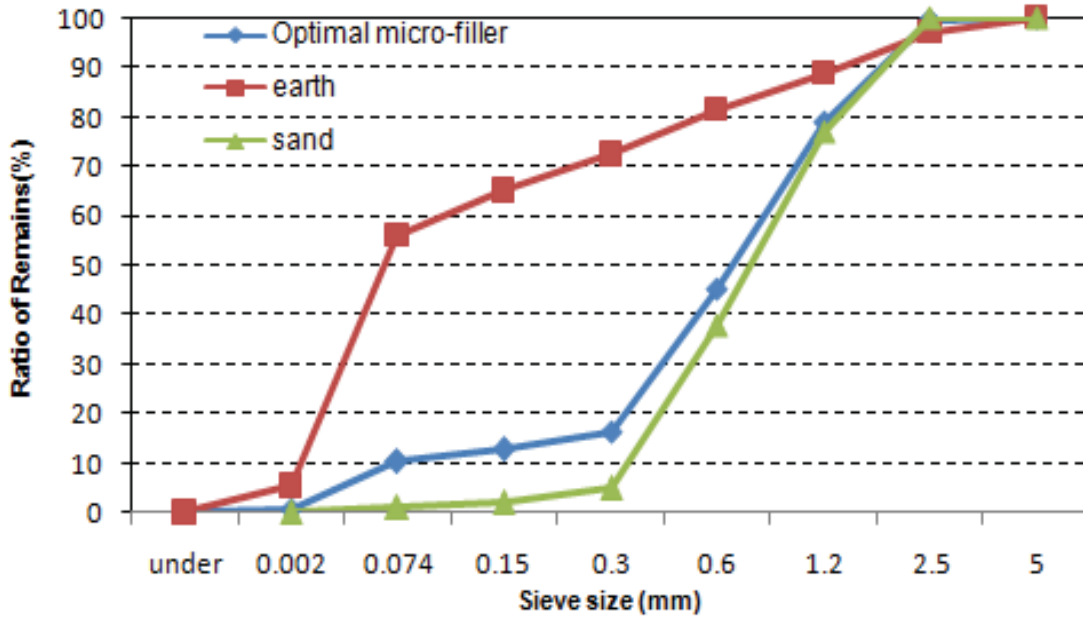


Fig. 5 - Particle Distribution Curve of Optimal Micro-Filler Mixture

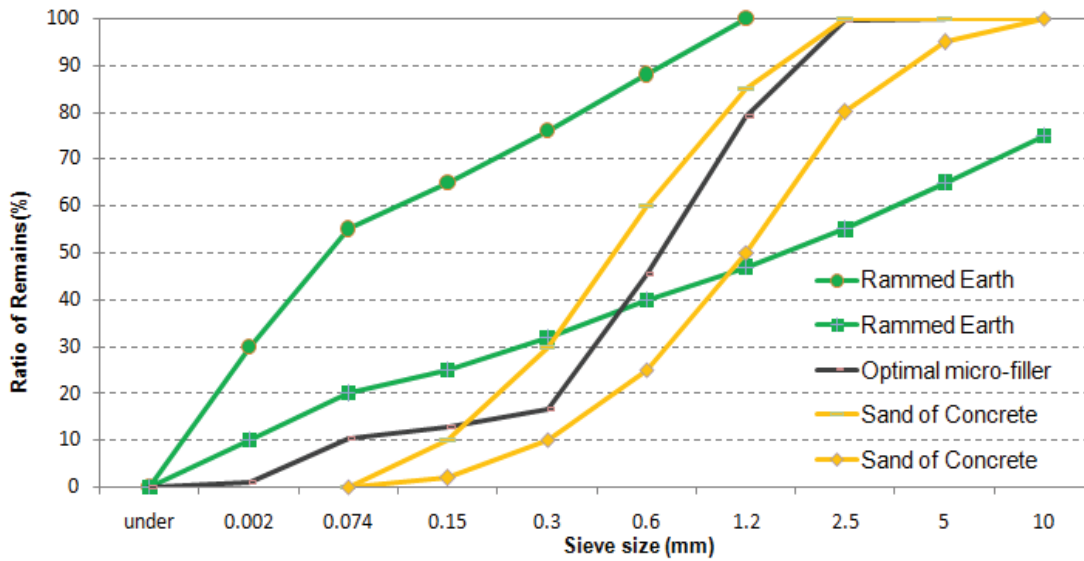


Fig. 6 - Particle Comparison by the Construction Method

The compressive strength measurement result by age of the rammed earth construction method is shown Fig. 7.

An increase in the unit binder weight generally leads to an increase in compressive strength. As the W/B increases, the compressive strength increases as well but once the W/B reaches a certain level, it gradually decreases.

At the age of 28 days, a unit binder weight of 450, and a W/B of 40%, the highest compressive strength of 29.2 MPa was recorded. With the compressive strength exceeding 21 MPa, a W/B of 50% and 60% were seen at a unit binder weight of 350 and a W/B of 40% and 50% were seen at a unit binder weight of 450. Excluding high-rises, in terms of strength this mixture could be used in general buildings.

A characteristic of the rammed earth construction method is the natural hardened texture of the wall. In general rammed earth, formwork is demolded right after the rammed earth task. If the formwork demolding period is delayed, earth sticks to the formwork to dig into the surface. However, in this test, since liquidity was made larger than in the general rammed earth, the formwork could not be demolded immediately. Therefore, it was determined that it was important to secure the compressive strength early for formwork demolding. In concrete construction, stripping time of formwork off the side of the building walls is said to be possible when the compressive strength of the wall is greater than 5 MPa. The compressive strength of the test structure after 1 day exceeded 5 MPa in all mixtures. This indicates that there will be no problems with the wall structure or any appearance change after the age of 1 day when the formwork is demolded.

The development of the compressive strength of the test structure at the age of 1 day was about 40% and about 60-70% at the age of 3 days. The development rate of strength has a tendency to slow as the unit binder weight increases and generally, the initial strength development is seen to be good.

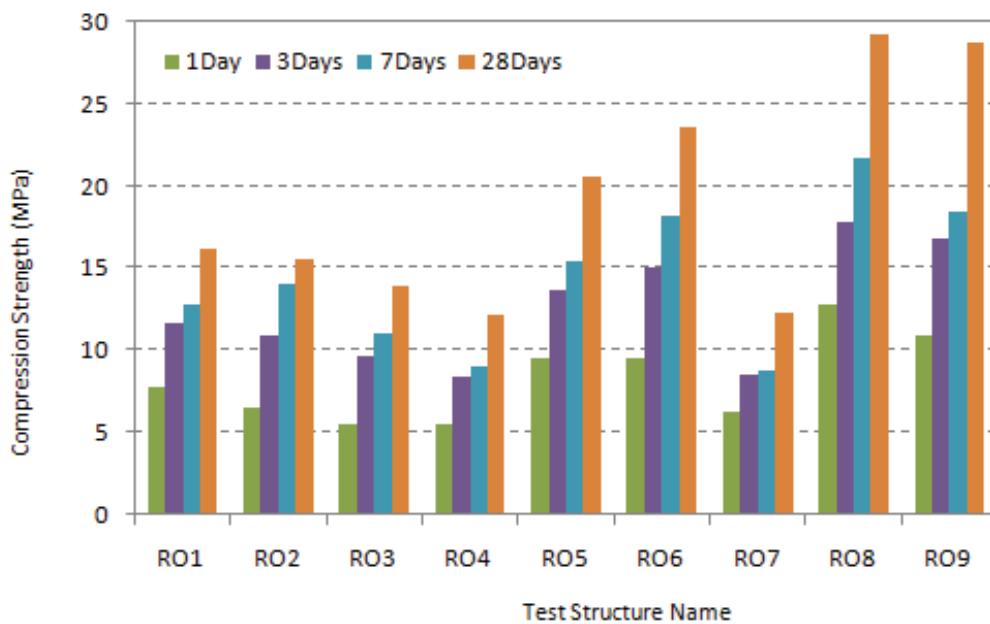


Fig. 7 - Compressive Strength by Age of Rammed Earth Construction Method

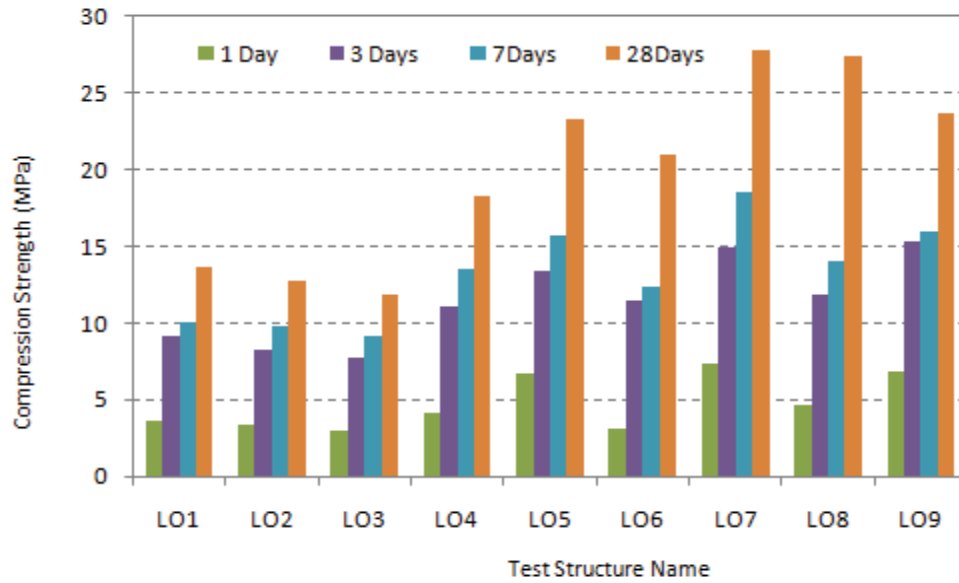


Fig 8. Compressive Strength by Age of Earth Concrete Method

The compressive strength measurement results of the Earth Concrete method is presented in Fig. 8.

As the unit binder weight increases, the compressive strength increases. For mixtures with an age of 28 days and a compressive strength exceeding 21 MPa, the W/B was 65% when the unit binder weight was 350, and the W/B was 50-60% when the unit binder weight was 450, and the compressive strength was highest at 27.7 MPa for a unit binder weight of 450 and a W/B of 50%.

The Earth Concrete method's compressive strength development rates relative to 28 days for the age of 1 day, 3 days, and 7 days are 20-30%, 43%-66%, and over 65%, respectively. For cement concrete with an age of 28 days and a compressive strength of 24 MPa in KCI 2007, the compressive strength development rate by age was 21% for 1 day, 56% for 3 days, and 70% for 7 days, and there was not a big difference with the Earth Concrete method. However, compared to the rammed earth construction method, the strength development rate by age was slower. For the rammed earth construction method, the initial strength exceeded 5 MPa at an age of 1 day but for the Earth Concrete method, most mixtures were lower.

Table 11 - Air Quantity and Slump Measurement of the Earth Concrete Method

Test Number	Unit Binder Weight (kg/m ³)	W/B (%)	Air Quantity (%)	Slump (mm)
LO1	250	100	5.5	105
LO2	250	105	5	212
LO3	250	110	5.5	260
LO4	350	65	5	45
LO5	350	70	6	190
LO6	350	60	4.5	265

LO7	450	50	5	115
LO8	450	55	6	185
LO9	450	60	4.5	280

The air quantity and slump measurement results are presented in Table 11. For cement concrete, the appropriate air quantity range was 3-6% as standard and when the maximum sizes of a thick aggregate decreased, the appropriate air quantity increased. For earth placement, the air quantity was in the range of 4.5-6% and did not deviate far from the range of the concrete.

The rammed earth construction method has the goal of increasing liquidity like cement concrete to allow for mechanized construction through remicon, pump car, etc. For cement concrete, the wall or column requires 100-150 mm of slump. However, for earth placement, as it includes a large quantity of particles smaller than silt and has large cohesion, 150-180 mm of slump is desirable. The test results showed that the mixture that develops greater than 21 MPa of compressive strength and satisfies the slump value was at unit binder weights of 350 and 450.

4.4 Conclusion

The results of the optimal micro-filler mixed earth and high-performance lime test revealed that the optimal micro-filler mixed earth reduced the W/B and increased the compressive strength. By reducing the earth by more than 50% of its particles smaller than silt to a 10% level, the W/B for gaining the required liquidity can be significantly lowered, and due to this, the rammed earth construction method showed at least a three-fold strength increase and the Earth Concrete method showed at least a two-fold increase in strength. In addition, for a mixture showing a strength of more than 21 MPa, there was the possibility of it being used in general strength areas where cement concrete is used.

5. CONCLUSION

The results of the this study on using earth as construction structure material and improving the particle size of earth and utilizing high-performance lime to derive a high strength mixture are as follows.

- 1) If general earth is used as it is, there is a large quantity of particles smaller than silt which increase the W/B and decrease the compression pressure. However, we conclude that it can be used as construction material for low-rise housing buildings.
- 2) If the particle sizes of earth are adjusted to decrease particles smaller than silt, the W/B can be lowered and a strength greater than 21 MPa can be secured. In the Earth Concrete method, a small amount of slump and air quantity are secured and we conclude that mechanized construction such as remicon, pump car, etc. can be used as in the presently used cement concrete construction.

This study mainly dealt with compressive strength but additional study on dynamic characteristics other than compressive strength should be carried out in the future.

Endnote:

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Curriculum:

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PRIORITY RESEARCH DIRECTIONS IN EARTHEN ARCHITECTURE FOR THE REPUBLIC OF KOREA

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world

Sub theme 2.1: Fundamental investigations on the material, research and development (R&D)

Keywords: Research in earth architecture, scientific knowledge, operational and technical researches

Abstract:

Earthen architecture in the Republic of Korea is an old tradition tracing back to centuries. Since the end of the 20th Century, the Republic of Korea has faced a rapid growth of its main towns and subsequent effects in terms of environmental pollution that have led to a growing popular movement in favour of the defence of nature and eco-habitat using natural materials, and particularly, earth. Some architects have achieved contemporary projects revalorizing the use of rammed earth and compressed earth blocks. Various projects of research and development have led to a massive production of such CEB within the private sector of the building industry. The University of Mokpo, with its Department of Architecture, has carried out successive research projects aiming at promoting an actual use of earth in construction, with the support of the Korean government. Nevertheless, the National Research of Cultural Heritage of the Republic of Korea (Ministry of Culture) did not want to duplicate research and investment efforts which have been developed during the two last decades and wanted to undertake a specific approach in research and development. At the end of the year 2008, the DOA-MNU asked CRAterre-ENSAG to carry out a study aiming at defining research priorities for the next ten years (2010-2012).

1. INTRODUCTION

It was of paramount importance, in this research, to bring to light the recent trend of earthen architecture revival in the Republic of Korea. Since the end of the 20th Century, the country has entered a new historical trajectory in the field. This movement is clearly expressed through the recent development of a contemporary earthen architecture but also, obviously, through a new attention given to the upkeep of the vernacular heritage, or to its restoration. Several dynamic vectors and processes are supporting and going with this tendency:

- the back effects of a « transcultural » process, global and international, in the field of the urban and architectural production ; these back effects are directly impacting the country that has recently and fastly entered for a modernization process, in this context of globalization ;
- consequently, a risk of cultural value reduction for the Korean architectural history and heritage, of its cultural identity, has grown up, as well as a risk of cultural scarcity creation ;
- a clearer political and social consciousness of the global ecological evolution has grown up within the research leading institutions (mainly in the universities), within the worldwide professional medium, and through a new generation of architects and engineers ; this new situation confirms the loss of accessibility to conventional fossil energies, and to the non-renewable resources, increasingly scarce and costly ; this is much more worrying in a situation of dependence, South Korea being considered today as the fifth world oil importer with a need of 14 million barrels per day ! A recent black tide, at the beginning of Decembre 2007, with dramatic environmental consequences, has strengthened the political and social will for exploring alternative solutions aiming at reducing this oil dependency ;
- the global impact of the actual architectural and urban production (generating stress and pollution) on people's physical and mental health, points to the need to pay greater attention to other scales of the building environment, and to natural materials ;
- new migratory phenomenons from the cities to the outskirts, and to the open rural areas can be observed in the country ;
- the question of the economical accessibility to housing for low-income families (and for the middle class) that are getting into long-term debt is much more worrying ; as in many other countries, this situation results from land speculation, and from a building production that uses conventional materials and technologies (reinforced concrete, steel, glass, components derived from the oil industry) exploiting increasingly scarce resources and high levels of « grey » energies in the production and building processes ;
- the modern technologies that have been developed for a mass society consumption have reached their limits ; the post-fordist production restores new possibilities for a production valorizing small quantities, and a diversity of technological and economic answers to the new expectations of society ;
- the evidence of a global climatic change encourages to investigate in alternatives for Habitat, and particularly for optimizing the thermal ambiances (heating and cooling) ; such new solutions cannot be only given by the technoscientific and economic approaches that are going on to promote, in application of the principle of the « permanent creative destruction » (Joseph Schumpeter), increasing scarcity, and more expensive and sophisticated answers ; it is impossible to promote a sustainable development with the tools of unsustainable development.
- urban growth and its resulting vertical townscape (high rise) is less considered as a fatality ; architects and engineers are exploring new possibilities and other scales – technical, economic, human and cultural – new approaches of the urban and architectural density : green towers and « nano » towers are opening new paths for a sustainable town planning.
- the question of the widening gap between urban and rural areas is becoming more and more crucial ; in this direction, at the heart of the new environmental paradigm, the lessons that can be gained from the architectural traditions (vernacular architectures) are receiving greater attention and are being analysed ; a new concept of « habitat of cultural interest » is emerging that valorizes traditional builders' intelligence

- s, and a more harmonious relation with the territory and local resources.
- a broader shared consciousness for the necessity of more solidarity with unfavoured people of the world, particularly with the « Great South » is growing through the new generations' mind ; we are living in a global world and it is crucial to facilitate the access to habitat and solve the fundamental needs (food, health, education), to encourage local development processes that could contribute to improving living conditions, generating local economy, and that could be more respectful of local environments and identities, of the cultural diversity ; in this context, earthen construction offers a great potential for contributing to poverty alleviation and local development.

Facing this new international situation and its regional and local expressions, the Republic of Korea has entered a research process to develop alternative responses in the field of earthen construction and architecture. This process is supported by a great research effort including new experimentations, building and architectural innovations. Four aspects of this new tendency can be observed:

- a real quality in recent contemporary earthen architectural achievements : see projects designed by Jeong Guyon Architect Associates and other young professionals ;
- a substantial investment of the Korean University for developing a scientific and architectural research programme : research on the energetic efficiency with the use of insulating earth-based materials (interior and exterior cladding with extruded earth panels), the development of earthen renders for finishing, research on thermal and hygrothermal comfort, research on new earthen building material as poured earth for pavements, on the reduction of the chemical stabilization rate, on other stabilizers than cement ;
- the development of a specialized higher education integrated in the curriculum of the Department of Architecture of the National University of Mokpo ; the organization of summer workshops on earthen construction ; the organization of symposiums dedicated to earthen architecture that are opened to a public of decision-makers, industrialists and professionals of the building sector, and to a broader public ;
- the recent creation of an Institute of Earthen Construction, TerraKorea, at the interface of the university and the private sectors that is already playing a decisive role for promoting the earthen architecture revival in the country.

2. STRENGTHS, WEAKNESSES, OPPORTUNITIES, AND THREATS (SWOT)

The interim seminar for research partners (DOA-MNU, TerraKorea and CRATERRE-ENSAG) that took place in October 2008, thanks to a « SWOT » analysis, allowed to better evaluate the situation of the recent earthen architecture revival in South Korea, and the new trends. The outputs of this SWOT are summarized below.

2.1. Brief synthesis of the Strengths

- The country is gifted with a great tradition of monumental and vernacular earthen architecture. There is a « noble » heritage built in wattle and daub, rammed earth or a dobe, and in unbaked earth and burnt brick. Even if its physical evidence has been reduced during the last decades, this tradition is still embedding a strong substratum of tangible and intangible cultural values for the nation.
- The national Earthen Institute for Earth Construction, TerraKorea, that has recently been created is gathering members from both academic and private sectors who are all interested and/or committed in the revival of earthen architecture in the country.

- The DOA-MNU is housing a team developing specialized scientific and academic activities : the « Architecture Community of Terra » (ACT). This team, in 2008, integrates 12 teachers-researchers and their assistants, with 15 years experienced members among them. Several members of this team are graduates from the « DSA-Terre » (specialized post master) of CRAterre, in the School of architecture of Grenoble. This team is developing a research programme on the built environment and on earthen building materials and techniques. Being located in a university medium, ACT is benefiting of a multidisciplinary environment.
- The DOA-MNU has developed a compulsory specialized academic programme for all students who are following their undergraduate studies in architecture.
- The university has recently decided to extend ahead specialized academic and scientific activities on earthen construction, and has allocated a new site of 3 300 m² for undertaking experimentations on building prototypes that will be monitored and evaluated.

2.2. Brief synthesis of the Weaknesses

- Facing the development perspective of the earthen construction in the country, the team ACT, though it exists, considers that human resources are not enough.
- Research funds allocated to the development of activities in the field are still unstable.
- Actual research policy, in the construction sector, is not focused on earth construction as a priority to be supported.
- Since the seventies, when the country entered a decisive step of « modern » development, a great part of the traditional earthen heritage has been abandoned. This heritage is not carefully maintained, and is progressively degrading, except rare examples of aristocratic vernacular architecture gifted with high cultural value.
- The earthen heritage of the country, and the traditional building cultures and know-how are not fully documented. These skills are unused today.

2.3. Brief synthesis of the Opportunities

- A social demand for a more healthy habitat is emerging in the country ;
- Near 55% of the country's population is now living in cities, flats and towers. Living conditions in an increasingly dense urban medium generating environmental pollution, push people out of cities, towards for the open country. There is a reverse migratory movement.
- Clay is considered as a healthy material associated to the living hygiene and its use is growing., the use of clayey earth is more appreciated by the public and is increasingly being used for plastering inside walls, or for public facilities (baths and saunas).
- The « potential » earth construction market is better identified as a « carrying » market that invites contractors to create specialized firms.
- Several regions of the country have begun to allocate support for restoring the traditional earthen housing stock, and for the development of new projects valorizing earth materials and building technologies.
- If, until today, the recent developments of earthen architecture in South Korea have substantially valorized the CEB technology (compressed earth block), more architects seems to be interested in the use of rammed earth. For such, the Korean movement is following the same direction that is adopted by other regions of the world, as in United States, Australia, New Zealand, or in other European countries (France, Germany, Portugal).

- The country, covered by 70% of clayey hills, can take advantage of this abundant resource in soil.
- The Republic of Korea presents a lot of powerful assets, specifically in the sector of engineering industries for developing a proper earthen production and construction equipment (press, mixers, shuttering, etc.).
- The country is also the fifth world producer of lime which is perfectly adapted for stabilizing clayey soils with a possibility to achieve very good results in the mechanical resistance of the earthen building materials.
- Actually, we can observe an obvious development of the environmental architecture, integrating new approaches for improving the quality of the air, new energetic devices (solar energy), for reducing CO₂ emissions, and a better use of water.
- All products that are considered dangerous for health, more specifically for paint, are more and more criticized ; so, the natural materials and products are much more promoted and used.

2.4. Brief synthesis of the Threats

- Interest for earthen construction has grown up in research laboratories but is still limited.
- Research budgets allocated to the field, from governmental or institutional origin, are still insufficient and irregular.
- The reviving market for earthen construction is slowly developing but the quantity of orders for projects is insufficient. This situation directly impacts the cost of earthen construction which is still expensive with regard to the current construction. Specialized contractors do not have enough openings.
- In front of a growing people's interest for earthen construction, there is a lack of professional qualifications.
- This new potential market is also caught by incompetent opportunists who are abusing a new clientele. This can be hurtful to the development of the market.
- The standards for construction in concrete are the reference in the construction sector. They impose excessive requirements for all other types of constructions and are not adapted for the individual housing, or for new projects of grouped housing that can be built with other materials and building technologies, and for other processes : self-help production, construction and finishing..
- Even if the interest for earth construction is manifest, it still concerns a minority. The general opinion is cautious because earth does not fit with the idea of modernity. Earth is considered as a fragile material in tropical humid conditions, specifically during the raining season.

As global synthesis, the seminar has identified three areas for developing priority research directions:

- Research in new applications for a more healthy habitat : reducing all kind of negative external impacts on people's health, reducing the noxiousness of products and components that are added to building materials (as formaldehyde) generating health troubles and diseases.
- Research in new applications for environmental and ecological quality housing : reducing energy consumption, the amount of integrated « grey » energy, the use of unrenewable resources, CO₂ production, and other environmental pollutions.
- Research related to the history and culture of the nation : producing a « Habitat of cultural interest » that would revalorize the societal intangible and tangible values that are founding a proper identity of the Korean people in its territory.

3. FINAL RESEARCH REPORT AND HELP FOR THE DECISION

3.1. Intermediary report

An interim report on the analysis of the state of the art, delivered at the end of September 2008, presented a provisional corpus of potential research directions for seven chapters. Provisionally, 73 research directions were identified. Based on this report, a joint working seminar with the Korean partner was organized at the beginning of October 2008, in the School of Architecture of Grenoble, to carry out a first evaluation of the priorities at the international and national levels. The provisional corpus of priority research directions was reduced to 53 subjects. Then the Korean partner was invited to specify the national needs and expectations through the prism of the provisional corpus of research directions which was submitted to its appreciation and according its confrontation to the national context.

3.2. Structure of the final research report

The final research report that was delivered to the Ministry of Culture of the Republic of Korea, via the DOA-MNU and the Earth Architecture Institute of Korea (TERRAKorea), included two sections:

- an analysis of the state of the art at the international and national (Korea) levels, in order to clearly identify the international research trends and thus establishing their relevance regarding the Korean context; and,
- a set of proposals of priority research (**R**) and study (**S**) directions for seven distinct chapters :
 - *Chapter 1 : the use of earth :*
 - **R.1.** Develop research on history of earthen architecture in South Korea ;
 - **R.2.** Develop a research on traditional earthen building cultures in South Korea ;
 - **R.3.** Undertake an inventory of noble and vernacular earthen architecture in the country ;
 - **R.4.** Analyze the tangible and intangible values of the traditional Korean earthen architecture for contributing to a declaration of the cultural significance, at both national and international levels ;
 - **S.1.** Study the acceptability of earthen architecture with enquiries amongst political decision makers, professionals, banks, insurance firms, population, etc.
 - **S.2.** Valorize the recent architectural achievements in the country : book, case-studies, awareness-raising, audiovisual products, etc.
 - **S.3.** Undertake the inventory of all actors actually committed in the revival of earthen construction in the country : prepare the launching of a national network.
 - **S.4.** Strengthen the development of a specialized research centre in the DOA-MNU ;
 - **S.5.** Develop a specialized data bank including bibliography, images, scientific and technical data, accessible to students, researchers and professionals.

- *Chapter 2 : earth to build with :*
 - **R.5.** Develop research on the earthen material rheology : liquefaction, viscosity, coagulation, pouring, etc ;
 - **R.6.** Develop research on the permeability of the material ;
 - **R.7.** Develop research on vapor transfer and surface exchanges in the earth material ;
 - **R.8.** Map the soil that are useful for earthen construction : geotechnical mapping ;
 - **R.9.** Correlate the types of soil and the main earthen building techniques ;
 - **R.10.** Correlate laboratory tests on earth materials with the field behaviour : define environmental parameters ;
 - **S.6.** Develop a mobile laboratory for on-site analysis.

- *Chapter 3 : earthen materials and building techniques :*
 - **R.11.** Develop research on mortars, reinforced earthen materials and building techniques : reinforcement with natural and synthetic fibers ;
 - **R.12.** Develop the research on the poured earth concrete ;
 - **R.13.** Develop the research on the construction in projected earth ;
 - **R.14.** Research on productivity improvement for the earth block technology : industrial moulding, compact and mobile production units ;
 - **R.15.** Develop research on building components in extruded earth, panels and cladding ;
 - **R.16.** Complete the research on earthen materials properties : physical, mechanical, static, hydric, thermophysical properties ; for wattle and daub, cob, rammed earth, adobe, CEB ;
 - **R.17.** Research on energy consuming (grey energy) for comparing with other current building materials : concrete, hollow concrete blocks, burnt bricks ;
 - **R.18.** Elaborate a specific method for the structural resistance of earthen construction and for the different earthen building techniques : earth and straw, cob, adobe, rammed earth, CEB ;
 - **S.7.** Undertake feasibility studies for the development of the earthen construction branches in South Korea ;

- *Chapter 4 : the stabilization :*
 - **R.21.** Develop research on the stabilization of clayey soils with « soft » cementation : pouzzolanic reaction or geopolymerization ;
 - **R.22.** Develop research on the biopolymerization of the clayey soils : organic macromolecules, colloidal systems ;
 - **R.23.** Develop research on the hydrophobization of clayey soils : hydrophobic molecules and protection against water ;
 - **S.8.** Undertake a global synthesis on the stabilization : typology of systems, products, mechanisms, reactions, variables, criteria of suitability, etc.

- *Chapter 5 : building elements and architecture :*
 - **R.24.** Develop the research and experimentations on eco-habitat through prototypes with innovative building systems and alternative energetic solutions valorizing the thermal and hygrothermal characteristics of the earth material ;
 - **R.25.** Develop a research programme on low-cost earthen architecture for the accessibility to less favoured people ;
 - **R.26.** Explore new solutions for underground housing : ecological and energy

- etic approach ;
 - **R.27.** Develop research and experimentations on earthen pavements : compressed earth, ribbed vaulting and other filling components for floors, reinforced earthen slabs ;
 - **R.28.** Develop researchs on the lightening of earthen materials for inside and outside insulation : earth and fibers mixing for panels, blocks, cladding ;
 - **S.9.** Develop technical specifications and recommendations for the main earthen building techniques and their application to the Korean context.
 - **S.10.** Prepare an Earth construction guide for the architectural design with earth.
 - **S.11.** Promote architectural competitions for earthen architectural projects, exhibitions of projects within the university and professional mediums.
- *Chapter 6 : surface protection, plastic arts and decoration :*
 - **R.29.** Develop research and experimentations on earthen renders, distempers and paintings: testing their adherence, mechanical resistance, measure their contribution to the thermal and hygrothermal control.
 - **R.30.** Develop research and experimentations on cladding elements in stabilized earth for the insulation and the decoration ;
 - **R.31.** Promote research and experimentations in the field of plastic arts and decoration using the aesthetics properties and resources of the material ;
 - **S.12.** Undertake the inventory of all types of earthen plasters and paintings that are existing in the Korean tradition : corpus of knowledge and know-how.
 - *Chapter 7 : earth architectural heritage conservation :*
 - **R.32.** Document and analyze all typical problems related to the earthen architectural heritage in the country : structural and humid pathology, problems linked with preventive conservation and maintenance ;
 - **R.33.** Develop a research on decay processes resulting from salts, humidity migration and porosity in the earthen building structures and materials ;
 - **R.34.** Develop a research on biological decay processes : vegetable parasites, moss and mushrooms, insects, rodents, etc. Establish the correlation between these biological processes and environmental pollutions ;
 - **S.13.** Identify all heritage sites of great value (archaeological, historical) and prepare a nation-wide list ;
 - **S.14.** Identify sites that could be proposed by the Korean Government for entering on the UNESCO World Heritage List ;
 - **S.15.** Develop a guide for the conservation, restoration and rehabilitation of the Korean earthen architectural heritage.

The final report was delivered at the end of December 2008. It proposed an original synthesis crossing the international and the national situation, a decision making matrix, and an exhaustive bibliography of all scientific references which were consulted for the research.

4. THE DECISION MAKING MATRIX FOR RESEARCH DEVELOPMENT IN EARTHEN ARCHITECTURE

The decision-making matrix proposed a classification of the priority research directions, according two main categories:

- First category : scientific knowledge, with :
 - fundamental research : earth material, physics, soil chemistry and biology, stabilization, modified mortars, material properties and performances ;
 - social and human sciences : history, anthropology, sociology, economy, architecture, culture and heritage ;
 - environment and sustainable development : energy and resources, local development.
- Second category : operational and technical researches :
 - research on the building materials and techniques, production processes, fittings and tools ;
 - research in construction : innovative building elements and systems, behavioural tests and measures ;
 - research in architecture : design of prototypes for an eco-responsible and a social low-cost architecture.

Finally, the decision making matrix (fig.1) proposes 28 priority research directions for the first category, « scientific knowledge », and a set of 25 priority research directions for the second category, « operational and technical researches ». All these items are considered according to five levels of priority (fig.2):

- absolute priority ;
- very high priority ;
- high priority ;
- medium high priority, and,
- low priority.

The total financial investment for developing this scientific programme is believed to be approximately € 6.000 000.

Decision making matrix

Research and study directions						
Categories	Scientific knowledge			Operational and technical researches		
Scientific Perimeters	1 – <i>Fundamental research</i> 2 – <i>Human and social sciences, architecture, culture and heritage</i> 3 – <i>Environment and sustainable developpement</i>			1 – <i>Researches on materials and building techniques</i> 2 – <i>Research in construction (processes)</i> 3 – <i>Research in architecture (project)</i>		
Scientific perimeters	1	2	3	1	2	3
Levels of priority	Number of researches and studies			Number of researches and studies		
Absolute		1			1	2
Very High	4	1	2	1	1	2
High	6	10		4	4	3
Middle	3	1		4		1
Low				2		
Sub-totals 1	13	13	2	11	6	8
Sub-totals 2	28			25		
Sum total	53 research and study directions					

Fig. 1 : Decision-making matrix for the development of the research in earthen construction and architecture

Absolute Priority		Category of research	
Chapters	Research and study directions	Global estimate cost (1)	Classification Category (2)
1 The use of earth	E.4. Strengthen and support a specialized research and training Centre	100 000 € (inciting and pluri-yearly)	1
2 Earth to build with			
3 Earthen materials and Building techniques	R.20 Contribute to the development of standards and certifications for the main earthen building materials and their use in construction	120 000€	2
4 The stabilization			
5 Building elements and architecture	R.24. Develop a research and experimentation programme in eco-responsible habitat : prototypes R.25. Develop a research programme on low-cost earthen architecture : prototypes	1 000 000 € (1 st phase)	2
		1 000 000 € (1 st phase)	2
6 Surface protection Plastic arts and Decoration			
7 The conservation of the earthen architectural heritage			
TOTAL	3 research directions in the operational and technical field 1 study direction in scientific knowledg 4 research and study subjects in absolute priority	2 120 000€ 100 000€ 2 220 000 €	

(1) The cost estimate has to be considered in « approximate value » and calculated with reference to the French context in equivalence with current working time per researcher. The cost of equipments and all necessary material support has to be added. This estimate constitutes budgeting base for the development of suggested activities.

- (2) Classification of the research categories :
- 1 : Scientific knowledge
 - 2 : Operational and technical researches

Fig. 2 : Exemple : suggested researches and studies in absolute priority

5. CONCLUSION

This study resulted in a better analysis of the potential of development for earthen architecture in the Republic of Korea in order to relate it to a wider international movement. To support this perspective, the study has obviously raised the necessity for developing research and experimentation that would be more concretely associated to projects that would revalorize the significant architectural heritage as well as more contemporary achievements giving an image of modernity. For such, the Korean earthen heritage would have to be better identified and documented. Its tangible and

intangible values, part of the collective cultural memory and identity have to be cared and preserved. It is also essential to support research on experimental prototypes at full scale aiming at supporting innovation in earthen construction and architecture, allowing to measure and monitor their behaviour; but also for promoting the earth revival beside a large public of decision makers and professionals. The support that should be given to the development of a specialized research centre, in the university, is one of the major priorities for progressively strengthening an excellence of the country in the field. This centre should support the development of PhD research and higher specialized education as well as professional training activities. The question of standards is also one of the major challenges to be taken up. This question is now central in the majority of the worldwide countries that are supporting the revival of earthen construction and architecture and should be dealt with both at national and international levels in order to harmonize approaches regarding standards on « products » (materials) and « processes » (societal outputs). Fundamental research on the matter, at the macromolecular scale (physico-chemistry of granular mediums) is also a major challenge to better know earth, this material used by Mankind for milleniums but still not fully explored. Research on « soft » chemistry including biopolymerization is also suggested. Innovative research aiming at developing new earthen building materials, as poured clayey concrete, or « green » concrete, is suggested for competing with other usual modern materials that are more energy consuming and CO₂ emitting, and for improving the productivity of earthen construction. On the other hand, the study has raised the paramount importance of undertaking more multidisciplinary research, at the cross of engineering, social and environmental sciences. It is essential to integrate a more holistic approach considering that questions related with territory development and urban planning have to be challenged. The decision-making matrix that we proposed suggests a set of priorities that could guide the country for defining a more concrete action plan. To achieve this ambitious programme, more human resources and funds should be allocated by the national institutions (from various ministries), and private donors. On the other hand, this study calls for more international cooperation in the field with potential partners sharing common interests, ambition and a vision for the future of earthen construction and architecture. We do not forget the famous John F.C. Turner's aphorism : « *A material is not interesting for itself but for what it can do for society* ».

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FROM “BUILDERS’ GRAINS” TO “MATTER TO BUILD” WORKSHOP PEDAGOGICAL TOOLS FOR EARTHEN MATERIAL UNDERSTANDING

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world

Sub theme 2.1: Fundamental investigations on the material, research and development (R&D)

Keywords: Earth material, clay concrete, granular matter, pedagogical workshop, constructive innovations

Abstract:

What are the constituents of earthen material? What are the physicochemical phenomena that govern their behavior? What are the forces that hold this material? Through hundreds of experiments carried out in real time, “Builders’ Grains” workshop is an innovative educational tool to familiarize oneself with earthen matter, in order to clearly understand how it works. Physics of dry granular media, physics of wet granular media and clays physical chemistry show, unexpectedly, the many analogies between earth and concrete. Over the past 5 years, this phenomenological approach of matter has enabled both to promote constructive innovation, and to open up many avenues of research and better dissemination of knowledge in both academia and general public. The educational content was developed through experimental lectures for engineering and architecture schools, a scientific and general public book, a big national and international exhibition, accompanied by a small regional exhibition, and many other products. In total, hundreds of thousands of people have discovered the virtues of earth material for construction. Given the success of this new form of pedagogical engineering, a “Matter to Build” workshop, unique place in the world, between studio and museum of science, especially devoted to materials science for the construction and replicating the approach of “Builders’ Grains” to other materials, is planned. In connection with the “Great Workshops”, dedicated to the experimentation of innovative structures for architecture, and future “Prototypes Workshop” in order to measure their energy performance, they will form a true educational facility, known as the “City for Sustainable Construction” dedicated to transform education in order to catalyze the emergence of sustainable building cultures within society.

1. INTRODUCTION

The city of Shibam, Yemen, is a town of 7000 people, inscribed on the world heritage list as the oldest skyscrapers city in the world and the first urban centre based on the principle of vertical construction. It is nicknamed the “Manhattan of the desert.” Its apartment buildings are up to 30 meters high and 8 stories. Nevertheless, this city is built entirely of mud bricks, molded and dried under the sun. How can we build with a material that turns to mud so easily? By what miracle this same material can withstand the considerable weight of a multi-storey building? In other words, what keeps earthen

buildings standing? This question, apparently trivial, involves using very recent theoretical tools of modern matter physics. This issue is likely to fundamentally change the opinion of the society on this material and, thanks to the junction with the architectural thought, leads to new ways of building and using this real “clay concrete”. Until very recently, physicists did not know how to justify the existence of a simple sand castle, or why it collapses when it is too dry. Consequently, what about the cohesion of an earthen wall, a much more complex material? To try to answer, we must dive into this earth to explore its components and to understand how the relatively new disciplines such as sand pile physics, sand castle physics and clay mud physical chemistry offer new light on this material still very poorly understood.

2. EARTH IS A CLAY CONCRETE

Earth is a mixture of grains of different sizes that have different names depending on their dimensions. The largest to smallest, are the stones, gravels, sands, silts and clays. The proportion of these grains varies from one soil to another. It conditions traditionally the use made of each soil, suited to a particular construction technique rather than another. For example, in France, stony soils are generally used for rammed earth, particularly common in the Rhône-Alpes region, where 50% of architectural heritage was built that way. Clay soils are mixed with straw to form a very sticky material that serves as filler material in a wooden structure: half-timbered houses, or wattle and daub houses, represent 60% of traditional buildings throughout the north of France (Normandie, Picardie, Champagne, and Alsace).

Stones, gravels, sands and silts are composed primarily of rock fragments. These grains differ only by their sizes. Clays are significantly different: the grains within them are so small that they are invisible to the naked eye. Mixed with water, they form a paste of uniform color, which is like glue: clay is the binder of earth material, as the cement is the binder of concrete. Stones, gravels, sands and silts are in turn the granular skeleton of earth: they bring their rigidity to the material. To produce a good quality building material, we can not do without either the binder or the granular skeleton. It is the latter that earthen material owes much of its strength: soils used to build are real “ready for use clay concrete”.

“Concrete” is a generic term: it refers to a composite building material made from aggregates bonded by a binder. Concrete, in which gravels and sands are bonded by cement, has essential similarities with earth, in which stones, gravels, sands and silts are bonded by clays. Earth is a clay concrete. From this awareness comes the next lesson: Most of the major innovations that, over the past 30 years, led to the spectacular development of ultra high performance concretes are directly transferable to earthen material.

3. “BUILDERS’ GRAINS” PEDAGOGICAL WORKSHOP

To better understand this clay concrete, hundreds of educational experiments have been developed to illustrate dry granular physics, wet granular physics and clays physical chemistry. “Builders’ Grains” educational workshop is a journey of discovery where you can handle a range of interactive experiments on mineral granular matter, which allow to acquire, through a path that goes from geology to architecture, a

scientific and technical culture of granular matter. The project aims to discover granular physics by having fun, to encourage the love of science and then scientific vocations in particular among young people, facilitating the understanding of architecture, and reintroducing the concept of territory, shaped by the natural link between geology and geography of a region and the presence of available materials that are used by its inhabitants for housing. "Builders' Grains" experiments are arranged in a path that, while discovering the basic functioning of granular matter, invites to pass successively from geology to building and links landscapes, matter and architecture. In this initiatory process, much more than the discovery of laws that govern matter, it is a transformation of world views that is at stake. Public is invited in turn to change of scale, both in space (from the infinitely small to the infinitely large) and time (human time and geological time) and have a close look at nature.

Experiments are organized by topics. The first theme addresses the ability of granular matter to pass successively from a solid to a liquid state. This property is fundamental: it gives all their interest to granular materials for building, such as cement concrete, which is a real "pouring stone", or such as earth, that can be poured into a formwork as a liquid, adopting its form, and turn into solid by simple compaction. The fewer the voids, the higher the resulting material is strong and resistant. The only difference between a ready for use earth pile and the compacted earth wall just with the formwork removed is the proportion of voids between grains. Hence the importance of grains packing which allows filling up the space with a set of different sizes grains. Researchers who formulate cement concrete use geometric models as "Apollonian packing" or "spaced packing" (Vernet, 2004 - Borkovec and De Paris, 1994 - De Larrard and Sedran, 1999): these concepts are also applicable to earthen material. Thus, the material strength depends primarily on the proportion of grains of different sizes that constitute it. Filling in the gaps for a more solid material is equivalent to increasing the number of contact points between the grains. But when two grains touch each other, what are the forces that bind them at each of these contacts? Before considering a material as complex as earth, we must first look at a dry sand pile (Duran, 2003 – Guyon and Troadec, 1994). Its organization reveals the existence of frictional forces, leading to the natural slope of the heap, and allows us to introduce the concepts of angle of repose and angle of avalanche (Duran, 1997 – Duran, 2001). Grains of different sizes have different angles of avalanche. When set in motion, grains spontaneously separate by size: this is the phenomenon of granular segregation, which cause many problems in industry and on building sites (Metcalf et al., 1995). Contact and friction interactions in a set of grains distribute the forces of very special way (Blair et al., 2001 - Erikson et al., 2002 - Radjai et al., 1996): stresses are transmitted through a network of forces chains (Fig. 1). In some cases, several grains in contact form a vault and then a void under this vault. These vaults prevent the grains from placing themselves in a more compact configuration.

After this overview of the dry granular media physics, water is added to discover the wet granular media physics. A set of experiments concerning liquids reintroduce the notions of surface tension (or capillary force) (De Gennes et al., 2002), hydrophilic and hydrophobic surfaces, which are linked with capillary rise and capillary cohesion phenomena. A drop of water between two glass beads forms of capillary bridge, which attracts the surfaces it wets. Thus, the cohesion of the sand castle is due to capillary bridges connecting grains together (Hornbaker et al., 1997 - Halsey and Levine, 1998 - Albert et al., 1997 – Bocquet et al., 2002 – Bocquet et al., 1998): water is real glue. It is the simultaneous presence of water and air between grains that holds them together. A

capillary bridge has a meaning only through the water-air interface: without air, the surface tension disappears. When water content increases, capillary bridges join themselves until gas phase disappearance: the sand castle loses its cohesion. Moreover, a block of fine sand is much stronger than a block of coarse sand: the capillary force between two grains of sand dramatically increases when the grain size decreases and the curvature of the capillary bridge increases. Between clay platelets, about a thousand times smaller than a grain of sand, capillary bridges have extremely small dimensions (around 2 nm): at this scale the capillary force becomes enormous and intense enough to build important height buildings (Van Damme, 2001 - Van Damme et al., 2007). For a particular type of clay, kaolinite, it was shown that cohesion is mainly due to capillary forces (Gélard et al., 2004): water is the real binder, due to size and shape of clay platelets which allow capillary cohesion to be much larger than in a sand castle. Then, if water is the glue of earth, why an earthen wall does not collapse when it dries, like a sand castle? At nanoscale, the one of capillary bridge between clay particles, water never evaporates completely, and it is even the opposite that sometimes occurs: air humidity can condense between clay platelets, forming capillary bridges of a few nanometers and coating clay platelets with a film of water molecules even thinner. Thus, an earthen wall is never completely dry: it always contains some water between clay platelets, and this water does not evaporate as it is in equilibrium with water vapor in the air.

The sand castle physics, where capillary cohesion is possible only if water and air are simultaneously present between grains, is of no help to understand plastic, liquid or viscous state of earthen material. In these three hydric states, earth is a mixture of grains saturated with water, without air: so there are no more capillary forces. Another discipline, clay mud physical chemistry (Van Olphen, 1963 – Cabane and Hénon, 2003) is then more suitable to describe and understand earth matter. There are many types of clay which have very different swelling and shrinkage properties. Swelling clays, such as smectite, can absorb a lot of water between their sheets: they crack a lot when drying. This is not the case of non-swelling clays, such as kaolinite. The main difference between these two clays is that smectite sheets bear a negative electrical charge while kaolinite sheets are neutral. Surface electrical properties of colloidal particles (Israelachvili, 1992) govern clay mud rheological properties. These can for example become a gel at rest or liquefy when mixed (Abend and Lagaly, 2000). The aqueous phase in which are dispersed clay particles plays a major role in the macroscopic properties of the mud (Tombacz and Szekeres, 2004 – Tombacz and Szekeres, 2006). A clay/water mixture can be liquid under acidic conditions and plastic under acidic conditions, for the same water content (Benna et al., 1999 – Janek and Lagaly, 2001). Salt concentration also changes clay mud viscosity dramatically (fig. 2). Water chemical composition modifies the nature of interactions between clay particles and their spatial organization, which in turn influences the material rheological properties.

4. CONSTRUCTIVE INNOVATIONS

“Builders’ grains” educational workshop, originally designed for schools and general public, quickly interested architecture and engineering schools. Then, physical and chemical concepts inspired architecture and engineering students to design innovative construction systems. Each experiment is like an open window towards innovation. For example, “magical balance” experiment, which is part of chains forces theme, formed

the basis of reflection for a prototype of hyper economic and very fast to implement housing, invented by architect Xavier Porte from National School of Architecture of Grenoble (www.cjmx.fr). In this experiment, a tube is placed just above the pan of a balance so as not to touch it. The tube is gradually filled with grains and weight change is recorded as one goes along. Quickly, the balance pointer jams and indicated weight no longer varies as the amount of grains in the tube increases dramatically: grains form arches which lean on tube walls. Weight is then deflected to the sides rather than head down, on the balance pan.

The same experiment can be reproduced by replacing the tube by an openwork stack of wood pieces that form a hollow column over a balance, without affecting the pan (fig. 3). A small amount of dry sand is poured inside the column. The balance indicates 76 g and only the bottom of the column is filled. By pouring sand on the entire height, the indication of the balance increases only about 20 g: the weight of the grains is transferred to the sides, in the wooden structure, and fixed by friction the elements, which then transform the horizontal force into tension. Moreover, the sand does not flow through the gaps due to its angle of repose of 30°. The experiment is reproduced at scale 1 with wide strips of stacked wood. Earth is poured between stacked wood. It is surprising that the structure, composed of elements simply laid without fastening system, does not collapse under the horizontal pressure of grains: the mass of earth, redirected into the structure, stabilizes the whole. No screws, no glue, no assembly system between wood elements, the construction process is super fast: filling is carried out by bulldozer. A prototype has been built to offer an alternative to containers for homeless housing during winter. Construction cost is 100€/m² instead of 1000€/m² (average cost in France). The construction can be completely and easily taken apart and assembled again.

5. RESEARCH TRACKS

Some experiments helped us to identify new tracks of research. For example, the precise control of grains size distribution, i.e. the proportion of grains of different sizes, significantly improves earthen mechanical properties and its workability during its implementation. The logic is simple: fill the voids as possible. Regardless of the material in question, a vacuum is always a weak area and earth is no exception to this rule: the more its porosity is low, the stronger it is. The proportion of void depends largely on the distribution of different sizes grains in a granular material. Researchers know this basic principle that allows them to design cement concrete as strong as steel, decreasing the porosity in the extreme. To achieve this, they use mathematical models of ideal stacks (Vernet, 2004 - Borkovec and De Paris, 1994) (fig. 4). From a geometrical point of view, the problem states: how to fill up a space only with balls? The optimal mathematical solution is the Apollonian packing, in which each space between four spheres is filled by a ball tangent to these surfaces, and where this principle is set to infinity in order to achieve the ultimate compactness. The model for Apollonian packing has real practical significance. He helped design ever more resistant concretes: between conventional concrete and high performance concrete, porosity changes from a value between 10 and 20% to a value between 1 and 2%, while the mechanical strength is simultaneously increased from 20 to 200 megapascals (MPa). However, the search for the ultimate compactness faces with the needs of concrete implementation, which must be as liquid as possible when it is poured. In search of a compromise between workability and compactness, we must move away

from the Apollonian packing to go to packing patterns called "spaced packing" (Vernet, 2004), where space is filled with spheres that do not touch. With this trick, the grains can move more easily, resulting in a more liquid material during the implementation - without adding water - and therefore more workable: this is the principle of ball bearing. The "spaced packing" is the key to the "self-leveling" concrete: of low water content, they are so fluid that they spread fully and spontaneously adopt a horizontal surface. In conventional concrete, excess water, which was added to liquefy the mixture, evaporates during drying and leaves voids. Thus, not only self-leveling concretes are more fluid, but they are also more compact when dry and therefore more resistant.

Similarly, changing earth size distribution creates new materials with new properties: the key to success lies in the accuracy of sand or gravel addition to natural earth. Pouring an earthen wall as concrete is also possible (fig. 5 and 6). Usually, it is unthinkable to cast an earthen massive wall without cracking when it dries. The trick is to complete the grading of a natural soil with sand and gravel, in order to approach the model of "spaced packing". It then becomes possible to cast earth like concrete with a minimum of water, and drying without cracking.

To go further in the development of clay concrete still more fluid and easy to implement, techniques invented by cement concrete researchers are again instructive. In addition to grains packing models, the formulation of a self-leveling concrete requires the use of deflocculants (Flatt et al., 2004). These additives have several names, significant of their mechanism of action and usefulness: deflocculants, dispersants, water reducers, superplasticizers, etc. All these terms are synonymous, since the goal is to disperse or deflocculate cement powder, in order to reduce the amount of added water and get more liquid material. Typically, cement, when it is mixed with water and before its hardening, has the form of tiny grains agglomerated as aggregates of several tens of particles. Each aggregate traps water in its microporosity: this water is not involved in the mixture liquefaction. It is necessary to disperse, in other words to break the aggregates, in order to free this water and liquefy the cement paste: the concrete becomes then more fluid without adding water. Why not applying this logic to earthen construction? In nature, clays are also most often in an aggregated state. Thus, a clay paste is made liquid by adding an equivalent of concrete superplasticizers. Earth can then be cast in a very fluid state. The small amount of water contained in these new clay concretes ensures obtaining compact materials, then strong, and that does not crack during drying. The research challenge is the discovery of natural clay dispersants that are effective, inexpensive and environmentally friendly.

6. SCIENCE AND SOCIETY DIALOGUE

Beyond innovative building systems and new research programs, this phenomenological approach of matter led to intense dissemination activities among the general public. The initial pedagogical workshop was then presented in different forms. Experimental conferences where experiments are filmed and projected live on big screen, have been tested in different contexts for students, professionals, researchers and teachers, schoolchildren and the general public, in rooms of more than 150 people, with a maximum of 450 people. A scientific book, named "Bâtir en terre, du grain de sable à l'architecture" ("Building with earth, from sand grain to architecture") (Anger and Fontaine, 2009) has sold over 7,000 copies. A major exhibition, named "Ma terre première, pour construire demain" ("My raw earth, for building tomorrow") (www.cite-

sciences.fr/francais/ala_cite/expositions/ma-terre-premiere) presented at the City of science and industry, in Paris (largest science museum in France), was visited by over 300,000 people for 1 year. It is now presented during 4 years in 4 major French museums.

A small version of this exhibition (http://craterre.org/diffusion:expositions/download/id/220648ff9e49e4e4bd1b9c7fdc576f61/file/exposition_grainsdebatisseurs_ficheinfo.pdf) for smallest structures was also performed. These activities were rewarded with four awards. The first was attributed to Laetitia Fontaine (one of the authors of the program): L'oréal-UNESCO-Academy of Sciences "For Women in Science" award. The second is dissemination award valuing the whole program: "Adolphe Pacault award for popular science". The third and fourth awards were given to the book: "The taste for science" award from the French Ministry of Higher Education and Research and the Roberval award. All these activities of dialogue between science and society have resulted in a media environment extremely favorable for the renewal of earth construction in France. Specialized building press has devoted special issues. The three major French monthly popular science magazine present articles several times. Two of the major French dailies presented a paper on the book. Radio and television programs on the subject are more and more numerous. In the mind of the public, a shift is taking place, from the image of a traditional and alternative material, or even backward-looking in the worst case, to the image of "material of the future", to use the expression of some journalists.

7. THE "MATTER TO BUILD" WORKSHOP

The way that "Builders' Grains" workshop tackles matter and materials naturally leads to replicate the experience for other materials such as wood, metal, polymers, etc. Faced with the originality and potential of this approach, one can imagine a place exclusively dedicated to the exploration of matter and materials for construction and architecture, drawing and deepening the model of "Builders' Grains". The "Matter to Build" workshop is born from this idea.

For the physicist and the chemist, matter is the substance of things. For the builder, it is the raw material to be worked, in the state where it is available before entering a production cycle (e.g. rocks, soil, oil, iron ore, tree, etc.). This matter taken from the natural environment is gradually worked to become a material for construction, then a product of use in the building process. In a world where we use and consume products without really knowing their nature and what has preceded them, it seems appropriate to give some understanding of the intrinsic nature and origin of matter.

We usually perceive the differences between materials by their sensory qualities such as color, grain, texture, tone, responsiveness to touch, smell, etc. Yet, if we were able to "see at the heart of the matter", we would discover a variety of shapes, buildings, intern structures much larger than what we can imagine. It is this plurality of "architecture" of the matter which is interesting to highlight. Matter consists of elements of different sizes, different shapes, different types that are linked by various "assemblies". To "build" is to aggregate together (Latin: *cum-struere*). Thus, matter is built.

We have to build relationships between matter microstructure and structural problems at the building scale. By providing a clear vision of what is matter and which are the processes that occur within it, we allow a greater clarity of mind for the future builder, who can even imagine its own solutions.

The “Matter to Build” workshop is a proposed extension of the “Great Workshops” (“Grands Ateliers”), place specially dedicated to the construction of structures for architecture, engineering and art students. A complementary project expansion, called “Prototypes Workshop”, will allow measuring housing prototypes performances. The “Matter to Build” workshop, the “Great Workshops” and “Prototypes Workshop” will form one of the largest place of experimentation, at all levels, for building: the “City for Sustainable Construction”.

8. CONCLUSION

The phenomenological approach of matter developed in “Builders’ Grains” workshop is a powerful tool for knowledge transfer. It promotes the opening up of knowledge between researchers, teachers and professionals of various specialties (architects, engineers, matter scientists, etc.). It brings out new tracks of research and fosters constructive innovations. It creates a strong interest from the public and society in general. In summary, it catalyzes the renewal of earthen architecture helping to give the image of a material consistent with the major issues of today. It would be particularly interesting to replicate this experience in other countries.

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Curriculum

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Fig. 1- In granular matter, stresses are transmitted through a network of forces chains, and usually deflected horizontally. That's why formworks must be very strong and rammed earth is compacted in thin layers (© CRAterre-ENSAG)



Fig. 2 - Salt concentration in water changes clay mud viscosity because of electrical interactions between clay particles (© CRAterre-ENSAG)



Fig. 3 - The "magical balance" experiment and the constructive innovation following: Xavier Porte prototypes (© CRAterre-ENSAG)



Fig. 4 - Packing experiments and mathematical model of Apollonian packing (© CRAterre-ENSAG)



Fig. 5 - Poured earth and the obtained wall without cracks (© CRAterre-ENSAG)



Fig. 6 - Changing earth size distribution by adding sand or gravel and its constructive innovation: Jean-Marie Le Tiec prototypes (© CRAterre-ENSAG)

EARTH BUILDING MATERIAL: STABILIZATION AND REINFORCEMENT

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world
Sub theme 2.1: Fundamental investigations on the material, research and development (R&D)

Keywords: earth, experimental research, development, stabilization, reinforcement

Abstract:

Over the past two centuries, the development model was characterized by high consumption of energy and consequently by high levels of pollution and environmental damage. Recent considerations of eco-social-economic character have led to debate this development model in favour of a low environmental impact and sustainable development. In the field of construction, this has resulted in an increasing interest in natural and eco-friendly building materials.

Earth is a traditional building material used all over the world. Its use is founded on cultural and architectural traditions that have developed over the centuries. The potential of earth as a building material is therefore interesting from an environmental point of view: in fact it responds very well to the request for sustainability because it is natural, healthy, easily accessible and renewable. For these reasons in recent years earth has been rediscovered as a modern building material and many studies have been done on it.

The Department of Costruzioni and Restauro of the University of Florence has undertaken an experimental study whose objective is to improve the physical and mechanical properties of earth. Particular attention has been paid to assessing the effects that the addition of stabilizing substances would have on such material. The aim is that the performances of the material earth can be increased to be comparable with those of other commonly used building materials such as stone, wood and concrete. The material has been stabilized with eco-friendly and biodegradable additives. In particular, stabilization with gypsum powder has been studied. Reinforcements have also been developed with various natural fibres which are able to adhere to the earth. Here the results of this experimental study will be presented and compared.

1. INTRODUCTION

Earth is an environmentally friendly building material but its physical and mechanical properties require the use of specific technical solutions. Stabilization has always been used in earth building tradition to modify the characteristics of the system earth-water with the aim of improving, even significantly, its physical, chemical and mechanical properties. In particular, a stabilizing additive is required to increase the mechanical strength of earth and its resistance to erosion and also to minimize the shrinkage of the

material during the drying process. Among the additives typically used to improve the performance of the material are vegetable or animal fibres, lime and some non-natural substances. The fact that earth is a sustainable and renewable material orients us toward the choice of an additive which will not affect this feature. In particular, the experimental research conducted at the Department of Costruzioni and Restauro of the University of Florence aims at identifying an additive which is able to improve the performance of the material without compromising the reuse of earth as agricultural land.

2. RESEARCH AND TESTING METHODOLOGY

The purpose of this experimental study is to find a method of stabilizing earth that improves physical and mechanical properties of the material. For this reason, physical, mechanical, and durability tests have been carried out. Each test was performed on both stabilized and reinforced specimens and on a mixture made of earth without additives in order to compare results.

The analysis of linear shrinkage has been performed according to BS 1377 Test 5 standards. Cubic specimens for the uniaxial compression test and prisms for the three point bending test have been prepared. With the ultimate aim of evaluating the carrying capacity of the material, the results of the experimental tests were used to calculate compressive strength, determined as the ratio between the peak load and the area of the specimen face in the contact with the test plates, compressive elastic modulus, determined in the branch of equilibrium path that could reasonably be considered linear, kinematic ductility, determined as the ratio between the displacement corresponding to the peak load and that at the end of the linear segment, available kinematic ductility, calculated as the ratio of the displacement measured at the ultimate load (conventionally established) and the displacement corresponding to the peak load and tensile strength determined by the three point bending test.

One of the main limitations of earth as a building material is its low capacity for water resistance. Immersion tests were conducted to assess water resistance for mixtures of earth with additives and without them. The test was carried out by performing several cycles of immersion for a period of 5 minutes. The specimens were placed in a water tank and covered by at least 5 cm of water. The immersions were interspersed by a drying process under infra-red lamps lasting 55 minutes.

3. STABILIZATION WITH GYPSUM POWDER

Gypsum powder has been used as a natural additive for the stabilization of earth because it is fully biodegradable and natural. Furthermore, it is even used to improve the quality of agricultural land for some crops, so it does not compromise the possibility of reusing earth for farming. Gypsum powder used in this experimental research is mainly composed of hemihydrate ($\text{CaSO}_4 \cdot 1/2\text{H}_2\text{O}$) with minor amounts of anhydrite (CaSO_4). This powder is characterized by a very fine grain and by the ability to incorporate large quantities of water. The test specimens were made with four mixtures each one containing a different percentage of gypsum powder. The percentage of water added to each mixture was calculated from the weight of the earth, appropriate

for an easily workable mix, while the percentage of gypsum powder was been calculated on the solid material.

The analysis of the shrinkage test results shows that the addition of gypsum powder significantly decreases the percentage of the linear shrinkage limit up to almost zero for an amount of 15% of additive. Table 1 presents the values of the linear shrinkage limit for every mixture tested.

Mixtures	linear shrinkage limit
water 23%	8.25%
water 23%, gypsum powder 10%	4.50%
water 23%, gypsum powder 20%	0.79%
water 37,5%	8.32%
water 37,5%, gypsum powder 10%	5.53%
water 37,5%, gypsum powder 20%	0.45%

Table 1- Mixtures with gypsum powder: linear shrinkage.

Gypsum powder added in a moderate percentage significantly improved the mechanical properties of earth. Table 2 presents the composition of tested mixtures and the results of the uniaxial compression test and of the three point bending test. Gypsum powder used as an additive proved to be successful. In fact, it gave good results in increasing both mechanical characteristics and water resistance, without significantly altering the appearance and colour of the material.

Mixtures	E (MPa)	σ_r (MPa)	μ_c	μ_{cd}	σ_t (MPa)
water 20%	93.69	1.47	1.31	1.44	0.322
water 25%, gypsum powder 10%	101.28	1.85	1.31	1.49	
water 25%, gypsum powder 15%	243.14	2.16	1.18	2.02	0.892
water 30%, gypsum powder 25%	157.05	1.50	1.31	2.19	0.495

Table 2 - Mixtures with gypsum powder. Uniaxial compression test and three point bending test: mechanical parameters.

The amount of 10% of gypsum increased performances, but with the percentage of 15% values were 1.5-2 times higher than those of specimens without additives. On the other hand, amount 25% of additive made earth particularly sensitive to humidity both regarding weight changes and mechanical performance.

The test results show that, beyond a certain percentage, gypsum is no longer able to improve mechanical performance compared to mixtures of earth without additives. The analysis of the test results indicates that an addition of 15% gypsum powder is the optimum value to improve performance at the highest possible value for the kind of earth analysed.

The immersion test showed a very significant loss of material for mixtures of earth without additives, while gypsum greatly reduces this phenomenon. The weight loss is very low even with a percentage of 15% gypsum powder but further improvement with the rate of 25% is minimal.



Fig. 1 - Comparison between mixtures with gypsum powder and mixtures without any additive after 6 cycles of immersion. The specimen marked with the letter 'b' contains 15% gypsum powder, the one marked with 'd' contains 25% gypsum powder, while 'c' does not contain any additives.

Gypsum powder was used as a stabilizing additive also in experimental research conducted by the Department of Architecture of the University of Istanbul. The 'Alker technology' studied in this study consists in stabilizing earth with gypsum powder and a small quantity of lime (Isik, 2011). Lime can increase the mechanical properties of the material compared to those obtained with stabilization achieved only with gypsum powder. The presence of lime, however, alters the soil composition in a way that makes it unfavourable for agricultural use, while gypsum actually increases the quality of agricultural land.

4. REINFORCEMENT WITH NATURAL FIBRES

Reinforcement of earth with natural fibres is a traditional practice. Straw or cactus are the most frequently used vegetable fibres. The research carried out by the Department of Costruzioni and Restauro of the University of Florence is based on the mechanical strength property of vegetable fibres used in the textile industry. The mechanical strength values for some of them are shown in Table 3.

Specimens reinforced with hemp fibres were made by varying the length of the fibres. Some prisms for the bending test were made with hemp fibres of the same length as the specimen, some with fibres of 5-8 cm length and others with fibres of 1-4cm. Cubic specimens for the compression test were carried out only with hemp fibres of 5-8 cm

length. A prismatic specimen reinforced with unprocessed broom fibre length of about 2 cm was also made. This fibre is thinner than the hemp one.

Fibres	Breaking strenght (g/den)
broom	9 – 11
hemp	5 – 8
nettle	5 – 6
flax	4 – 8
cotton	3 – 5

Table 3 - Mechanical properties of vegetable textile fibres.

The difficulty in finding broom fibres has not yet allowed for the realization and testing of a larger number of specimens. The fibre used was provided through a pilot project for the extraction of broom fibres with natural and environmentally friendly methods. This project is called PROGETTO GANTT and is being carried out in Calabria by ARTES and ARSSA and financed by the European Community. Even the stumps resulting from bending tests were submitted to the uniaxial compression test.

During the drying process the specimens behaved differently in relation to the length of the fibres. The ones realized with fibre of the same length as the specimen revealed significant cracking during the drying phase. This is due to the resistance exerted on earth shrinkage by fibres. Fibres prevented the natural and regular shrinkage of earth. Specimens made with 1-8 cm length fibres had a lower shrinkage than the ones made without any fibres, but they did not suffer any kind of cracking. The shrinkage of the specimen with broom fibres was the most regular.

The analysis of the three point bending test results shows that long fibres and short ones added in excess of 0.14%, create discontinuities in the specimen and undermine the resistance.

Fibre % by weight	Fibres length (cm)	σ_t (MPa)	E (MPa)	σ_r (MPa)	μ_c	μ_{cd}
No fibres		0.29	242.08	2.41	1.47	1.59
hemp 0.22%	28-30	0.35	103.89	4.65	2.49	1.78
hemp 0.40%	28-30	0.08	165.02	4.00	1.30	1.91
hemp 0.16%	1-4	0.44	434.90	6.48	1.70	2.60
hemp 0.14%	5-8	2.28	310.76	5.57	2.54	1.89
hemp 0.14%	5-8		143.30	3.60	1.00	3.50
broom 0.12%	1-2	1.21	354.81	5.09	1.60	2.23

Table 4 - Mixtures with vegetable textile fibres. Three point bending test and uniaxial compression test: mechanical parameters.

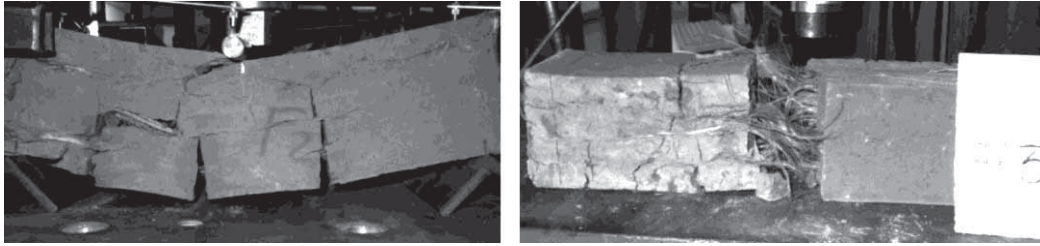


Fig. 2 - Three point bending test: specimens with long fibres after the test.

In Figure 2 it is possible to note that the specimens with long fibres have a lower strength but they are able to stay on the supports without falling even when they are completely cracked. This is due to the hemp fibre tenacity that kept the two stumps together.

5. CONCLUSION

Both the methods used in this experimental study have proved to be really useful for increasing the mechanical properties of earth and for reducing its shrinkage. It was also verified that gypsum powder significantly improves physical properties of durability and water resistance. The vegetable fibres tested showed an excellent adhesion to earth.

The experimental studies carried out so far on these methods of stabilization and reinforcement have yielded encouraging results for further research in this direction.

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Curriculum

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BUILDING CODES AND STANDARDS IN EARTH BUILDING – CURRENT SITUATION IN GERMANY

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world
Sub theme 2.1: Fundamental investigations on the material, research and development (R&D)

Keywords: Standards, Germany, international, DIN

Abstract:

Today building is a complicated commercial process characterised by legalised agreements between all participants. For commercial building projects, all materials and constructions have to conform to building standards and regulations. Material properties must be reproducible in standardised test procedures. This also applies for the control of the quality of production of earth building materials and constructions. Building conservation is a part of this process. Generally, national building standards have to reflect the current situation of building materials / construction systems of that country for which they have been developed.

In the last decade the use of earth in construction has become increasingly widespread in many countries. Building with earth can contribute to sustainable development by reducing environmental impact compared with other building materials or systems. This new consciousness has given rise to a growth in the number of earth building standards in recent years although, in absolute terms, the number is very small compared with other typical building materials and systems.

25 different earth building standards come from 14 different countries were examined. The standards provide varying degrees of technical information. With regard to their scope of application, the documents can be classified into three types, each of them dealing with a particular aspect: soil classification, earth building materials, earth construction systems.

In Germany, a revival of building with earth first came about in the 1980ies as an awareness of ecological criteria grew. A product of this development was the elaboration of an earth building standard, the *Lehmbau Regeln* by the Dachverband Lehm e.V., the German national earth building association. This standard was approved by the German State Building Authority in 1999 and 2008. Presently, that part of the *Lehmbau Regeln* concerning earth blocks and earth mortars is being adapted to the circumstances of national DIN / European building codes. This project includes the elaboration of three DIN drafts for industrially produced, chemically non-stabilized earth building materials: earth blocks, earth masonry mortars and earth plaster mortars. A fourth document was developed for soil as substantial ingredient of earth-based

building materials defining procedures for the control of parameters during soil excavation. The drafts will be submitted in 2011 to the German NSB DIN for approval. The project was accompanied by a three years research programme at the BAM Federal Institute for Materials Research and Testing, Berlin.

1. INTRODUCTION

Traditional earth building was practised over hundreds or even thousands of years on the basis of local experience with tried and tested building materials and construction methods. The suitability of a soil for building purposes was judged by the local masters, based on experience. Their accumulated technical knowledge was passed on from generation to generation.

Building today is a complicated commercial process characterised by legalised agreements between all participants – the client, the contractor, the architect, the building materials manufacturer etc. For commercial building projects, all materials and structures have to conform to building standards and regulations. Material properties must be reproducible in standardised test procedures. This also applies to quality control in the production of earth building materials and structures.

In most countries around the world, building with earth is primarily a traditional or “non-engineered” form of construction and lacks standards. In countries where no standards exist, building with earth lacks a legal framework for use in commercial projects.

In the last decade, however, the use of earth in construction has become increasingly widespread in many countries. Young architects in particular have discovered new ways of working, designing and building with this traditional material. Soil as a raw material for building purposes can be found in significant quantities in numerous regions of the world and many consumers, architects and producers of building materials value the favourable ecological properties of earth building materials and their contribution to sustainable development. This new consciousness has given rise to a growth in the number of earth building standards in recent years, although in absolute terms the number is very small compared with other typical building materials and systems.

Building with earth can contribute to sustainable development by reducing environmental impact compared with other building materials or systems. This aim can only be achieved by elevating earth building to an “engineered” building system based on building standards issued by national standards organisations.

2. INTERNATIONAL SITUATION

25 different standards from 14 different countries were examined in the frame of a book project (Schroeder, 2011). The standards provide varying degrees of technical information. With regard to their scope of application, the documents can be classified into three types, each dealing with a particular aspect:

- soil classification,
- earth building materials,
- earth construction systems.

Our analysis shows that standard, internationally accepted terminology is still lacking. This, however, is an essential general prerequisite for developing standards and normative documents.

In those countries that do have established standards, there are usually three types of document that govern the degree of implementation in the system of national building codes:

1. Standards and regulations of national standards bodies (NSB),
2. Normative documents,
3. Technical documents.

For earth building to be integrated into national standards, the highest degree of implementation, the materials and techniques usually have to pass a general process of approval with the NSB:

- draft development by a group of specialists (“the technical committee”) with proven competence in building with earth,
- draft presentation to a broad range of specialists with a view to reaching a consensus between them,
- presentation of the “consensus draft” to the NSB for final approval,
- in Europe the draft has to pass the EC Bureau for Standards for certification,
- publishing in a state decree.

Table 1 provides an overview of the countries that have established earth building standards and norms. The subjects most frequently covered in the earth building standards are:

- Building materials / techniques: adobe, compressed earth blocks (CEBs), rammed earth, timber-framed structures with earth infill.
- Material properties: texture, plasticity / binding strength, natural constituents (organic, lime, salt content), shrinkage, compatibility, classification, test results, safety performance.
- Local conditions: earthquake damage.

No.	Type of standard	Country
1	NSB	USA (New Mexico, California) , New Zealand, France, Peru, India, Nigeria, Sri Lanka, Zimbabwe, Chile (draft 2010, only for restoration of monuments), Germany (NSB draft in 2011)
2	Normative doc.	Australia, Spain, Switzerland, Germany
3	Technical doc.	Several authors

Table 1 - An overview of countries with established standards for earth building

Compared with other “normal” building materials, the field of earth building is less well defined and there is a general lack of standardized test procedures for determining soil parameters for earth building purposes. Most such tests have been adopted from other fields (concrete, soil mechanics, ceramics etc.) that were not originally devised for earth building and only partially take into account their particular properties. In order to

develop building with earth into an “engineering” building method the development of material-specific building standards is necessary.

3. THE GERMAN STANDARDS FOR BUILDING WITH EARTH

The development of standards for building with earth has a long tradition in Germany that reaches as far back as the 16th century in different German Federal States. As a result of the rapid growth of cities, two main problems developed with regard to building at this time: Timber as a prevailing building material became scarce and it was not fire-resistant. These constraints limited the use of timber, so earth was increasingly used as a building material. Fig. 1 shows a decree of the Elector of Saxony Friedrich August from 1786 regarding the use of cob for house construction.

In the last century the first German building standards were introduced in 1951 by the German NSB as DIN 18951 based on a draft drawn up in 1944. Increased industrialized production of building products displaced the production of earth-based building materials and earth building all but died out for over three decades. DIN 18951 was withdrawn in 1971 and not replaced.

A revival of building with earth first came about in Germany in the 1980s as an awareness of ecological criteria grew. A product of this development was the creation of an earth building standard, the *Lehmbau Regeln* by the Dachverband Lehm e.V., the German national earth building association (Dachverband Lehm e.V., 2009). This standard was approved by the German National Building Authority in 1999 and 2008 (3rd revised edition, fig. 2). The main aspects covered by this standard are:

- the selection of soils suitable for building purposes using testing procedures,
- earth building materials: definition of testing procedures and qualities,
- earth building structures: definition of construction, technologies, testing procedures and qualities.

Special attention must be given to load-bearing structures. The standards stipulate permissible strength parameters, including a safety coefficient for the calculation of walls made of rammed earth, cob or earth blocks. Normative physical parameters for the different earth building materials also allow the thermal and physical performance of building elements to be calculated, so that heating and insulation schemes can be drawn up and submitted for approval by the appropriate authorities.

4. THE WAY TO EUROPEAN EARTH BUILDING STANDARDS

In future, all European national standards will be replaced by European norms (EN) in response to the process of convergence in regulations. In the context of building products, this will be achieved by the Construction Products Directive (CPD) of the European Economic Commission of 1989. In April 2011, this document has been replaced with a new “Regulation of the European Parliament and the Council for the Marketing of Construction Products”.

The aim of this document is to foster the free movement and use of construction products in the internal European market, emphasised by the use of a common

technical language and clear terms for applying the CE mark. The CE mark guarantees defined qualities and reproducible testing procedures for quality control of the industrial production process of building products (Fig. 3).

For the conversion period, national marks will be accepted in the EU which guarantee standards for material properties and reproducible testing procedures for the quality control of the production process. In Germany, this is the “Ü mark” (conformity mark).

The *Lehmbau Regeln* developed by the Dachverband Lehm e.V. do not meet this requirement. Therefore, the DVL has prepared three standard drafts for industrially produced unstabilized (i.e. no artificial binders) earth building materials, which have been applied to the German NSB DIN for approval in 2011 and published parallel as Technical Recommendations TR (Dachverband Lehm e.V., 2011):

- TR 02 Earth blocks (EB)
- TR 03 Earth masonry mortar (EMM)
- TR 04 Earth plaster mortar (EPM).

A fourth document “Quality control of soil as an ingredient of industrially produced earth building materials” (TR 05) was also developed and published but is currently not part of the DIN approval process.

The project was accompanied by a three-year research programme “StandardLehm” at the BAM Federal Institute for Testing and Research, Berlin.

The standard drafts include procedures for achieving the Ü mark and consider aspects of Life Cycle Assessment (LCA) for sustainable building. Parallel to the industrially produced earth building materials, the use of locally manufactured earth building products is allowed. This will also be covered by the *Lehmbau Regeln* in the future.

4.1. DIN draft “Earth blocks EB”

Earth blocks in accordance with this standard draft (TR 02) will be classified into classes of use and classes of properties, which describe their suitability for a specific use (e.g. compressive strength CS) (Table 2). The earth block sizes are defined according to the DIN standard for brickwork (NF, DF, xDF). The dry density classes are given in kg/dm³. The types of block production are defined by abbreviations in Table 3.

Type of use	Class of use
Masonry infill of exterior framework walls, exposed to weather	Ia
Exterior masonry walls, continuously covered with plaster and exposed to weather	Ib
Exterior masonry walls, weather-protected; interior masonry walls	II
Dry building, interior use	III

Class of block CS	Mean value CS, MPa	Smallest single value CS, MPa
0	No requirement	No requirement
2	2.5	2.0
3	3.8	3.0
4	5.0	4.0
5	6.3	5.0
6	7.5	6.0

Table 2 - Classes of use and compressive strength (CS) of earth blocks

Type of block production	Mechanically "thrown"	Compressed	Extruded	Perforated
Abbreviation	f	p	s	g

Table 3 - Type of block production

Earth blocks of Class of use I and II can be used in load-bearing situations if their minimal Class of Block CS is 2. Laboratory test values are not allowed to fall below the mean and smallest single CS values.

4.2. Example of declaration

Earth block DIN xx – abbreviation with type of production, perforation and CS class – class of use – class of dry density – size abbreviation

Earth block DIN xx – EB p 3 – Ia – 1.6 – NF

Compressed earth block without perforation and CS class 3, class of use Ia, class of dry density 1.6, "normal size": length 240 mm, width 115 mm and height 71 mm.

The most important supposition for integrating earth building as an accepted technology in the general system of construction methods is the development of earth building codes accepted and introduced by the NSB. These standards must be harmonised in important fields such as testing procedures, quality parameters (strengths, safety coefficients) etc. in order to allow reproducibility and control of test results at an international level, as in other areas (concrete, brick etc.). This will be a long process.

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- *TM 02 Lehmsteine (Earth blocks)*,
- *TM 03 Lehm-Mauermörtel (Earth masonry mortar)*,
- *TM 04 Lehm-Putzmörtel (Earth plaster mortar)*,
- *TM 05 Qualitätskontrolle für Baulehm als Bestandteil industriell hergestellter Lehmbaustoffe (Quality control of soil as an ingredient of industrially produced earth building materials)*

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Fig. 1 - Decree by the Elector of Saxony Friedrich August from 1786 regarding the use of cob in house building

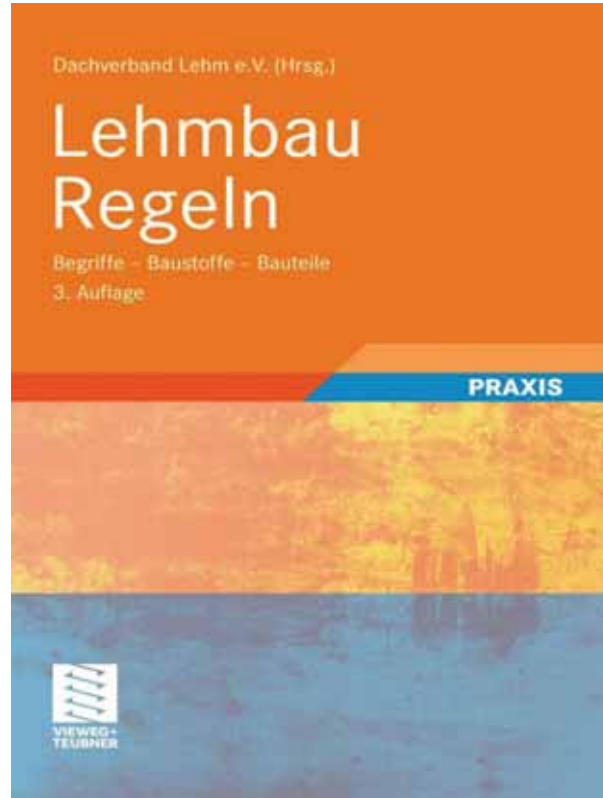


Fig. 2 - Lehmbau Regeln issued by the Dachverband Lehm e.V. (DVL)

CE (Ü) 01234
Name / symbol and address of the producer Year of application of the CE certificate Number of certificate
Number of the European (national German) norm Description of the product Declaration of characteristic properties defined by building standards / norms of NSB / EC (compressive strength, max. grain diameter, thermal resistance, declaration of special ingredients such as artificial binders etc.)

Fig. 3 - General scheme of a CE mark

BADGIR, EARTHEN RESISTANT STRUCTURE

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world

Sub theme 2.1: Fundamental investigations on the material, research and development (R&D)

Keywords: *Badgir*, earthen structures, construction, stability

Abstract:

Durability and stability of *badgirs* (as an earthen structure) over the decades, indicates the structural preparations during the construction time. The survey of used materials and ingredients, form and details, show the specific characteristic of *badgir's* structure which leads to its long-term durability.

This article is to introduce structural features and behaviour of *badgir*. Therefore, the reviewing of written references and checking the examples of *badgir* in historical city of Yazd, indicates the existence of the spaced structural design with a combination of vernacular materials (mud and wood) which has been used in *badgirs* construction.

1. INTRODUCTION

In the studies conducted about the *badgir*, the structure and materials aspect of the *badgir* have not been discussed much. The studies have mostly focused on its climate performance, typology, morphology and urban marks. The researches done by others, including McCarthy, Bahadorinejad, Roaf, Mahmoudi and Ghobadian have mostly taken into consideration its morphology and role in ventilation, mostly giving a simple short review on the materials used and its structure.

Knowing more about *badgirs* will result in the improvement of this vernacular knowledge and help the usage of past experiences in today's architecture. Lack of

categorized studies about the building procedure and used materials in *badgirs* will cause difficulty in the restoration, repair and the reconstruction of these structures. On the other hand increasing demolition causes loss of valuable old knowledge regarding these architecture elements.

This paper is presented according to an experimental study acquired from a field study about *badgirs*. Theoretical and basic studies were achieved by library studies. Structural and material researches were prepared by investigating Yazd *badgirs* and interviewing experienced workmen.

The results obtained from the study show that using compatible vernacular materials, junctures and material involvement together, lightening and applying the stagnation basis, for resistance in gravitational and lateral forces, will result in the strength and stability of these fine elements.

2. YAZD , THE CITY OF *BADGIRS*

The province and the city of Yazd are located on the central part of the Iranian plateau. Being located beside the central mountains and far from the Caspian Sea and the Persian Gulf, Yazd has a climate which mostly resembles dry and semi-dry desert climate. It is also due to proximity to the two major deserts of the Iranian Plateau and in the shadow rainy region. Hot weather, low dampness with lowly rainfall and highly evaporation are the main factors that make Yazd Province one of the driest provinces of Iran.

Historically, Yazd, with a large number of monuments and sites possesses a rich heritage of ancient culture and civilization during various historical periods of Iran. Fortunately, due to its distance from important capitals and its harsh natural surroundings, the city remained immune to major troops movements and destruction from wars and mainly held its urban forms and architectural style as well as its traditions for centuries (Abouei, 2006).

"Most historic areas of Yazd contain various traditional structures such as the *badgirs*, *ab-anbars* (water cisterns) and *qanats*, many of which are still remained in use. Among the important architectural and urban features of Yazd there have also been a large number of the *badgirs* (traditional wind catchers or wind towers) which is among the most significant elements of its built environments for centuries" (Ibid, Abouei, 2006) (fig.1).

"The existence of integrated earthen residential complexes in central regions of Iran, specially in the city of Yazd indicates Continuation of the historical construction with earth in long term. Particularly that such works before Islamic time or the first AH century like *fahraj* mosque have been explored in the sites near to the city of yazd. Most of the remained buildings and earthen architecture in the yazd relates to the Islamic era and the sixth century (the building of *jamee* mosque) and the seventh century onwards which includes the religious building (mosques, mausoleums,

Hosseiniyah) , defensive fortifications, schools, palaces, gardens and residential complexes" (Farahza, 2009, p.50).

Badgir have been used in these buildings to provide comfort conditions and the people of Yazd remarkably battled against the dryness of the neighbouring deserts for centuries.



Fig. 1- Skyline of the city made of clay and mud brick has been dominated by the domes and *badgirs* (authors)

3. THE *BADGIR*

"The *badgir*, literally the 'wind-catcher' is a high structure built above the roof of the buildings that catch the passing fresh air and channel it down to the ground floors and basements. The weathering shaft, ventilation shaft and wind tower are other names which are also used for the *badgir*. In the *badgir*, the hot air is captured at the top of the structure and passed through a simple canal, delivering the air at the bottom of the canal where there is ground floor or basement "(Ibid, Abouei, 2006).

4. FUNCTION OF THE *BADGIR*

There are actually two kinds of main functions about *badgirs*:

4.1. The function according to the principle of traction of opening facing the wind and the suction of openings back against the wind. "The way a *badgir* works is mainly based on taking the fresh air into the building and sending the hot and polluted air out or" the suction functions" perhaps it is not so necessary to explain that when the wind hits against the walls of internal partitions of the *badgir* it necessarily falls down, but it is

necessary to refer to this point that the other holes of the *badgir* turning back to the wind direction, gives the hot and polluted air into the wind and so works like a ventilation and a sucked machine (Pyrnia, 1981).

"The function of this kind of *badgir* is actually performed according to this fact that when the wind hits an obstacle, and since the density of the air is thick on the side of the wind direction, so in this direction there is a positive pressure, but a negative pressure on the other side. Therefore, when the ventilation is open on the sided of the wind there will be a positive pressure to a negative pressure. In the *badgir*, according to this principal, the opening facing the wind takes the air into the space under it (Tallar) [1] and the air in the tallar with its negative pressure on the opening back of the wind is drawn out" (Azami, 2005) (fig. 2).

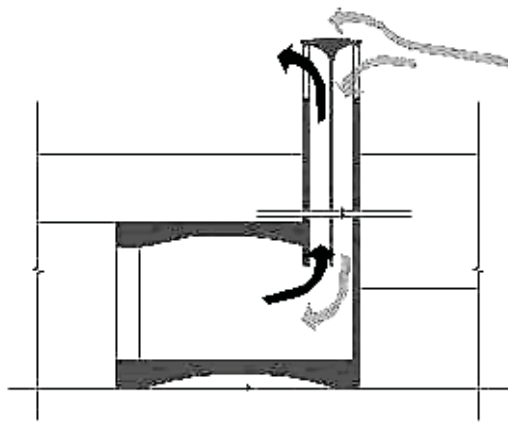


Fig. 2 - Traction and suction in *badgir* (Azami, 2005)

4.2.The function according to temperature difference. It seems that there is a little attention of technicians about the function of a *badgir* regarding the temperature difference. In fact when there is not a windy blast sensibly, the *badgir* acts according to this action. "During the day, since the sun hits on the southern face of the *badgir*, the air heats in the southern face of the *badgir*, and goes up" (Bahadori, pp. 144-54). This air taken above through the inner air of the tallar is changed and in fact it makes a kind of proportional vacuum inside the tallar, and takes the cool air of the inner court into itself, so the existing air in the northern opening is pulled down too (fig. 3). During the night it becomes cold outside, and the cold air moves down. This air is saved by the heat and becomes warm on parapets and then goes up. This circle continues till the temperature of the walls and outside temperature become equal. But before it usually arrives at this situation the night ends and once again the *badgir* acts its function as mentioned above. In general, in most time, *badgir* does as we explained it, in order to the traction, suction, and the effect of temperature difference" (Ibid, Azami, 2005).

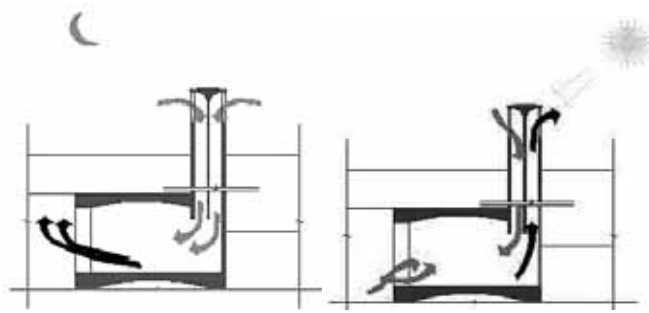
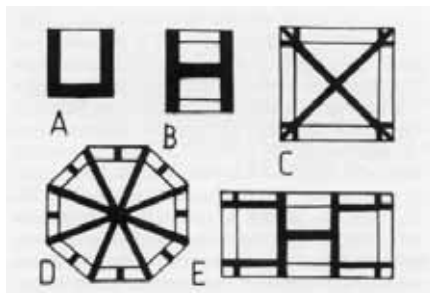


Fig. 3 - *Badgir* function during the day and night (Azami, 2005)

5. KINDS OF YAZD *BADGIRS*

"*Badgirs* are seen in a diversity of forms and plans; there are square, rectangular and octagonal types. The square form is the type used in the four directional *badgirs*. The rectangular forms consist of one, two, four directional. The octagonal form is the type used in eight directional *Badgirs* in Yazd. (fig.4). The four directional towers are the most popular *badgirs* in the city of Yazd. They have four main vertical shafts divided by partitions" (Roaf,s,1982) (Fig. 5).



A: Unidirectional

B: Two directional

C: Four directional

D: Eight directional with two vents on each side

E: Four directional with two "false" vents on two opposite sides

Fig. 4 - Diversity of Yazd *badgirs* forms and plans (Roaf, 1982)

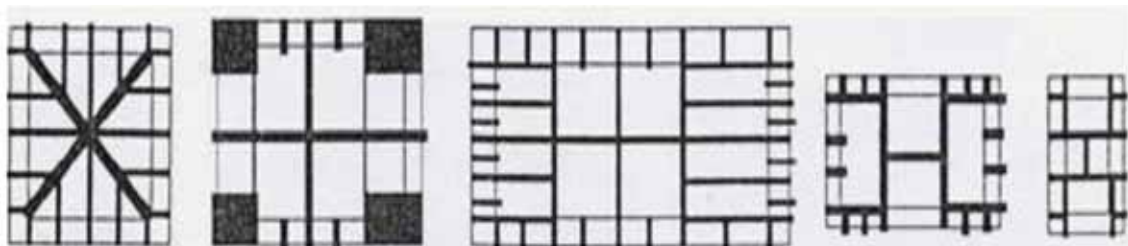


Fig. 5 - Typical plan of four directional Yazd *badgirs* (Roaf, 1982)

6. PARTS OF *BADGIR'S* STRUCTURE

Badgir is constructed of different elements which cooperation of these parts together will be effective in the final formation and structure. Every part has special structural and functional properties and the way they settle in *badgir* is stalk, partitions, shelf and crown respectively from down to the top.

6.1. Stalk

Stalk or column is the lower part of *badgir* which is placed between roof and shelf of *badgir*. The stalk is the connection between shelf and the room under *badgir* that most of the weight of *badgir* is on it and the mass center is located there. The stalk's shape is like an incomplete pyramid which will help in stability.



Fig. 6 - Stalk of a destroyed *badgir* in Sahlebneali quarter of Yazd (Authors)

6.2. partitions

Partitions are made of *khesht* (mud brick) and brick which divide *badgir's* canals into smaller canals and move the air down the *badgir* from different directions. These partitions are placed from the bottom of *badgir* to the ceiling of it. The partitions have been seen in different shapes and according to the used materials, they absorb lots of heat. In addition to increase the wind speed by decreasing the canal's width, the partitions increase the structure's stability. As the wood are placed between partitions, the partitions and other parts of *badgir* are more connected that will cause more stability and strength.



Fig. 7 - above left) : the major partitions of a constructing *badgir*

(Rudiger Lorenz, der Windturnbauer)

Fig. 8 - (above right) : the major partitions of 3D model of *badgir* (Authors)

6.3. Shelf

Source, mouth or shelf is the upper part of *badgir*'s stalk which sends the air into the *badgir*. The normal form of the shelf is horizontal, vertical or square like. The source surface is divided by some blades which increase the beauty of the *badgir*. These Blades are connected to the walls by wood which are inside them and they are strengthen against destruction and fall.



Fig. 9 - (above left) : the shelf facade of a *badgir* in yazd (Authors).

Fig. 10 - (above right) : the 3D model of a *badgir*'s shelf (Mahmoudi,M,2007,p103).

6.4. Crown:

In fact, the crown is the ceiling cover and the highest part of *badgir* which is decorated by a special kind of brick. The materials used for crown are mostly brick and mud that are put together like floors and have created a kind of projection that plays main role in directing the wind to the source.



Fig. 11 - the crown of a *badgir* in yazd (Authors)

7. *Badgir* building Technology:

To build a *badgir*, first the Stalk is built up to a certain height and then the inside partitions. The partitions' weight will be transferred by the wood that is placed between them. After finishing the Stalk and placing the partitions, the process of building the shelf begins. After finishing the shelf and its inside and outer blades and fixing the

wood between them, it's time to put the ceiling and crown on it. At the end of building process, *badgir* will be covered by mud and some decoration will be added to some parts.

To increase the stability while building *badgir*, they connect the parts with a kind of wood named Shouruneh[2]. The most important and considerable point is about using lots of wood in different parts and levels of *badgir*. These woods are mostly Shouruneh which has a high resistance and high mass and also is resistance against penetration of insects and ants. The wood plays the main role in stability of structure of *badgir* and acts as joint. The connections between this wood is Sazou [3] and in modern kinds is nail and these connections are linked and fixed to other parts by plaster of stucco with mud.

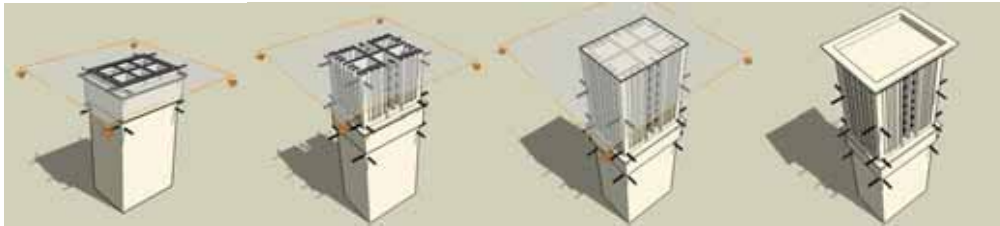


Fig. 12 - 3D model of a *badgir's* construction procedure from left to right (Authors)

8. Analysis of *badgir's* materials and ingredients :

Every parts of *badgir* have special functional and structural properties and are made of different materials. Analysis of materials used in different parts of *badgir* can develop today's knowledge and applying past experiences to use in today's architecture.

In this study, we selected some of Yazd *badgirs* and examined the materials to get a point of typology of materials in these *badgirs*. Selection of *badgirs* was from different kinds of *badgir* and the samples were selected from the buildings that were easily accessible.

The result of this study is available in the appendix [4] and a brief result is shown in the following chart.

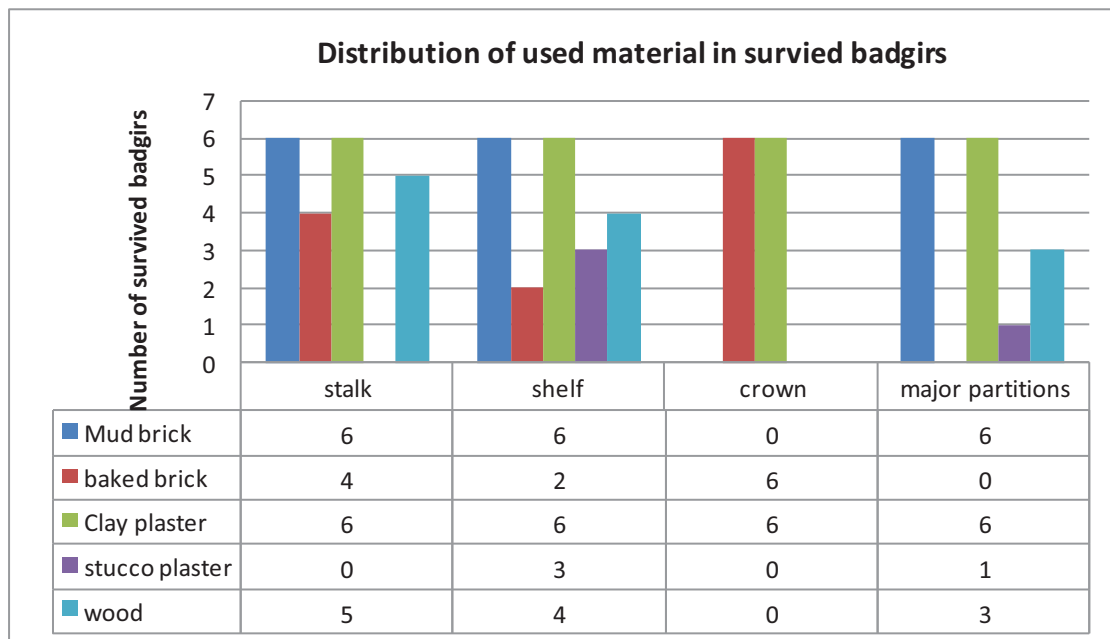


Fig. 13 - the chart of used materials in different parts of Yazd *badgirs* (Authors).

The usage of these materials and ingredients in each parts of *badgirs'* structure differentiate from the others as we see in the chart.

The construction materials used for *badgirs* depend on structure and function. The choice of materials ensures that the *badgir* operates effectively as a passive cooling system. *badgirs* in hot dry climates are built either of mud brick or more commonly, of baked brick covered with mud plaster. Mud brick (adobe) absorbs heat slowly, because soil has uncompressed volume.

Mud plaster (*kah_gel*) is a mixture of wet earth with fine or chopped coarse straw. These construction materials give the *badgir* a coarse texture. The mud plaster covering the facade of a *badgirs* has a light colour and therefore reflects the sun.

The other materials in *badgir* are stucco plaster and timber (shouronah) which used in different parts of *badgirs'* structure.

These materials and ingredients have some similar properties like Abundance, vernacular, sustainabile, economical and matched. The usage of the characteristics in yazd *badgirs* leads to the stability and durability of these high structures.

"It should be noted that these materials are still using at restoration and construction of *badgirs* in the city of Yazd" . (Khajehrezaei, 2009)

9. CONCLUSION

Despite its fine appearance, the *badgir* has resisted forces and causes of environmental degradation for years and has remained static. Using the correct vernacular and matched materials has caused the partial integration of this structure. Also the architectural knowledge used in *badgirs* has made it light which has caused the increase of the center and mass toward the ground.

The correct integration of the materials together and joining them together by the junctures used in different parts of the *badgir* is another reason for its stability. Primary study on the capability of *badgir* in resisting the lateral forces shows that the *badgirs* structure has the necessary resistance due to correct material composition together and the usage of tensile elements such as Shurune Wood in general connections such as walls and wings. Restoration management and the possibility of repairing the *badgir* using vernacular materials and architectural knowledge have been effective in its stability.

Mortazs' house <i>badgir</i>	Mud brick	Baked brick	Clay plaster	Stucco plaster	wood	Height
Stalk	*	*	*		*	
Shelf	*	*	*		*	5.4 m
Crown		*	*			
Partitions	*		*		*	
Rasouliaus' house <i>badgir</i>	Mud brick	Baked brick	Clay plaster	Stucco plaster	wood	Height
Stalk	*		*		*	
Shelf	*		*			5.2 m
Crown		*	*			

Partitions	*		*		*	
Kermanis' house <i>badgir</i>	Mud brick	Baked brick	Clay plaster	Stucco plaster	wood	Height
Stalk	*	*	*		*	
Shelf	*		*	*	*	8 m
Crown		*	*			
Partitions	*		*		*	
Rouhaniuons' house <i>badgir</i>	Mud brick	Baked brick	Clay plaster	Stucco plaster	wood	Height
Stalk	*		*		*	
Shelf	*		*			4.1 m
Crown		*	*			
Partitions	*		*		*	
Shokouhis' house <i>badgir</i>	Mud brick	Baked brick	Clay plaster	Stucco plaster	wood	Height
Stalk	*		*			
Shelf	*		*	*		2.4 m
Crown		*	*			
Partitions	*		*			
Rig mosques' <i>badgir</i>	Mud brick	Baked brick	Clay plaster	Stucco plaster	wood	Height
Stalk	*	*	*		*	
Shelf	*		*		*	5 m
Crown		*	*			
Partitions	*		*			

Endnotes:

1. Covered terrace overlooking the courtyard (semi-open space), called Tallar is the flexible and multi-functional space in traditional yazd house.
2. Kind of wood that has excellent strength and is resistant to termite attack.
3. A kind of rope made from palm fibers which used as building material in yazd historic house.
4. The following chart indicates the survived result of used material in different parts of investigated yazd *badgirs*.

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EXPERIMENTAL INVESTIGATION ON THE ANTI-SEISMIC EFFECTIVENESS OF TEXTILE-FIBRES NET APPLIED ON EARTHEN BUILDINGS

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world

Sub theme 2.1: Fundamental investigations on the material, research and development (R&D)

Keywords: Antiseismic strengthening, textile fibres net, experimental analysis

Abstract:

This paper attempts to evaluate the effectiveness of the addition to an earthen structure of a resisting plate, made of natural textile-fibre nets laid on an earthen matrix, as anti-seismic defense. An experimental campaign was conducted to test the efficacy of two types of fiber, jute and a coconut derivate, which are commonly used for geotechnical applications. In particular three-point bending tests have been conducted on adobe bricks produced in laboratory, which have been plated on the intrados side with the aforesaid nets laid on a mud mortar layer.

The experimental analysis permitted to evaluate the tensile strength and the strain capacity due to the net. On the basis of these results it will be possible to define criteria for the choice of net as anti-seismic devices and especially to propose guideline for earthen house strengthening.

1. INTRODUCTION

Earthen buildings host the lives and the activities of a large part of the world's population. As many advantages of some of the traditional earthen techniques are well known (for instance in terms of economy, simplicity, ecology and healthiness), also they mostly show a low grade of safety against destructive natural events like floods and earthquakes. The mechanical performances of earth as a building material are lower than the ones of stone or fired bricks (Minke, 2006). In masonry structures, this is not a problem as long as the loads (self and working weights) are vertical and the thick bearing walls ensure low compressive stresses, but they are vulnerable to seismic events. In case of earthquakes a building is exposed to horizontal forces with alternating sign which induce both compressive and tensile stresses, thus causing damage and the collapse mechanisms.

In the tradition and in recent times, the main strategies to improve the behavior of earthen construction may concern two issues: 1) the improvement of mechanical properties of the material; 2) the improvement of the global behavior of the structure.

The first is achieved through an earthen stabilization, or through the use of a higher pressure in the production processes. Stabilization can be achieved by melting into the wet mix substances such as vegetal derivates (Achenza and Fenu, 2006) minerals like

gypsum (Işık, 2005) or a little percentage of lime or concrete (Smith, 2010); either, the mix can be added with fibrous materials (for instance straw, hair, dung have been used; it has also been proposed to reuse industrial plastic waste (Binici et al., 2005) High pressure machines allow to make stronger pisé walls and to produce the abundantly used compressed earth blocks (BTC) (Morel and Pkla, 2002).

The second objective may be pursued by improving the resisting properties of the masonry wall box, retrofitting the connections among the walls (and among walls and storeys) or by adopting strategies that product ductility. Many cultures introduced wooden structural elements to gain quake resistance in earthen buildings. Those features usually are tie-beams, storeys or top belts and they sometimes transform the whole into an infill-frame structure (see the exceptional case of the *torchis*, as well as the timber-laced structures (Langhenbach, 2007). This is widespread from the West to the East, especially where there is an Ottoman heritage, but also in northern Europe's practice as well as in some areas of Africa and South America. It has been also proposed to build up the walls inserting vertical and face-to-face bond canes among the adobes (Méndez *et al.*, 2010). In the last years the application of nets (plastic, metal or natural hemp) anchored and laced with mud mortar on the external surface of earthen walls have been proposed in order to strengthen the buildings against seismic actions (Blondet and Aguilar, 2007). The effectiveness of this a system depend on the adhesion between the net and the mortar and on the wall-net anchorage solution.

This paper presents the results of an experimental campaign testing the effectiveness of natural textile-fibre nets used as a retrofit device. The two types of fibre chosen are jute and a coconut derivate, which are commonly used for geotechnical applications and available in different formats. Three-point bending tests have been conducted on adobe bricks (40x20x12 cm sized) produced in laboratory, which have been plated on the intrados side with the nets laid on a mud mortar layer. The experimental analysis permitted to evaluate the increase of tensile strength due to the net. On the base of this fundamental parameter it will be possible to carry out adequate consolidation projects able to achieve a better seismic response for earthen structures. This work could also help to develop guidelines for mud house strengthening.

2. THE EXPERIMENTAL ANALYSIS

The purpose of this experiment is the evaluation of the effectiveness of the addition of a resisting plate made of natural textile-fibre laid on a mud and straw mix matrix to an earthen structure. This strengthening system is supposed to improve the tensile strength of the walls and to help avoiding collapses of the masonry wall box, especially the ones caused by the seismic lateral forces.

The goal of the investigation is to see and quantify whether an increment of resistance and deformation qualities is achievable. The plates were applied to the larger face of the adobes, and five different sets of samples were prepared to be subjected to three points bending tests. Since this test produces tensile stress in the intrados of the sample, it is used to simulate the condition of the external surfaces of a wall box which is opening under the effect of an earthquake.

3. THE SAMPLES

For the experiment, 15 adobes were made using 42x21x10,5 cm formworks, with a 5% shrinkage taken in account. The soil was collected in Terranuova Bracciolini in the

valley of the Arno river, Tuscany and analyzed by ICVBC of Florence's CNR. Its mineralogical composition (quartz: 32%, feldspars: 32%, argillaceous minerals and others: 36%. The latter are: kaolinite: 15%, illite: 55%, chlorite-vermiculite: 20%, chlorite: 10%) shows that the material is suitable for adobe making: it is a lean soil with a sand structure, and it has only a little percentage of expandable clay particles (chlorite-vermiculite). The earth was subjected to the following process: grinding, cleaning up of the larger impurities and a 8 mm sifting in order to reduce the unevenness this implied a divergence of response among the samples. Three parts (considered in volume) of this cleaned powder was later mixed with one part of straw (of an average length of around 10 cm), and little less than a part of water. Thanks to a kneading machine, the mixture was transformed into an homogenous plastic state, ready to be put into the formwork. The adobes were left to dry for two weeks in a room with minimal fluctuations of humidity and temperature.

In order to check the effectiveness of the proposed system, two different fibrous materials were selected for a comparison. The nets chosen for the reinforcing plates were made of jute and of a coconut derivate, which are commonly used for geotechnical purpose, and have been kindly offered for this research by SEIC Geotecnica of HARPO Spa (Trieste). The main mechanic characteristic of the two products used (Geojuta and Coconet) are contained in the technical sheets:

Geojuta

mesh size:	16x10 mm
weight:	500 g/m ²
tensile strength:	15-20 kN/m
ultimate strain:	6-8 %

Coconet

mesh size:	11,5x12,5 mm
weight:	700 g/m ²
tensile strength:	20 kN/m
ultimate strain:	34 %

Since they are made of natural fibres and produced throughout unsophisticated processes, they are intended to represent a sample for the use of similar ones in various regions of the world, especially in poor or rural contexts.

It was assumed that the effectiveness of the reinforcement mostly depends on the adhesion between the net and the adobe, thus two attachment system were tested for each kind of material: the first one consists on laying the net over the surface and in plastering it with a simple earthen mortar (same of mix used for the adobes, but with more liquid), while the second had the addition of U shaped nails (Φ 1,5 mm, length 200 mm) anchoring the net to the brick. The comparison between such different devices allows deducing a quantification of the contribution both of the material's adhesion and of the metal joints. On the whole, 5 sets of 3 samples have been subjected to the test:

• 3 adobes with no reinforcement	ADOBE
• 3 adobe + Geojuta + earthen mortar	JUTE_Simple
• 3 adobe + Geojuta + U nails + earthen mortar	JUTE_Anchored
• 3 adobe + Coconet + earthen mortar	COCO_Simple
• 3 adobe + Coconet + U nails + earthen mortar	COCO_Anchored



Fig. 1 - Production process of a sample: a) the mesh nailed to the surface. b) the plate plastered. c) COCO_Anchored1

4. THE TESTS

For earthen materials, the three-point bending test has been proposed as an acceptance test, both for legislation (Standards Australia Handbook 194, 2002; New Zealand Standard 4298, 1998) and for specific test purposes (Houben and Guillaud, 2005). In fact, it may be carried out rather easily directly on the bricks at the building site without the need for cuts or the need to create *ad hoc* samples. The bricks are supported at their extremities and loaded on the centre line, perpendicular to the axes. This gives the additional advantage that the load which produces the collapse by bending is very low and does not require the use of special presses (it is in fact possible to apply the load simply by overlaying bricks). In the laboratory the sample is put with the plate on its intrados over two iron cylinders (Φ 20mm) set around 3 cm from the extremities (side B) and parallel to them; in the middle of the upper surface, another cylinder also parallel to the other ones transfers the vertical force given from a press with a load cell, while the lowering is read by two displacement transducers.

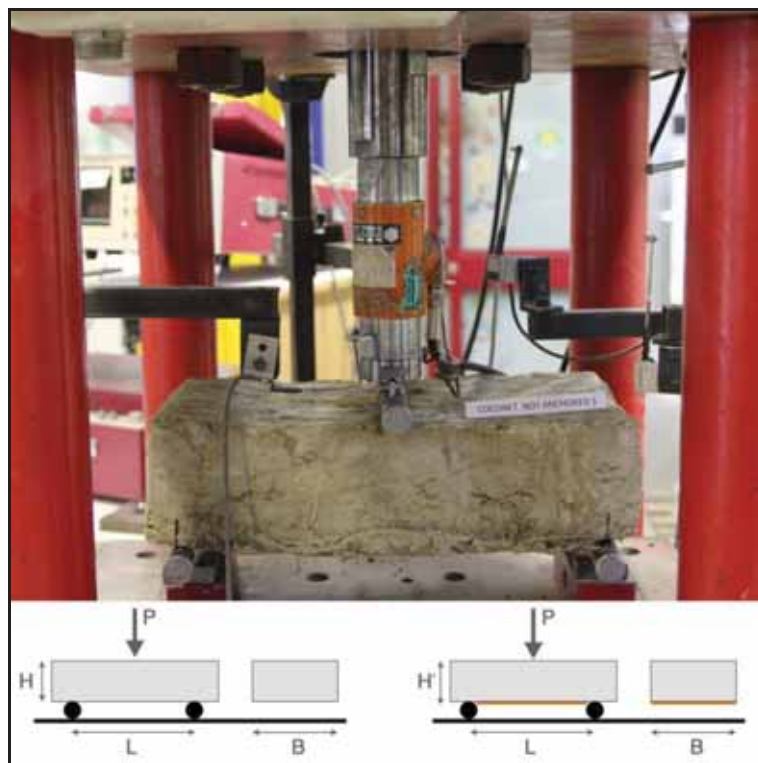


Fig. 2 – Experimental set-up

A TDS recorded the load/displacement diagrams which also contain the post-peak phase, being the tests conducted under displacement control.

It is thus possible to determine the stress in the middle cross section of the sample induced by the bending, and therefore the tensile stress to which the intrados is subjected to. The formula used is the following: $\sigma_t = (1.5 \times P \times B) / (L' \times H^2)$, where P is the maximum load, L' the distance between the axis of the cylindrical supports and BxH is the surface of the cross section of the brick.

5. RESULTS

All the load/displacement diagrams are reported in Fig. 3. For each set the average values of load with related displacements were identified at the first load peak (p1), after the brittle load loss (l), at the second peak load (p2) and at the ultimate load (Lu, conventionally 90% of Lp2). Also the tangent stiffness of the two parts of the diagrams (α and β) were found. Those results are reported in fig. 4.

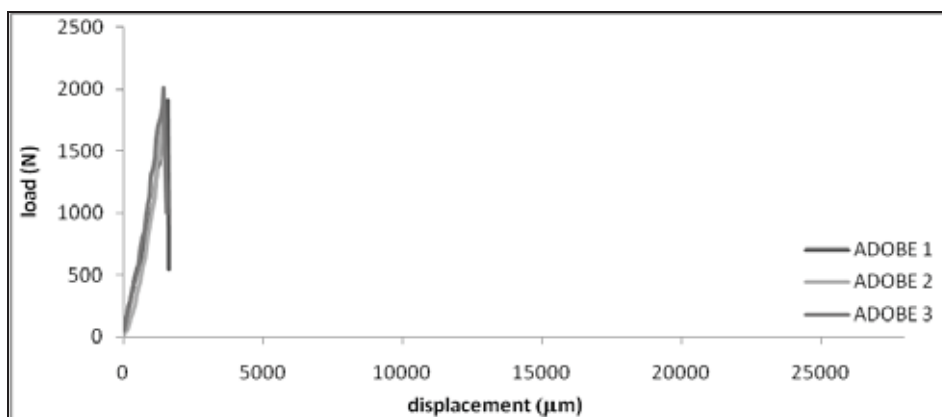


Fig. 3 - Load/displacement diagrams

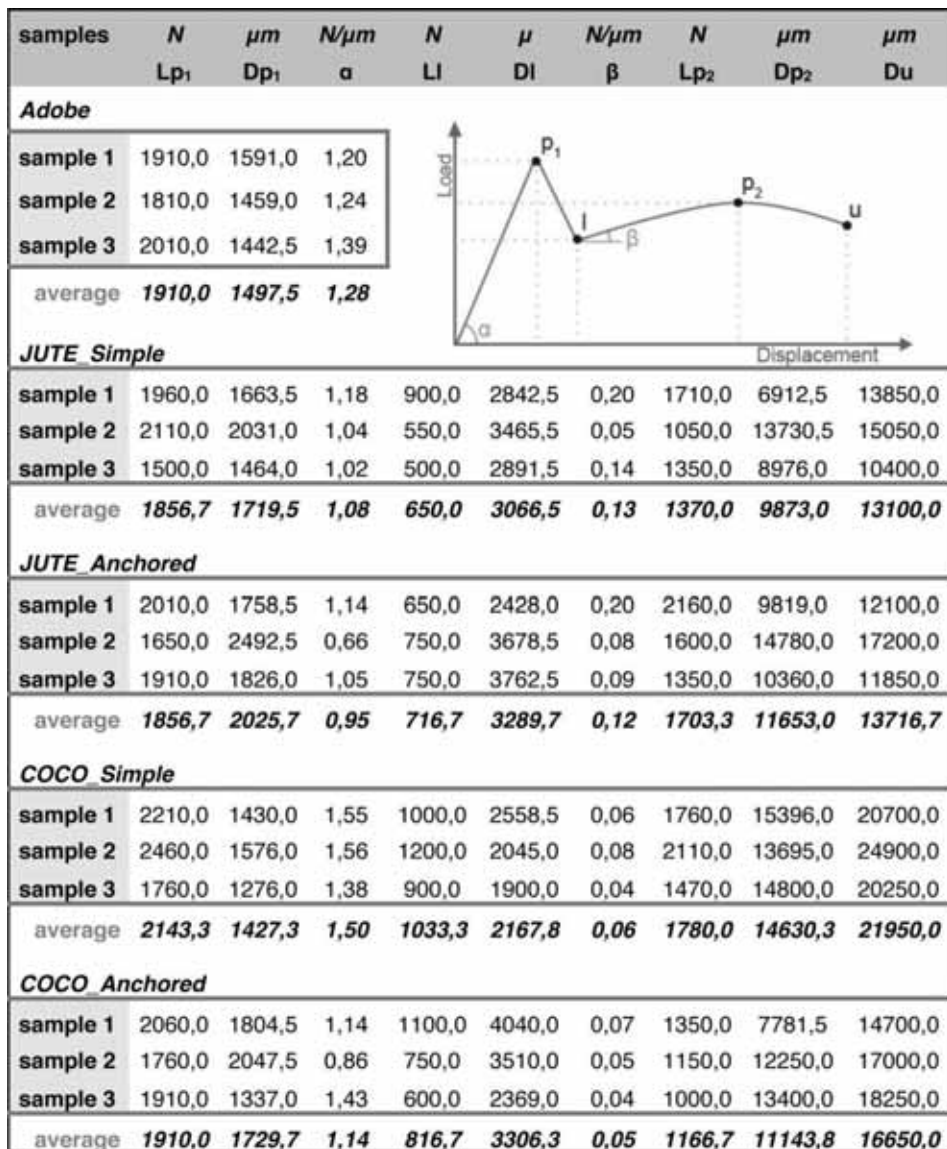


Fig. 4 - Experimental results

6. CONCLUSION

The following observations are prevalently on the basis of the load/displacement diagrams recorded during the tests. The résumé of the main values is shown in the confrontation (fig. 5) where the schematic average diagrams of each typology of samples are reported. The comparison among the diagrams shows that the reinforcement with nets gives a very high strain capacity. The ultimate displacements of the reinforced samples are around 15 times bigger than the ultimate displacements of the not reinforced ones. This is crucial in allowing energy dissipation under seismic actions. All the diagrams of the reinforced samples share the same path, and two main phases can be identified: the brittle fracture of the adobe with its loss of load, and the subsequent increase of load bearing thanks to the cooperation of the plate.

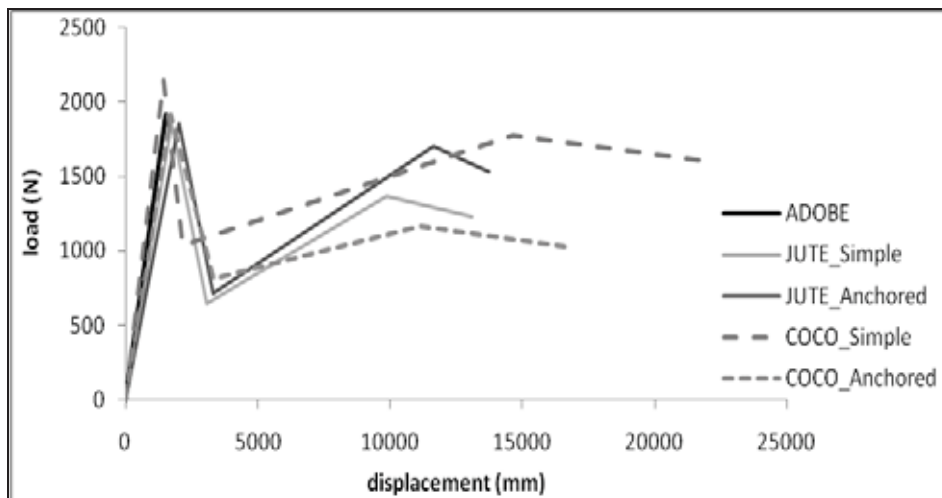


Fig. 5 – Schematic average diagrams

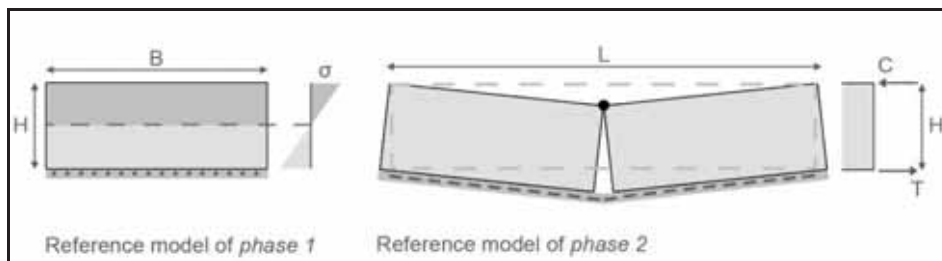


Fig. 6 - Mechanic reference models in the two phases of the diagrams

The first phase concerns the behavior of a rectangular cross section under a simple bending moment. It is subjected to the classic butterfly diagram where the upper part is compressed and the intrados is tensed. Basing on the average maximum load values of the ADOBE samples, the tensile strength of the material was calculated (0,43 MPa). The remarkable performance is due to the fact that the adobes were made with care in laboratory with the use of selected and clean material.

In the first phase of the bending test, the plates (whether they contain jute, coconut or nothing but the mud mortar) do not play any role. In fact there are no appreciable differences in the first peak loads of the samples. The only perceptible singularity is the higher value of α (i.e. the stiffness of the sample) in the samples with coconut made meshes. This fact may indicate that the coconut net starts earlier its collaboration and alters the first branch of the diagram making it stiffer.

A further example of this is the fact that the coconut's higher LI value, as if it entered the synergy sooner than in the case of the jute. This fact is imputable more to some practical aspects in the making than to the fibre net's resistance itself: Coconet is more robust and it is easier to lay it down keeping the ropes stretched parallel to the stress direction thus ready to be activated. The limper Geojuta, instead, moves when plastered and disposes its ropes along sinuous paths; when tensed, many displacement units are wasted before starting its action, and perhaps compromises the adhesion with the mortar.

Observing the developing and the shape of the cracks, it has been noted that the presence of the nails make them more regular and vertical in the middle of the sample.

The second phase shows a regain of load bearing capabilities thanks to the cooperation of the plates. It refers to another mechanic model: the bending moment is opposed by the internal couple produced by the compressed upper edge and the tensed intrados fibres. Here there is the evidence of the contribution of the nets. For each set, the maximum force per length unit that the plate was able to face was computed (JUTE_S: 6,1 N/mm; JUTE_A: 7,6 N/mm; COCO_S: 8,0 N/mm; COCO_A: 5,2 N/mm).

The different stiffness is appreciable by the values of β . Coconet containing plates gives slower ascending path in load bearing, and reaches bigger ultimate displacements. COCO_Simple plates had the best performances both in terms of maximum force per length unit and ultimate displacement. In the case of the coconut mesh, the anchorages may interfere with an homogeneous distribution of the adhesion stress. This does not happen with the jute because the stretching of the ropes from the sinuous position may damage the mortar they are laid in. Hence jute nets must rely on the nails.

This interpretation is also confirmed by the fragmentation of the plates observable after the tests. It shows the effect of the stresses transmitted by the adhering nets to the mortar. These are more marked closer to the main cracks in the middle and they fade out getting closer to the extremities.

The fragmentation in the case of Geojuta is barely visible and irregular. With Coconet, they are homogeneously spread and appreciable, especially in the not anchored ones where the adhesion is fully employed.

This test shows the contribution that a “poor” reinforcement, obtained by the net embedded in an earthen matrix, can offer to a building made in adobe or in pisè (as example near the corners). An average value, useful to design the strengthening against earthquake of earthen houses, can be deduced from the test. In fact the maximum force per length unit, corresponding to P2 point in the diagram, permits to evaluate the global force needed to support a wall against the overturning during an earthquake. For example a strip of COCO_S one meter high can bear till 8000 N of horizontal traction, produced during the earthquake. It is yet to determine the effective anchorage length that can be useful in order to design the longitudinal extension of the strip (in present test a 20 cm length was used). For this aim it will be necessary a specific test.

Endnote

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LOW-COST HOUSING IN UNDERDEVELOPED COUNTRIES: SIMPLE STRATEGIES FOR A MORE SUSTAINABLE CONSTRUCTION

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world
Sub theme 2.1: Fundamental investigations on the material, research and development (R&D)

Keywords: Low-cost housing, flexibility, burnt brick, adobe

Abstract:

This paper pretend to show how simple intervention strategies, using minimal resources, can be applied to low-cost residential buildings in underdeveloped countries in order to reduce environmental impact. Malawi was chosen as a case study, consequence of a research project conducted at the University of Minho (Portugal), in partnership with a construction company. On a visit to Malawi some low-cost houses were analyzed and functional and environmental problems were detected. Proposed strategies were based on the optimization of the constructive system. One problem found was associated with the burning of bricks for construction; thus it was proposed to replace these by Compressed Earth Blocks. Another problem was related with the lack of acoustic and thermal insulation on roofs, composed of a single metal sheet. It was proposed to build a false ceiling with local straw and cardboard as insulation, under ventilated attic.

1. INTRODUCTION

Underdeveloped countries, such as Malawi, have high rates of urban growth. The planning is traditionally held on the basis of space delimitation in areas with different land uses but without a vision of sustainable growth. The highest occupancy rate density occurs along the communication lines. Such planning does not allow an adequate capacity to meet the fast growing cities, with drastic consequences in terms of infrastructure, which quickly become inadequate, always running at the limit of its capabilities, occurring frequent cuts of electricity and water supply.

There is great pressure on housing caused by fast urban population growth. With an average rate of urban growth of 5.2%, there is a need for rapid responses in the supply of Housing dwellings. The number of available houses is much smaller than the number of required houses. Thus, the legal system of housing can only serve a fraction of the demand, which means that the remaining demand is solved through illegal constructions. This situation leads to illegal plundering of land, poor construction quality and overcrowded housing. UN-Habitat (2009) estimates that 90% urban population of Malawi lives under minimum health conditions, which is translated into about 2 million people living in overcrowded houses, with serious lack of clean water and adequate sanitation facilities².

The dwellings can be classified by their permanence or transience, resulting in greater or lesser durability of materials and systems used in its construction. It can be distinguished three different categories: permanent, semi-permanent and traditional (non-permanent). The permanent is defined as having roofs constructed with steel plates, ceramic tiles or cement and the walls of burnt bricks, concrete blocks or stone masonry. The traditional, is defined as having thatched roofs and walls made of clay, rammed earth or adobe. In Malawi, approximately 16% of dwellings are permanent, 19% are semi-permanent structures and 66% are traditional. These values are quite different depending on the type of area in question: urban or rural areas. In urban areas, 43% are permanent, 38% semi-permanent, and only 19% are traditional. The majority of housing stock appears in the urban context, which deserves special attention by the constant need of renovation to keep it permanently³.

2. RECENT CONTEXT

Malawi is one of the least urbanized countries in the world (about 17% in 1998); its urban population will reach 3.8 million by 2014 (circa 23% of total population). The large urban centers are Blantyre (the dominant commerce center) and Zomba (the former capital) in the south, Lilongwe (capital) in the central and Mzuzu in the north. The largest city, Blantyre, has a population of over half a million people, of whom over 50% live in illegal houses.

Licensed housing ownership is only available to social groups with higher incomes. The major part of people has to choose between rent or build an illegal house. Thus, the economy takes an important role in housing supply. The reduced regulatory requirements and supervision in construction, means that people can build any type of house, although incomplete and without minimal living conditions, with the possibility to improve it or increase it, later.

In Malawi it is possible for, low-income families, to own their single house. This is due to the availability of suitable land which, by traditional means, permits the manufacture of bricks at the site of work. In rural areas is often used adobe and thatched cover. Most houses in rural areas have a floor area between 20 and 30m². 19% of housing in Malawi has only one compartment; the majority of houses have two or three compartments, 31 and 27% respectively, 15% have four compartments and approximately 8% have five or more compartments¹. Many houses have no access to infrastructure such as water, sanitation and power supply. In some cases, even in the urban context, the drinking water supply exists, but is located in the public space, shared by several households.

In Malawi, the major part of housing is of one storey and single-family occupation. Row-housing, geminated (three facades) or isolated (four facades) can be found. These are mostly built with burned brick, produced locally with the ground soil extracted from areas near the building. The roof structure is in timber with a corrugated sheet metal (galvanized or zinc) as waterproof element without insulation. The manpower is, in most cases, from future inhabitants or from small teams of workers, working by their own. These usually inhabit their own work place during its construction, including their households. The building technologies are simple in order to minimize the construction cost.

3. PROPOSED INTERVENTION STRATEGY

The current housing stock in Malawi is minimally adequate to the needs in terms of number of dwellings, but leaves much to what could be desired in terms of livability and quality. Around half of families have their own houses, with occupancy rates with circa two people per compartment, but with living conditions far from the reality of developed countries. The enlargement of the possibility of access to housing for the poorest social classes, improving the urban land markets and access to finance, are measures that allow them to fight poverty, social exclusion, environmental degradation and slow economic growth.

3.1 Analysis of existing assets to implement the proposal

The case study country of this paper is Malawi, but the methodology and principles proposed could be extended to the analysis and intervention in other undeveloped countries in Africa, South America and Asia. The dwellings studied were located in the cities of Lilongwe, Blantyre, Salima and Ntcheu. The typology with only one bedroom is the most common found in this country in low-cost housing; are presented here examples from three cities visited: Lilongwe, Ntcheu and Salima. The data collected on these three houses, are listed in the following Table 1.

	PARAMETERS	DESCRIPTION	DRAWINGS
NTCHEU	Overview	Urban area	
	Household	2 adults and 2 children	
	Building System / Materials	Masonry brick walls, roof in zinc sheets and floor bricks	
	Anomalies	Brick pavement with much wear	
	Conservation status	Reasonable	
	Typology	Room, bedroom, kitchen, pantry, shower and bathroom	
	Gross floor area	83,0m ²	
	Floor area	66,9m ²	
	Indoor area	24,7m ² + 8,5m ² + 1,5m ²	
	Outdoor area	32,0m ²	
	Covered area	48,7m ² + 21,7m ² + 3,4m ²	
Others	Rented house 35-40 years		
LILONGWE	Overview	High density urban area	
	Household	2 adults and 2 children	
	Building System / Materials	Burnt brick masonry walls, towed or painted with lime, roof in metal sheets and cemented floor.	
	Anomalies	Deterioration of the bricks and cracks in some corners of the house.	
	Conservation status	Reasonable	
	Typology	Room, bedroom, kitchen and bathroom	
	Gross floor area	46,2m ²	
	Floor area	37,1m ²	
	Indoor area	34,2m ²	
	Outdoor area	2,9m ²	
Covered area	48,7m ²		
Others	Income of 7.000 Kw per month; construction from the 80's		
SALIMA	Overview	Urban area	
	Household	3 adults and 1 child	
	Building System / Materials	Burnt brick masonry walls, towed or painted with lime, roof in metal sheets supported by timber beams	
	Anomalies	Damage caused by flooding, settlement support cracks in the corners and openings	
	Typology	Room, bedroom, kitchen, pantry, shower and bathroom	
	Gross floor area	74,2m ²	
	Floor area	59,2m ²	
	Indoor area	24,3m ² + 8,6m ²	
	Outdoor area	26,1m ²	
Covered area	41,1m ² + 18,6m ²		
Others	Income of 3.000 Kw per month		

Table 1: Details of dwellings with only one bedroom visited in Ntcheu, Lilongwe and Salima

3.2 Proposed solution

Table 2 shows the process used to find the average areas used in the typologies studied in Malawi in order to arrive at reference typology. Sometimes some of the analyzed houses didn't present optimal conditions of solar orientation and partitioning. However, these assumptions were considered in the proposed dwelling unit in order to be able to demonstrate the possibility of improvement, regardless of conditions, as show Table 3. In the proposed solution there are only openings to the north and south, allowing associations in row or twin-housing, and especially avoiding harmful solar gain. Using the guidelines as east and west like divisions between homes or just as blind gable on tops, allows to reduce the cooling need⁴. The areas of sleeping, living and work receive natural light while there is a commitment to the thermal performance. Thus, the openings require shading that causes the light to be more uniform and at the same time, the temperature may be more controlled. In typologies flexibility was improved for proper usage compartments (Figure 1).

	House in Linlongwe	House in Nitcheu	House in Salima	Reference House, Average
	m ²	m ²	m ²	m ²
Distribution area	1,6			1,6
Room	18,1	12,6	11,7	14,1
Kitchen	3,5	3,0	3,1	3,2
Bedroom 1	9,1	10,5	11,5	10,4
Wc1	1,9	1,9	1,5	1,8
Wc2		1,5		1,5
Shower		1,6	1,5	1,5
Pantry		3,6	3,8	3,7
Open porsh	2,9	3,8	2,6	3,1
Gross area (GA)	46,3	54,2	48,2	49,6
Usable area (UA)	37,1	39,9	35,7	37,6
Fixed area	46,3	54,2	48,2	49,6
Flexible area	0	0	0	0
Ratio UA/GA (%)	0,80	0,74	0,74	0,76

Table 2 - Comparative analysis of the studied typologies with only one bedroom with the reference house

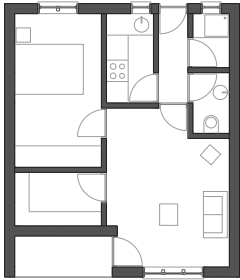
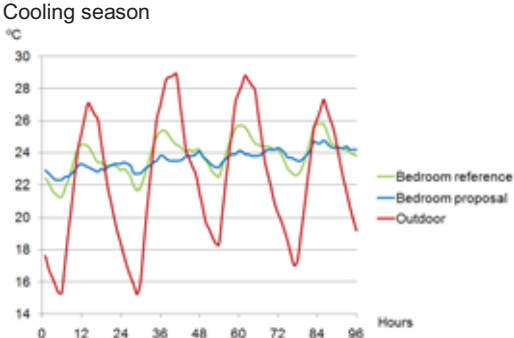
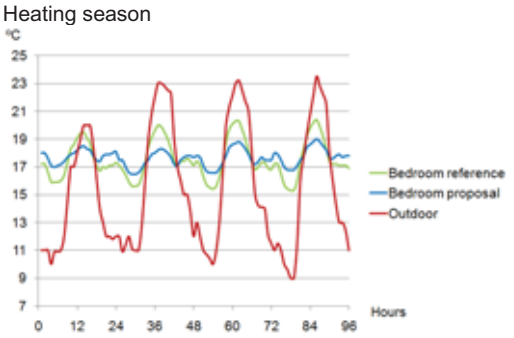
	PARAMETERS	DESCRIPTION	DRAWINGS
REFERENCE AND PROPOSED SOLUTION	Overview	Urban area	
	Household	2 adults and 2 children	
	Building System / Materials	Masonry burnt brick walls, roof in zinc sheets with straw as insulation and cement floor	
	Typology	Living room (14,1m ²), bedroom (10,4m ²), kitchen (3,2m ²), pantry (3,7m ²), bathroom (1,8m ²), shower (1,5m ²) and terrace (3,1m ²)	
	Gross floor area	49,73m ²	
	Floor area	64,39m ²	
	Indoor area	39,05m ²	
	Outdoor area	3,10m ²	
	Covered area	49,73m ²	
		Thermal behavior	<p>Cooling season</p>  <p>Heating season</p> 

Table 3 - Analysis of the reference and proposed solution



Fig. 1 – Proposed solution: street with the proposed dwellings arranged in rows.

As it is shown on the sheets above, the proposed system for the roof improves significantly the thermal behaviour in the cooling season (summer) and in the heating season (winter).

This is due by the fact that the proposed system has a ventilation system improved, and thus the ventilation is more controlled and acts more efficiently. On the reference solution we used to have some openings usually above the windows without an integrated control of the air changes. The insulation on the ceiling and a consequent ventilated roof works well with this hot humid climate, characteristic of the Central Africa.

In a global analysis (fig. 2), as the cooling season comprises 8 months of the year, it is admitted that the proposed system was conceived as benefiting this situation. In the winter season interior temperatures are on the comfort range (22-25°C). On the other hand, and in spite of the improvements, when it concerns to the minimum temperature, the solution in the heating season interior temperatures still doesn't fit the comfort band (20-24°C). That situation takes less importance because this is not the critical season.

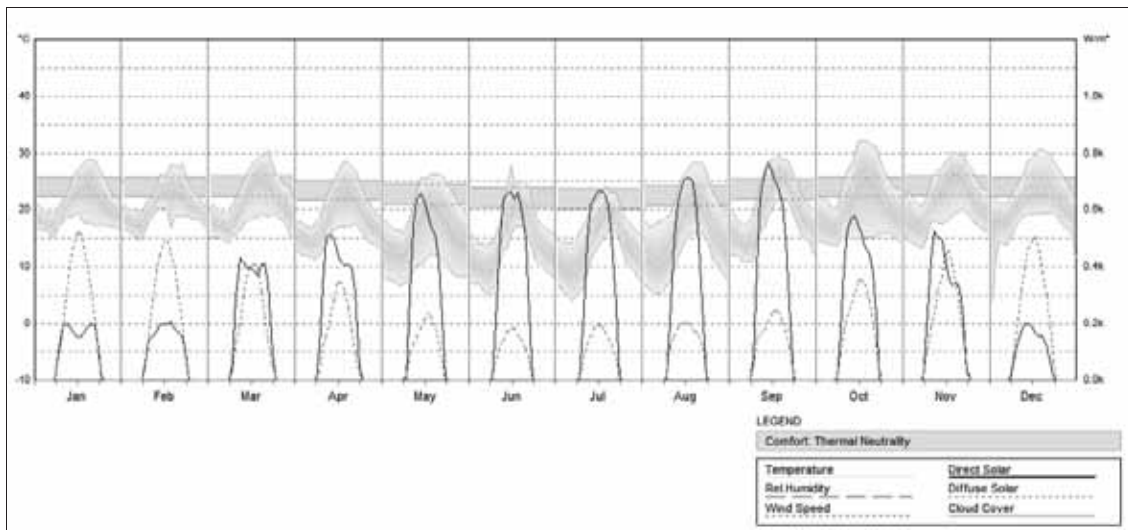


Fig. 2 – Global analysis of the thermal comfort in Malawi

4. CONCLUSIONS

The purpose of this study is showing the possibility, although maintaining the areas and minimal economic costs, to achieve environmental improvements in housing of underdeveloped countries. The integration between environmental pre-occupancy and functional post-occupancy aspects is desirable, demonstrating that through some simple strategies, such as the improvement of building systems, this can be achieved. Proposals with a different image and very different constructive solutions could undermine the acceptance of the solution. Moreover, an increment of the areas would mean an increase cost of land and unaffordable building for the households economy, whose resources are very scarce. It is expected that this study may be relevant in the approach to the design of new housing buildings, but also as a strategy suited to the refurbishment of existing housing buildings, both for the country on the presented case

study, as well as for other underdeveloped countries, especially in Africa and Asia, where prime-material soil is abundant, cement is scarce and manpower is not qualified.

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ENDNOTE

¹ UN-HABITAT, *Malawi - Urban Housing Sector Profile*, UNON, Nairobi, ISO14001:2004, 2009, p.53.

² HomelessInternational, Malawi, in:
http://www.homelessinternational.org/standard_1.aspx?id=1:28496&id=0:276&id=0:262,
consultado em 12 de Novembro de 2009.

³ UN-HABITAT, *Malawi - Urban Housing Sector Profile*, UNON, Nairobi, ISO14001:2004, 2009, p.54.

⁴ MENDONÇA, P.; DUARTE, D.; RAMOS, L.; *Habituação social em países subdesenvolvidos – estratégias de intervenção com recursos mínimos*; Lisboa, 2010.

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DESIGN AND CONSTRUCTION PROPOSAL FOR AN EP METHOD OF CONSTRUCTING AN EARTHEN WALL MADE OF ENVIRONMENTALLY FRIENDLY MATERIAL

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world
Sub theme 2.2: Architectural design and sustainable development

Keywords: EP construction method, environmentally friendly design, environmentally friendly material, earth house

Abstract:

The growing trend of using environmentally friendly materials in the construction industry has led to an increase in the building of earthen houses and similar structures. However, the lack of various design methods for building earthen houses has created a number of challenges. This study explores the concept of an egg packing (EP) construction method for an earthen wall made of environmentally friendly material; it explores the design characteristics and methods; and it reports on a research-based design of an environmentally friendly EP earthen wall. The construction of the earthen wall is based on the design of an EP earthen wall. Construction problems related to the foundation, windows, doors, and roof were identified and improved for the implementation of the design and construction methods.

1. INTRODUCTION

1.1. Background and Purpose

Interest in the construction sector's role in the reduction of greenhouse gases is increasing worldwide. Since the declaration of its "low carbon, green growth" slogan, the Republic of Korea has implemented various energy conservation and environmentally friendly policies. It has also adopted energy-saving design standards for new buildings and established a certification system for the energy efficiency of buildings. There has consequently been a gradual increase in the construction of environmentally friendly buildings; there is also greater interest in these types of buildings. The growing popularity of environmentally friendly buildings can be attributed to the fact that they alleviate the environmental problems caused by the hazardous substances in building materials, some of which cause diseases. Structures built with environmentally friendly materials have become a topic of keen interest in many countries, including the Republic of Korea. Modern industrialization still relies heavily on such construction materials as concrete, cement, and reinforcing bars. These materials have long overshadowed the renewed interest in the use of earthen materials, which are an environmentally friendly alternative. However, in the construction industry today the renewed popularity of houses made of earthen materials is increasing is hindered by a lack of design methods. This study examines the egg packing (EP) construction of an earthen wall made of environmentally friendly materials; it also explores the characteristics and methods of this type of construction and reports on the research-based design of an environmentally friendly EP earthen wall.

1.2. Method and Scope

In spite of the growing interest in building earthen houses and similar structures, the construction of earthen houses is hindered by a lack of design methods. Accordingly, this study proposes a new design method for an EP construction of an earthen wall made of environmentally friendly materials. The main objective of the study is to implement design and construction methods that overcome the common construction problems.

The first step is to identify the theoretical concept and characteristics of an EP method of constructing an earthen wall. The second step is to propose appropriate design methods and address common construction problems.

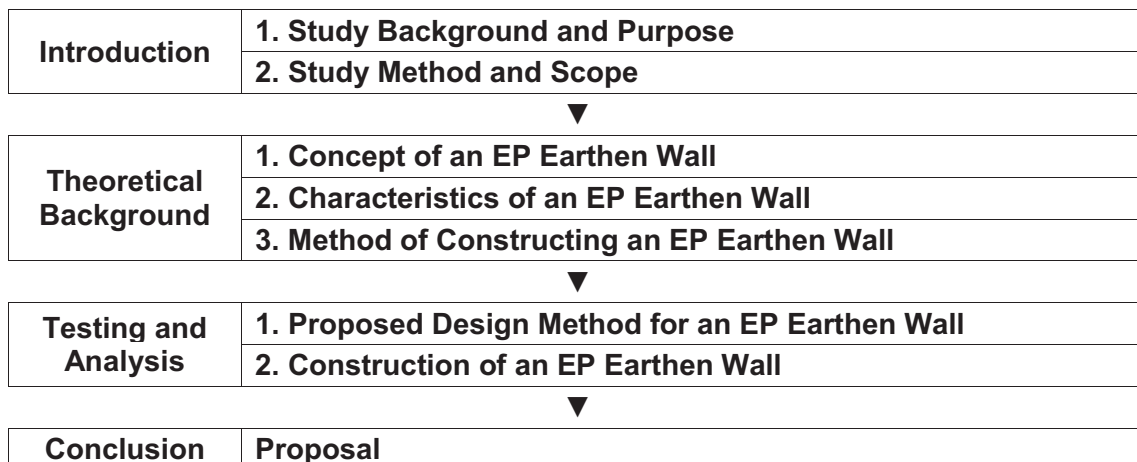


Table 1. Study flow

2. THEORETICAL BACKGROUND

2.1. Concept of an EP Earthen Wall

The concept of an EP earthen wall is derived from a traditional earthen wall. A traditional earthen wall, as shown in Fig. 1, is made of natural materials such as clay, rocks, and tiles. Nowadays EP boxes are used because they are made of nature-friendly material and recycled paper.


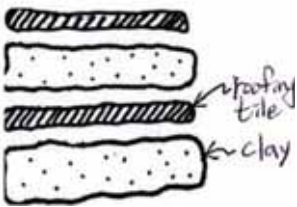
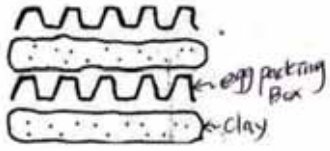

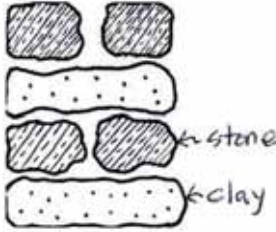
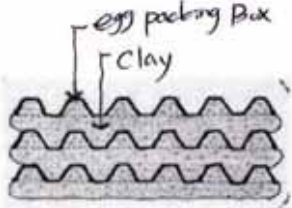
Concept	Composition	Application
		
		

Fig. 1 - Traditional earthen wall

2.2. Characteristics of an EP Earthen Wall

Anyone can construct an earthen wall out of earthen materials and EP. No special expertise is required, and the EP and earthen materials are inexpensive and readily available.

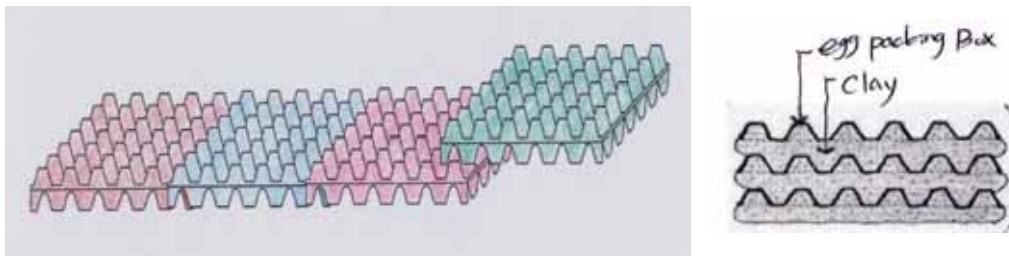
An EP earthen wall can function as an independent wall (without being attached to other structures). And because the EP and earthen materials can be easily stacked together, the work can be performed by anyone.

An efficiency test on an EP earthen wall and other existing earthen walls compared Korea's most widely used earthen bricks as well as samples of earth ramming, rice-sheaf walls, and EP construction methods. Each category was analyzed in terms of economic efficiency, constructability, and work time.

The task of stacking an earthen wall covering an area of 1 m² was analyzed with respect to various factors such as the labor cost, the complexity of the earthen mixture, the availability of the materials, the required level of construction expertise, and the required work time. In terms of material costs and labor costs, the most expensive process involves earth ramming, followed by rice-sheaf walls, earthen bricks, and finally EP walls. Thus, EP earthen walls are the most economical of all the earthen architecture construction methods.

Earth ramming has the most complex earthen mixture. This type of earthen mixture must be made in a humid state. Earthen bricks are also somewhat difficult due to the joint masonry. A rice-sheaf wall and an EP wall use a plastic earthen mixture, which even a non-expert can mix.

Several observations can be made about the availability of the materials. Firstly, the components of earthen bricks must be purchased separately. Secondly, earth ramming involves the use of formwork and earthen materials in a humid state, both of which non-experts may have difficulty obtaining; and, thirdly, the solid, uniform rice-sheaves of a rice-sheaf wall are difficult to acquire, so the manufacturing components must be purchased separately. Finally, because an EP earthen wall is made of common EP and earthen material, the components are readily available. Earthen bricks, earth ramming, and rich-sheaf walls all require a professional skill level, whereas an EP earthen wall can be constructed by non-experts.



Each layer of EP is covered with a 10 mm to 20 mm thick layer of earthen material

Fig. 2 - The stacking of EP and earthen material

2.3. Method of Constructing an EP Earthen Wall

The ratio of clay, sand, and water for the EP earthen wall is 1 : 1 : 0.5. The ratio may vary slightly, depending on the state of the earthen material. The earthen material must be in a plastic or dough-like state so that it can be easily molded into any desired shape; specifically, it must be able to fill the EP mold.

When the mixing is uneven and there is an abundance of water, the earthen material must be applied carefully. If it is applied too thickly, big cracks can appear.

When the foundation is completed, the earthen material is stacked to a certain height (10 cm to 20cm). If it is stacked unevenly, the task of stacking the EP becomes difficult.

As each EP box is laid on top of the earthen material, it overlaps the adjacent EP box by one-sixth of the width of the EP box. Because of the structural valleys and mountains of the EP, the interlocked EP boxes have a strong lateral force.

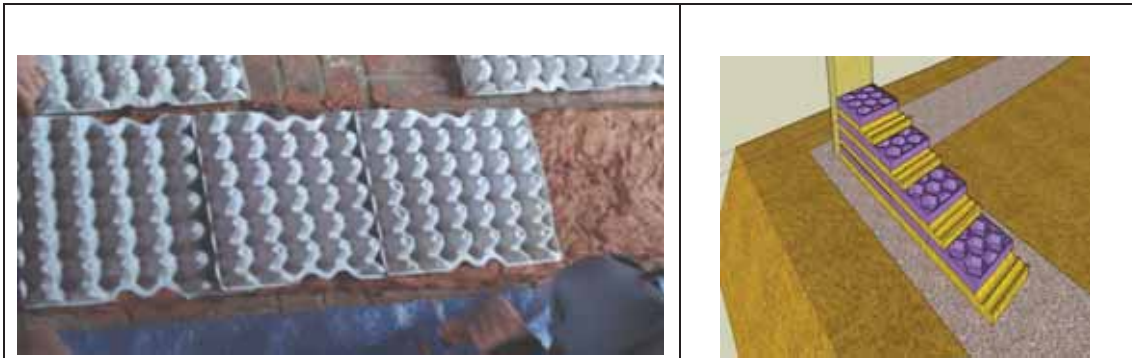


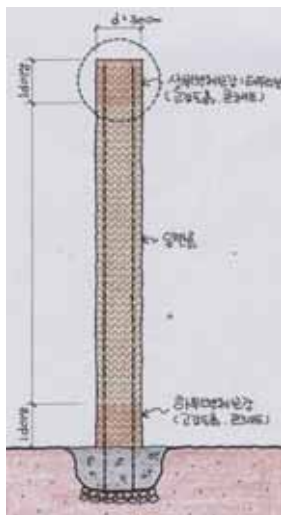
Fig. 3. EP stacking order

During the stacking process, each EP box should be pressed firmly with the hand so that the layer of earthen material fills the spaces between the valleys of the EP box. Any spaces that form between the valleys during the stacking process may result in the formation of residual settlement, thereby creating a twisting phenomenon at different heights.

Owing to the plastic nature of the earthen material, the daily stacking height is based on a standard of 1.2 m to prevent the wall from sagging or warping.

Lime can be mixed with environmentally friendly binding materials to enhance the intensity and speed up the drying time.

A vertical reinforcing bar is connected to the foundation of the wall when the wall exceeds a length of 3 m. The vertical reinforcing bars are installed at @900 intervals to strengthen the lateral force.



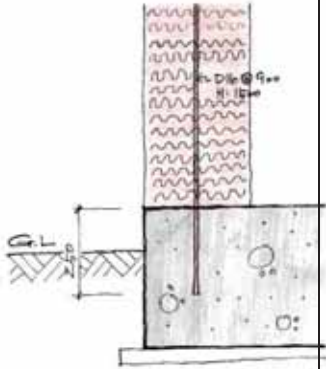

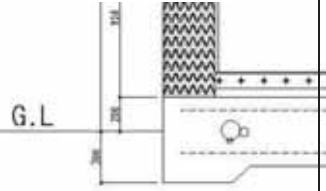

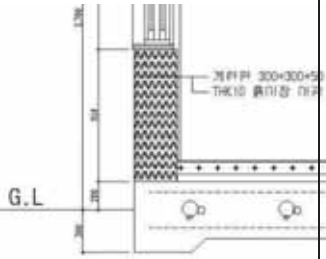

The upper area acts as a wall girder near the roof to directly sustain the weight of the roof, so it must be strengthened by lime or some other environmentally friendly binding material.

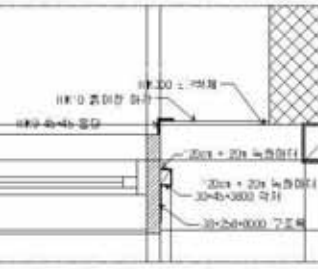

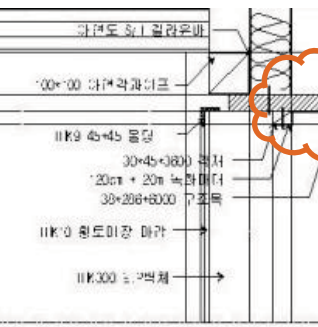

The area close to the foundation of the wall is affected greatly by water, so the water resistance needs to be enhanced by a 30 cm layer of lime or environmentally friendly binding material.

Fig. 4 - Method of constructing an EP earthen wall

3. ANALYSIS OF THE DESIGN FOR AN EP EARTHEN WALL

The foundation area of the EP earthen wall, the lower area of the wall, the window and door joining segments, and the upper area of the wall were carefully designed so that the wall could be drawn in detail and built on-site for the purpose of identifying and analyzing various construction problems.

Category	Design	Construction	Analysis
Foundation area			<p>The reinforcing bar connected to the foundation had an effect on the lower part of the earthen wall. However, warping occurred when the height exceeded 1 m. The reinforcing bar must be connected to the beam in the upper area to prevent the warping effect.</p>
	<p>For an earthen wall longer than 3 m, the design foundation to reinforcing bar D16 @1000 and a height of 1.5 m</p>	<p>Build as design</p>	
Lower area of the earthen wall			<p>Given that the lower area of the EP earthen wall is vulnerable to water, it can be supplemented by changing the construction to 0.5 B two-column earthen bricks.</p>
	<p>Design of the EP earthen wall</p>	<p>Change of construction to a 0.5 B two-column earthen brick</p>	
Lower area of the window /door of the earthen wall			<p>Due to dry shrinkage of the EP earthen wall, the construction problem prevented any twisting during the construction of the window/door lower area</p>
	<p>Design of the window/door lower area</p>	<p>Change of construction of the window/door lower area</p>	

	of the EP earthen wall	with earthen bricks	
<p>Window area of the earthen wall</p>	 <p>The wooden structure was raised where the window/door and EP earthen wall meet. As the dry state shrinks, spaces form where the wooden structure is in contact with the earthen material. On account of the spaces, 30*45 rectangular pieces of lumber were installed in the upper area and on the side. Jute tape was applied where the wooden structure was in contact with the EP earthen wall.</p>	 <p>Build as design</p>	<p>The flow of air from outside to inside can be blocked by installing 30*45 rectangular pieces of lumber at 2 mm spaces caused by the dry shrinkage in the EP earthen wall.</p>
<p>Upper area of the window/door</p>	 <p>Design of the upper area of the window/door</p>	 <p>Construction change in the upper area of the window/door</p>	<p>When designing the upper area of the window/door area, a protruding 100 mm wooden structure is installed to counter the rainfall. However, it is most likely shorter during construction, so it is reinforced with a colored steel plate.</p>

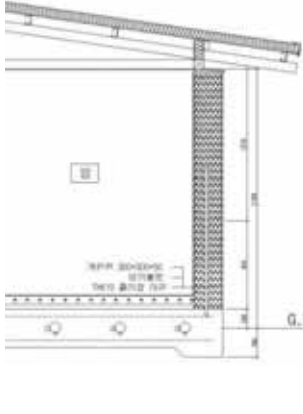

EP earthen wall			<p>Observance of the daily height standard prevents the EP earthen wall from sagging or warping. The full state phenomenon occurs if the wall reaches a height of 1.2 m.</p>
	<p>The daily stacking height is 1 m due to the plastic state of the earthen material.</p>		
	<p>Design of the EP earthen wall</p>		

Fig. 5 - Detailed analysis of the EP construction method

4. CONCLUSION

This study proposes design methods for the construction of an EP earthen wall made of environmentally friendly material; it also suggests ways of overcoming some of the problems of the construction process. The purpose of the study is to provide basic data on the design and construction of earthen walls. The following conclusions can be drawn from the results of the study:

- Firstly, if the earthen wall is longer than 3 m, the foundations of the wall should be strengthened with reinforcing bars (D16 @1000) up to a height of 1.5 m. When the reinforcing bars are used there is no warping in the lower area of the earthen wall foundation but warping occurs in areas higher than 1 m. The warping effect can be prevented if the reinforcing bars are connected to the beam in the upper area of the wall.
- Secondly, the lower area of the EP earthen wall is supplemented with earthen bricks because of its vulnerability to water.
- Thirdly, a wooden structure was raised in the area where a window or door meets the EP earthen wall. Because the earthen material in this area is subject to dry shrinkage, a number of 30*45 rectangular pieces of lumber were installed in the upper and side areas of the wall. Jute tape is applied to the area where the wooden structure is joined to the EP earthen wall.
- Fourthly, in the case of an EP earthen wall that exceeds 3 m, a limited stacking height of 1 m prevents any cracking or sagging behavior. A stacking height that exceeds 1 m can lead to sagging or a full state phenomenon. Furthermore, dry shrinkage can induce the formation of 1 mm to 2 mm cracks in the wall, though the

cracking can be avoided if vertical structures are built at 1 m intervals. The vertical structures are expected to facilitate the construction of EP earthen walls.

This study examines various methods of designing and improving the construction of EP earthen walls.

Endnote

This study, which forms a part of the project, has been achieved with the support of national R&D project, which has been hosted by National Research Institute of Cultural Heritage of Cultural Heritage Administration. We express our gratitude to it.

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Curriculum

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EARTHEN ARCHITECTURE, CHUNG GU-YON, AND WORKS OF GUYON ARCHITECTS ASSOCIATES

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world

Sub theme 2.2: Architectural design and sustainable development

Keywords: Chung Gu-Yon, Gimje Jipyeongseon middle&high school, earthen construction method

Abstract:

Guyon architects applied methods to build structures using earth such as a rammed earth construction method using an earth wall frame (formwork), a masonry method using earth bricks or earth blocks, a method to create effects using earth plaster, etc. to realize various housing and public building designs.

With initial design done by Chung Gu-Yon and Guyon Architects, construction of Paju Yeondasan-ri housing and Muju Jindo-ri Town Hall were accomplished by earth wall frame construction methods using formwork.

In the Gimje horizon school project, many types of earth architecture construction methods were used for the school buildings including a porcelain room consisting of earth bricks and wood in the construction structure frame, compressed earth brick and compressed earth block masonry walls, internal and external earth rammed walls in earth wall frame types, earth plaster construction methods, etc. Also, in the Jechun Gandhi school dormitory project, although somewhat lacking, an earth rammed wall in an earth wall frame type using a concrete foundation and steel frame was applied to create an excellent structure. Instead of concrete, recyclable materials in a steel frame and wood were used to realize an alternative earth architecture method.

1. INTRODUCTION

Earth can be easily gathered from our surroundings. And it is well-known for its insulation effect or heat storage capability while having excellent functions in moisture control, air circulation, ventilation, etc. Building a structure using earth materials is very healthy from an environmental aspect as earth is not only used to build the structure but also structure naturally returns to the earth once its life span is finished. On the other hand, the development of construction methods to compensate the shortcomings of weak durability and structural stability and securing appropriate design technology for elegant spatial design through a wealth of construction experience are required.

Guyon Architects has applied methods to build structures using earth such as a rammed earth construction method using an earth wall frame (formwork), masonry methods using earth bricks or earth blocks, methods to create effects using earth plaster, etc. for both housing and public building designs.

With initial design done by Chung Gu-Yon and Guyon Architects, construction of Paju Yeondasan-ri housing and Muju Jindo-ri Town Hall was accomplished by earth wall frame construction methods using formwork. Yeondasan-ri housing is significant in that it is the first single-family house to employ earth for the entire construction process while the Jindo-ri Town Hall is significant in that it is the first public building made of earth. These works have accordingly served to popularize earth architecture.

Following these projects, detailed construction methods were explained to people who were interested in earth architecture and through a field study of completed earth houses, the quality of earth houses was promoted to encourage more construction opportunities.

To improve the weakness of earth, Yeongwol's Guinhun was a composite architecture with concrete and Chuncheon's Plum Tree House attempted to combine earth construction with a wood structure. In Gimje's horizon school project, many types of earth architecture construction methods were used in designing the school buildings, including a porcelain room consisting of earth bricks and wood in the construction structural frame, compressed earth brick and compressed earth block masonry walls, internal and external earth rammed walls in an earth wall frame type, earth plaster construction method, etc.

In Jechun's Gandhi school dormitory project, although somewhat lacking, earth rammed walls in an earth wall frame type using a concrete foundation and steel frame were employed to create an excellent structure. Instead of concrete, recyclable materials in a steel frame and wood were used to realize an alternative earth architecture method.

Such architectural design tasks have important implications. In seeking sustainable architecture alternatives, our traditional architectural techniques are reconsidered. Such attempts to apply these methods to today's environment should not merely end up as an architectural experiment by individual architects but should become a more realistic, systematic task. For the popularization and development of earth architecture, efforts to introduce, develop, and spread earth architecture must be accompanied in order to promote interest in more users and architects.

2. MAINS PROJECTS

2.1. Yeondasan-ri Earth House

Yeondasan-ri house is the first building designed by Guyon Architects that employed earth for the entire process. The house resembles the land. The land for the Yeondasan-ri house is a neat lot with a large chestnut tree to the left, a large plain to the north, and a small hill surrounding the house at the right.

Even though it is an earth house, the foundation is made of concrete, considering issues of durability and weight of the building. Concrete is used to raise the wall foundation and the main frame is built with wood columns (200 x 200), crossbeams, etc. For construction of earth walls, the middle beam was not raised until later. The thickness of the earth wall was 40cm. A formidable amount of time was required to ram the earth of the wall frame. Forms cannot be used one by one, and thus a hammer drill or equipment that rapidly and effectively rams the earth was used. After building the earth wall, the upper portion is shaved off to raise the middle beam. To reduce noise and provide an insulation effect for the upper floor, the floor was made of earth and insulating materials. The landscape that can be seen from here becomes part of the house. Throughout the process, problems were discovered through trial and error, and this proved helpful in seeking useful solutions in earth architecture tasks.

Creating a wall frame that improves upon traditional methods is complex and requires much effort for formwork and to fill the holes of threading cast, thus leading to inefficient work speed and functionality. Consequently, Euro-Form formwork was used, which also led to many problems. The greatest problem was insufficient moisture discharge. As an alternative, general wood formwork appropriate for wall frames was used. This was not used once after assembly but served to be a test of repeated use.

As a result, the moisture problem was exacerbated due to weather when the Euro-Form was used. Since this project was the first construction of this kind, the formwork removal technique improved as the construction progressed.

In the process of removing formwork, problems arose regarding damage or unclean finishing to the earth wall corners. The ramming strength during the ramming process was underestimated. This problem occurred because the workers did not know how to control the ramming strength. Another problem was shrinkage that occurs due to the characteristics of earth. During the construction process, dry shrinkage of the earth was miscalculated. Consequently, a discrepancy at a connection area to a different construction arose. The earth rammed wall's height of 2.4M underwent shrinkage of 2~3 cm (0.8~1.25%). Furthermore, in the length direction, shrinkage was dispersed in both directions. Although the shrinkage thus seemed minor compared to that in the height direction, there was a total of 1~2 cm of shrinkage. The total quantity of used earth was more than 3 times the planned quantity (12cm^3) of earth for rammed walls requiring 30.5m^3 . Since total surface area was about 152m^2 , the used formwork quantity was about 300 pieces of 600 x 900 standard Euro-Form.

Engaging in earth work for the first time, 2 people who had studied at an earth architecture workshop performed the tasks together. Under their supervision, other people were educated and a supervisor made on-site visits to oversee the construction.

However, as time passed, carpenters built according to their “own methods”, which led to problems. A preliminary tour of the earth architecture construction site or training under an experienced consultant should be required before engaging in construction to secure completeness and quality.

2.2. Jindo-ri Town Hall

After the earth architecture institute work was established within Guyon Architects in 1989, experiments for earth architecture continued to take place. Muju Jindo-ri Town Hall is perhaps the first project to apply earth in a public building. It was a resting area for the elderly in a small Muju village. The main task was to create a practice space with simplicity matching the village atmosphere with minimal construction cost.

The village has a distant view of the Mt. Deogyu foothills. Chung Gu-Yon believed that earth architecture, which is not easy in an urban setting, would be feasible in a rural area. Therefore, he lectured on earth architecture to Jindo-ri residents and engaged in heated discussions. Most villagers, largely elderly women and men, touched on practical issues during the discussions. Residents raised points such as, ‘How could you build a house out of earth in such modern times,’ ‘building with earth will lead to cracks and breakdowns,’ and ‘it may look picturesque but a building is best when slabs are set on the roof and floor.’ The preconception that a house built of concrete is best for durability and low maintenance costs has been deeply ingrained. In conclusion, most people held negative views about building the town hall with earth. These residents had to be convinced of the fact that earth architecture does not symbolize poverty and can be used to build comfortable and sturdy houses. As examples, Gyeonggi-do Anseong City Juksan-myeon’s ‘Smiling Rock’ stage (built using earth wall construction methods) was shown and field trips to several earth architecture structures in the outskirts of Seoul allowed them to directly witness the viability of this approach. After returning to the village, all residents except one person voted to approve the project, and finally the town hall was able to be built with earth.

In traditional architecture, there is a common house-building language that cannot be left out, with the first being the creation of a stereobate. Instead of digging the ground, the ground is evened out and packed to make a low platform where a foundation stone is placed to fit the base of a column. This exact method was applied to the Jindo-ri Town Hall. Also, all houses consist of compartments (modules). The size of the compartments is not uniform and is generally within 8 ~ 10 Korean feet. If the distances between columns are specified as compartments, the depth of the building is usually equal to that of the height of the roof. This is a natural dimension relationship between the fabrication-type wooden architecture part and the entire structure. While utilizing the traditional house-building method as is, the shape is converted to a modern form.

From residential house to gazebo architecture, Jindo-ri Town Hall used a technique to involve the surrounding landscape. On the 1st floor, a room and kitchen for elderly women and men were situated, while on the 2nd floor, a gazebo and a reading room for teenagers were arranged. A unique characteristic of the structure is that the frontal columns are not standing in a straight line but naturally bend in line with the curving road. The roof is also treated as a curved surface to unify both horizontal and vertical aspects. Instead of a building that penetrates the surrounding scenery in a normal

Korean village landscape, the architecture naturally blends the structure with the environment. The town hall made of earth and wood is rough and is lacking in many aspects, but it served as an opportunity to develop ideas and concepts for earth architecture.

2.3. Yeongwol Guinhun

2.3.1. Another start

Earth architecture combining the earth wall method with wooden furniture was attempted for Paju Yeondasan-ri and Muju Jindo-ri but it is considered a failure. Instead of reproducing traditional earth architecture, it did not have the quality to fulfill the requirements of the modern era. The structures had three major flaws. First was a lack of experience for basic elements such as earth formulation or shrinkage for sound realization of the intent of the earth architecture design. Second was the lack of a contractor who could handle the combination of earth and other construction methods. Finally, it was difficult to accurately estimate the construction costs regarding earth architecture. After visiting the two above locations and sufficiently understanding such characteristic, the employer requested a design for a house in a plot in Yeongwol that was not planned to be occupied right away. In effect, the employer proposed an earth architecture experiment. This is how the construction of Guinhun began. Fortunately, Shin Geun-Shik had just returned from earth architecture technique studies at the earth architecture institute (CRATERRE) of France's Grenoble Architecture College. In addition, Gyeongang Construction's President Cho Hak-Rae understood the intentions and agreed to participate as the contractor. It started with a different system and different team from the Paju and Muju projects.

2.3.2. Land

"Yeongwol land is deep in the mountains. After passing Jechun, there is a valley slightly out of the way on the corner of Guinsa, and inside the valley, there are three to four houses keeping each other company. In the quiet and still scale valley, murmurs from the neighboring houses can be heard while the clouds drift pass the mountain peaks. Although it is a shallow valley, it is called the 'water valley', as water does not completely disappear even during the dry season. On the land of the Guinhun at the entrance of the village, there is a small spring that does not dry and to the immediate west, several Kalopanax trees grow together to serve as the village's holy place, creating a feeling of placidity. A plain is set with the mountain at the back and water in the front, and although it is sunny, the distance between the mountain and water is too small and the mountain with a slope facing northwards cuts off the water path to the south, creating a rather obstructive landscape. It is a land already full of 'architecture by nature' and building a house on the land has exhausted the 'nature's building-to-land ratio and floor space index' and has the limitation of just adding on top of the existing features."¹⁶

¹⁶ Ideal Architecture 1999 September P.79. Guinhun article

2.3.3. House of Comparison and Collision

Therefore, the house should 'rescue humanity' when being built on this land.

"For a land difficult to match other than with the appearance of a traditional farmhouse with low protruding corners of Korean eaves lying hidden with slight traces by the mountainside, a new type of order is erected. But this is done through dual code methods of comparison and harmony and of collision and mitigation. A horizontal plane is emphasized in the roof line at the end of the steep slope of the foot of the back mountain and at both ends of the continuous line; a concrete wall emphasizing vertically surrounds the house. Minimum shelter made by this builds an earth wall inside to make the inner boundary.

By mainly closing the south side and opening the north side more, the back mountain is met closer than the light from the north slope of the front mountain. This is especially so for the study area in the back room. Concrete is employed to handle rainwater while an earth wall is designated the role of controlling heat and air. The earth wall was placed with a transparent glass layer, mitigating the collision between the concrete roof and side walls, and absorbing the light reflected from the yard. The height of the upper glass window is the minimal height to allow for earth ramming work during rain below the roof, which was completed early in the earth wall construction process. Concrete, the popular material of this era, and earth, which is as old as the planet itself, will meet in one corner of the Yeongwol land and will be reflected by the surface of water flowing from underground. At that time, the rather stiff-looking box building will break under the shimmering waves and repeatedly try to return to its actual state of appearance."¹⁷ And the house will be completed at that very moment. Under the most natural foothill, a collision occurs with a controlled mass consisting of exact geometric lines that cannot be drawn by nature. Here, only tectonic architecture can further enhance nature.

2.3.4. About earth architecture technology

Guinhun is not 100% earth architecture. But the wall frame construction method (board compression method) of earth architecture was used to construction the earth wall to give the appearance of an earth architectural structure as the house's total image. Since the walls surrounding the house and the role of the earth are essential and not decorative or auxiliary, the house can be considered a type of earth architecture. Rather than using earth for construction, it is more correct to say that we tested what possibilities earth can achieve in today's architecture.

The reason that more energy is spent on earth wall methods instead of the core wall is due to its inherent similarity for ease of use with concrete, instead of the expectation of reproducing the elegance of a traditional earth wall house, matter property creating the whole due to packing of individual earth particles by external pressure, and warm breath responding to light. Concrete formwork is similar to wall frames of the board compression method. The only difference is that one is poured and condensed by chemical reaction while the other is compressed by physical pressure. The earth wall preservation capacity is proportional to the ramming strength used to create it and it has a functional relationship with the type of earth and mixed ratio. In Yeongwol

¹⁷ Ideal Architecture 1999 September P.79. Guinhun article

Guinhun, Juchun area's red clay, Jechun's soil, pebbles, and coarse sand are mixed in 1:5:1:1 ratio and lime was added for abrasion and moisture absorption. The wall frame uses a modified traditional wall frame. The basic material is made of wood but to save disassembly and assembly time and eliminate seams (The height of the wall to be erected at one time is the same as the wall frame height and typical amplitude of 30cm ~ 60cm), compressed air was used to manufacture a machine wall frame that showed good performance. Mixers to mix various soils were produced. Analysis of earth shrinkage and color/size after curing were performed on site. To stabilize the wall for installing windows, rectangular timber was placed in some parts of the earth frame. It was not perfect but the completeness was relatively high. The earth wall's quality depends on how much detailed devotion is applied without haste.

Our ultimate goal is not to complete earth architecture but to engage in good construction. We do not have the illusion that earth will help us in achieving that goal. For achieving good construction, there are wise ways to use earth everywhere. In that sense, Guinhun is a small start towards that goal.

2.4. Chuncheon Plum Tree House

The 'Plum Tree House' is located in Chuncheon, Seosang-ri, Saemak-gol. Saemak-gol is a dream-like village hidden in the plains of Chuncheon. The plot of the plum tree house at the village entrance is an ideal place dreamed everyone. Enclosed by mountains, it is not only surrounded by fertile fields but also a stream flows along the plot and joins with a bigger waterway in front of the village. On the side of the stream stand large trees. In the triangular lot, a private home shaped like a 'C' exists. Other than facing west, it seems appropriate in its scale and location, so efforts were made to save the advantages of the existing structure.

The key difference with the existing house is that the main entrance is placed on the south and the 'C'-shaped arrangement is flipped to the east so that the view is facing towards the fields and stream. In particular, towards the stream, a wood deck is placed to create an outdoor living room-type space. But in Chuncheon Plum Tree House, the most important architectural plan is the cross-sectional plan. The fields east of the plum tree house's living room are a four-season yard. Therefore, the heights of the living room and inner yard were set at the same level of the height of the fields. No wall was placed towards the east. So when sitting in the living room, the fields sit together and the fields rise as well when standing.

The workshop is independently arranged north of the living room and the workshop building with a high ceiling blends together with the rural scenery. The earth architecture basic model of the Chuncheon Plum Tree House is the same as that of Yeongwol Guinhun. If there is a difference, instead of a flat roof, the roof ends of each building are slightly lifted to give slopes to the roofs. The small slopes of the roofs ease the rigidity of modern architecture into the rural landscape.¹⁸

Chuncheon Plum Tree House was the second effort in housing architecture using earth as the main material and an important difference is that the basic framework used a wooden structure this time. Using the theme of earth, we sought to create different

¹⁸ Writing cited from the works of Chung Gu-Yon

structures providing elegant spaces. Having the experience of using a wooden structure as framework and finishing with earth architecture in Jindo-ri Town Hall, the problems during design were improved to make completeness very high but due to design constraints, there are areas that were built unsatisfactorily.

2.5. Jechun Gandhi School Dormitory

In Jechun's secluded mountainside of Deoksan-myeon Seongo-ri, there is a closed-down elementary school. Gandhi school was established on this foundation. It is not a branch school of Gandhi school in Jirisan but an independent alternative school deep in the mountain created independently through efforts by alternative school teachers and parents. The 2nd floor of the abolished school was moderately modified as a dormitory but due to a lack of classrooms and living difficulties of the students, land was prepared in a solitary foothill near the school.

Although there is slope to the north, the land is mildly sloped with the village and school viewable far down and a forest is located to the south. The geographical aspect of the mountain and environment make it an ideal location for building a dormitory. It is a suitable walking distance to walk to school, and students will see many things on their way back and forth. The village is set up so that the roads connecting the school and dormitory are all part of the school and dormitory. The students cross a stream, walk past an old village on a slope, walk up a trail, and see mountains, plains, and trees. They can see something every day that cannot be seen in cities, and it is a textbook of the four seasons.

The dormitory separated by gender is divided and repeated in two masses with an entrance and community hall space set up between the two masses. The second floor of the dormitory is planned to be a two-tier structure sloped roof. The rooms are arranged to face the north and a section is created to attract maximum light from the cool scenery to the south while on the side of one of the two courtyards, a funnel-shaped 'star watching space' is created to give a particular impression to the dormitory. The growing teenagers can view the night sky on occasion and it seemed important to allow children to watch stars and nourish their imaginations.

The material that matches best with foothills and rural scenery is earth. For both the interior and exterior, we tried to make 'earth' the main subject as much as possible. Since first becoming interested in earth architecture, I have always hoped to try using a steel structure as a frame in the earth architecture context, and in a sense, this was somewhat accomplished here. There were many difficulties with earth construction, which has infinite possibilities. In particular, the quality of completeness was low due to building in the winter, but a multiple-story building made of earth was completed with many people's assistance. The building had most of its walls built by earth ramming. There are many lacking aspects in the external space still, but as time passes, the dormitory function will not only exist inside the building but also expand out to all areas outside the building to join the surrounding nature and people together.

2.6. Musu-dong Artist Village

Blueprints for the Musu-dong Artist Village were voluntarily created principally by cultural artists sensitive to life and threats to the planet Earth. The village was started to

become a cultural production center providing ideas for regional development. As the first task of preparation meeting of the 'space defining practice steering committee' formed to straighten the space reality of this land. The artist village is in line with eco-village discussions, local cultural characterization of local self-governments, back-to-the-farm phenomenon of urban dwellers, search for new community culture, etc. and is expected to become a model to bring forth sustainable life and specialization.

2.7. Muju Traditional Soybean Paste Factory

Jeoksang-myeon Bangyi-ri is a village in a very deep mountain valley in Muju. A waterway is in front of the village and along the waterway at the center of the village, a zelkova tree stands magnificently, symbolizing a traditional rural village. On the land across the village's waterway at the bottom of the low foothills, the ultimate goal is to create a collective scene of a factory producing soybean paste, with an outdoor stand of jars storing soybean paste, and a farm experience learning yard and small accommodations in conjunction with the factory establishment. Thus, the plan is to build not only a factory but also auxiliary facilities to increase the revenue of the entire village.

Now, rational facility arrangement of the soybean paste processing factories located all over Korea has a close relationship with the construction design. Although the entire process of storing, washing, steaming, and floating beans is not that complex, the factory will not only manufacture soybean paste but is designed to interest and teach visitors as well. Therefore, architecture will focus on earth, but the long factory building will be given rhythm and natural lighting to bring about environment-friendly architecture. Even though it is an obvious though, it was not achieved completely similar to other works so far.¹⁹

¹⁹ 'Sensitive Architecture' 238P content excerpt



Fig. 1 - Muju Traditional Soybean Paste Factory

2.8. Gimje Jipyongseon middle&high school

From Gimje land, it is hard to see the mountains. As you travel west, you can see the horizon. In one corner in that direction, the horizon school is located. The old school building, a school field open to the south, and old trees lining the playing field speak about its past history.

In terms of securing the unique assets of the horizon school, after designing the porcelain room with earth bricks, the following areas were designed using earth as the main materials in sequential order: male student dormitory (earth brick, earth plaster, inner image earth wall), woodwork room (earth brick), porcelain room-2 (earth wall), current high school dormitory (earth brick, earth plaster, wood), cafeteria (earth brick, earth plaster), female student dormitory (earth brick, earth plaster), middle school main building (earth brick, earth plaster, earth block), and high school main building with library (earth brick, earth block, earth plaster).

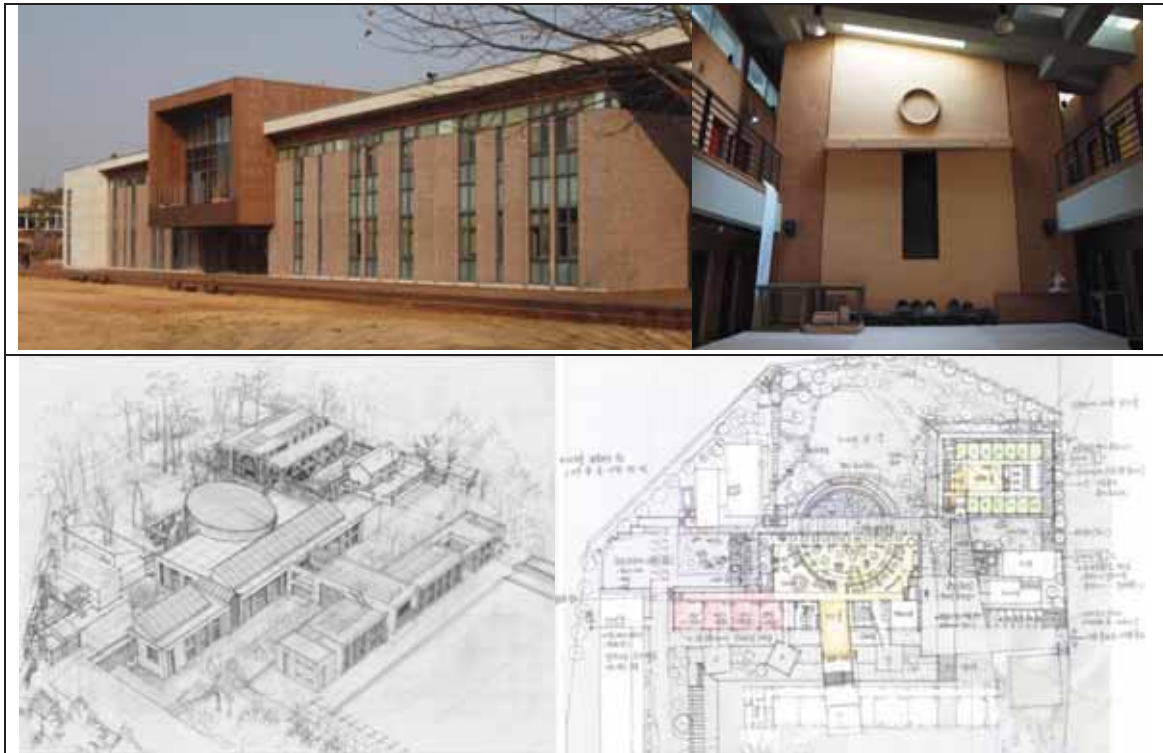


Fig. 2 - Jipyongseon middle&high school

3. CONCLUSION

It has been 27 years since Chung Gu-Yon started and worked with Guyon Architects. Throughout this time, Guyon Architects and Chung Gu-Yon have together sought to reveal the public and social natures of architecture and were successful to a significant degree. The key is found in the words frequently said by Chung Gu-Yon: everything starts from trying to show how freely an architect forms our lives instead of how beautiful the architecture is. Looking back at recent developments in the architecture field, architecture has become instrumentalized and commercialized, leading to a tendency to prefer economic and preferential rationale over culture in architectural production.

Many architects concentrate on the freedom of modernism, and fall into auteurism. Under the name of high-tech architecture, while the illusion that architecture guides technology proliferates, most display their individual desires through architecture and wealthy capitalists shows off more monumental and more precise devices through their 'office buildings.' This phenomenon naturally ends up providing a preferential model to the majority living in the same time frame and fans the media and ends up leading the overall trend of architecture.

On the other hand, through discussions to re-think the energy problem due to the oil crisis and the damaged environment, I have emphasized that there is another possibility to rescue the world at the opposite side of the realistic and dominant trends of the construction environment. That is probably why words such as Eco Habitat, Low-

tech Architecture, and Green Architecture or Environmental Architecture were created. These words can be put together to be called Sustainable Architecture, but the important thing is not the concept or definition of the word but rather to accept the current bifurcated reality and practical behavior to narrow down such distance in a specific, realistic space.

Therefore, Guyon Architects and Chung Gu-Yon aimed to accommodate the lives of modern people through the oldest construction material on Earth within the limit of intervention possible by architects. In particular, despite the importance of the role of earth, similarly to wood in Korea's past construction properties, research and experiments regarding it seem lacking. Rather, the general public has brought forth a retro-preference trend where "old things are important and our things are good" unconditionally.

However, we are not just instilling value in earth as a natural construction material but more meaning as an important environment factor, as a warm landscape of our lives, and as a value shared by all since the past. Technology is after this.

By gathering earth lying on the ground and then packing it using the strength from the body, it seems like a grand task to raise a structure on top of the ground and create space. Building a person's house using the flesh and skin of planet Earth seems like the most natural thing in the world, especially in today's era, not only where environment and ecological problems are serious but also where regional architecture is being discussed in many angles. Of course, it goes beyond the meaning of just modernizing traditional ways. The inherent properties of the earth projected into today's life and restoring sustainable 'old values' onto this land are important tasks. This is not about how to build but to find the figurative answer to the question why we have to build. It is also about restoring the values that we have to share. This is not merely a problem about architecture but about the problem of recognizing to re-evaluate this period of time.

Endnote:

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CURRENT SITUATION AND OUTLOOK OF EARTH CONSTRUCTION IN CHINA

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world

Sub theme 2.2: Architectural design and sustainable development

Key words: Earth Building, regional culture, living environment, sustainable development

Abstract:

Chinese nation originated from Central Plains within the reaches of Yellow River, with rare rainfall. Abundant loess provides the Chinese civilization with primary construction materials. People here created all kinds of earth dwellings according to production practice through history. Earth architecture properly provides the solution to harmonize the relation between man and nature, maximize the utility of local conditions, gaining relatively high living conditions at small cost.

Research on earth architecture bears more significance today, when we entered the time of ecological civilization. The development of modern earth building in China is greatly challenged today. It is important to discover and categorize the good historical examples of great earth architecture and settlements that is harmonious with the environment, cave building villages. And to upgrade and renew traditional earth building settlements, exploring the essence of regional culture. This article also focused on integrating earth buildings into urban-rural ecological system, from the standpoint of ecological civilization, taking sustainable development of human settlement as guiding ideology to realize a living condition that accord with the positive cycling of biosphere.

PREFACE

Earth construction mainly refers to the buildings, the body frame of which is built using earth that is simply processed but has not been baked as their main materials. They include buildings and constructions, the body frame of which is made of earth materials, as well as cave-dwellings dug in earth in original form or all kinds of constructions covered by earth, sand and stones. Earth constructions are distributed widely as they can be found almost all over the world. Earth constructions have a long history in the process of civilization of Chinese Nation. From the Beacon Towers of the Great Wall,

ruins sites of tombs and old cities, we can realize the situations where the ancient Chinese people constructed buildings using earth.

The Yellow Plateau district in central and western parts of China is the major area where the Chinese earth constructions are distributed. This area is covered with loess layers of 30 to 300 meters high, covering an area of 530'000 km² and accounting 1/18 of China's total area, is show in fig. 1 the loess distribution in China.

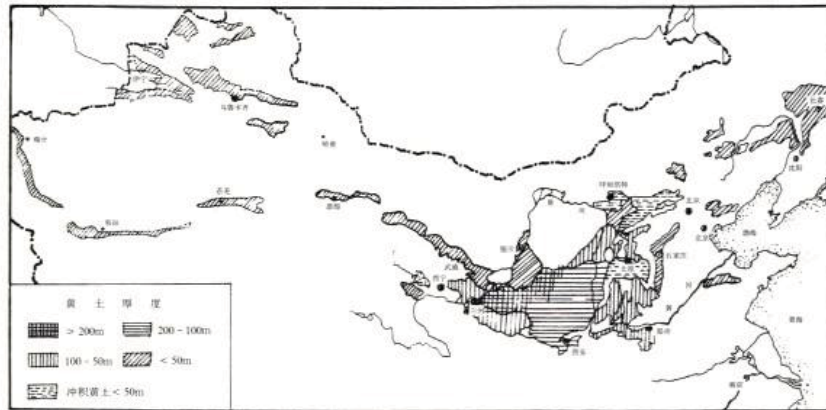


Fig. 1 - Loess distribution in China

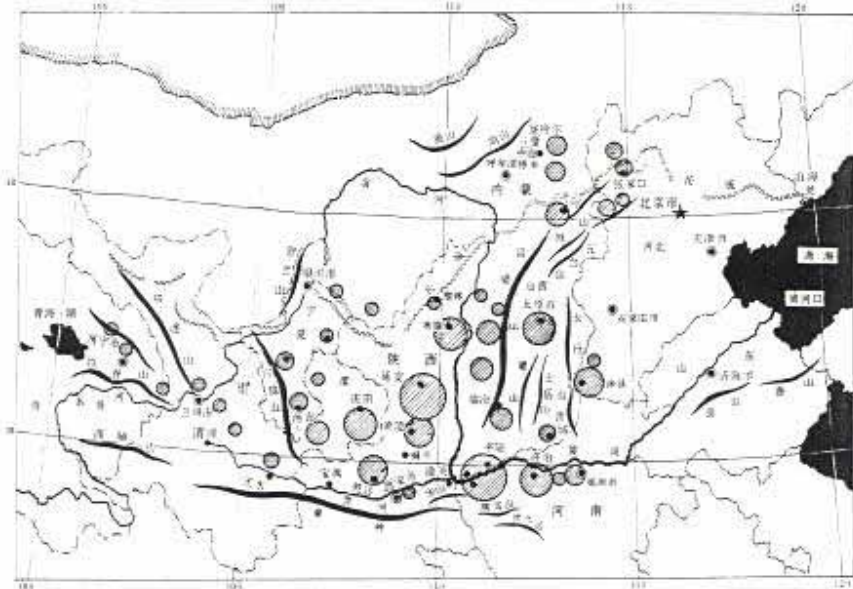


Fig. 2 - Cave-dwellings distribution in China

The Yellow River district is mainly distributed in the central and eastern parts of Gansu Province, the southern part of Ningxia Hui Nationality Autonomous Region, the northern part of Shanxi Province, the western part of Shanxi Province, etc. The rich loess layers in the Yellow Plateaus district became the natural construction materials in the initial stages of Chinese civilization. A great amount of earth buildings represented by loess cave-dwellings can be found in this area is show in fig. 2 the cave-dwellings distribution in China.

Because of the different geographical conditions, life styles, historical traditions and ethnic custom, earth constructions in different areas have different features in terms of construction technologies and construction styles.

1. BACKGROUND OF THE EMERGENCE OF CHINESE EARTH CONSTRUCTIONS

Chinese Nation has been a farming-based nation since ancient times. Since the Chinese people relied on and worshiped the Great Nature in the process of development of agriculture, they pursued the consistence between life style, technology innovation and the Nature. At the same time, their ecological value and construction value were directly influenced by Chinese traditional philosophy, among which the living pattern of Taoism express, Human Race is one part of the Nature, and the laws of the Nature are laws that the Human Race depends on to exist; the Human Race must not claim the natural resources unlimitedly, because the resources are limited, instead, the Human Race should preserve the Nature properly; the way of survival of human shall be accommodated to the local environment so as to realize co-existence between human and the Nature”, in the constructions of traditional living houses and scenery gardens, the Chinese people’s ideal of living and landscape is a natural, bucolic and Utopia-style landscape, which makes the life of human mingle with the Nature together perfectly. The oldest living mode is cave-dwellings. In terms of the development history of constructions, earth dwellings can be traced back to the Stone Age when the natural material and simple technology is a certain choice due to the limitation from manpower and technologies.

2. STYLES OF CHINESE EARTH CONSTRUCTIONS

2.1. Styles of Chinese earth constructions

If the earth constructions are sorted out according to materials, frames and construction technologies, they include loess cave-dwellings, adobe cave-dwellings, adobe buildings, tamped earth walls or grass-mud-piled walls constructions and all kinds of “earth sheltered buildings” as well as tamped earth constructions of large volume. According to construction and use functions, they can be classified as cave-dwellings, other earth construction dwellings and public buildings that are built using earth material (eg. city walls, granaries and dams, etc).

According to their long term production practice and accommodating the constructions to local conditions, people of all ethnic groups living all over the country have created all kinds of earth constructions. The earth constructions, typically represented by loess cave-dwellings is shown in fig. 3 loess caves-dwellings villages , in the northern part of China concentrate on areas of such provinces as Shaanxi, Shanxi, Gansu, Neimeng, Ningxia, etc; the earth constructions in the southern part of China mainly concentrate on such provinces as Fujian, Guangdong, Yunnan, etc, and the earth buildings in the northern part of Guangdong Province and the southern part of Fujian Province are typical representatives is shown in fig. 4 the earth buildings groups in Fujian Province ,as well as the Tu Zhang Fang in Yunnan province, dome adobe houses in Xinjiang province, etc.

According to the form of site, Chinese cave-dwellings can be classified as three types: sunken-style cave-dwellings, mountain-backing cave-dwellings and independent cave-dwellings, is show in fig. 5.



Fig. 3 - loess caves-dwellings villages



Fig. 4 - Earth buildings groups in Fujian Province



Fig. 5a - Sunken-style cave-dwellings

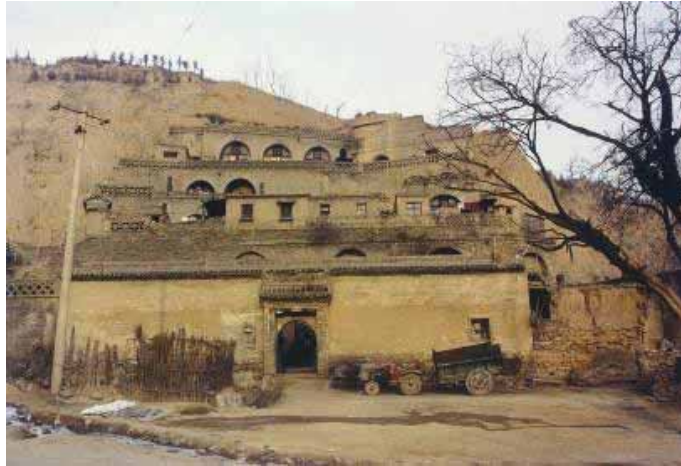


Fig. 5b - Mountain-backing cave-dwellings



Fig. 5c - Independent cave dwellings

2.2. The advantages of earth constructions

The materials for the earth constructions can be collected locally, so it is convenient to carry out construction; it cost a little to build an earth construction; earth constructions can help save energy for they keep warm in the winter while they cool down the interior of the house in summer; earth constructions mingle with the Nature, which can help protect the environment and keep the balance of ecology; they are authentic ecological low-carbon and environmentally friendly buildings, which are made of the most economical construction materials in a traditional construction way; in addition, they are adapted to the local climate and local culture. Owing to the above-mentioned advantages, this type of ancient constructions still has vitality till now.

1) Good heat performance

In summer, the temperature in the earth buildings is lower than that in brick houses, which is usually called “cool in summer”; while in winter the temperature in the earth buildings is higher than that in brick houses r, which is usually called “warm in winter”.

2) Relatively strong humidity adjustment power

The relative humidity in the earth building both in winter and summer is stable; this explains that tamped earth wall itself has a good humidity adjustment power.

3) Breathable outside walls

Owing to its multi-holes nature, the tamped solid adobe wall has certain power to adjust the humidity in the house. When the humidity of the air in the room is relatively high, the moisture will pass out the adobe wall; while the humidity in the room is relatively low, the water stored in the adobe wall will be transpired into the room; therefore, the earth construction materials can be called “breathable” fabric.

4) Low-carbon environmental protection

The so-called low-carbon and green construction shall refer to the constructions that are given careful consideration in the planning and design, taking advantage of the environmental factors, which make the harm done to the environment the lowest in the construction process, which can provide people with healthy, comfortable, low energy-consuming and harmless space in “the operation stage”, and which can make the harm done to the environment the lowest after they are demolished. Therefore, green constructions can be interpreted as constructions that reduce the production of various wastes through reducing the consumption of resources and energy in the life cycle of the construction, so as to realize co-existence between the constructions and the Nature. The earth construction materials are basically collected nearby with earth as the main material, and grass, straw, Korshinsk Peashrub and red willow as auxiliary materials. Because the earth materials are collected from the Nature, they do not cause consumption of energy, what]s more, the waste produced by the deserted earth constructions can totally be absorbed by the natural environment, which is in accordance with the low-carbon and environmental protection standards.

It is because of the special natural geographical characteristics and climate conditions in the Yellow Plateau that the vegetation there is destroyed seriously, the erosion of the earth and the loss of earth and water have become a serious problem, there emerge traditional villages with adaptation to climate and natural economic conditions in the region where the natural ecological system is relatively weak. All earth constructions ranging from single body constructions with adaptation to climate to traditional villages that rely on the regional natural ecological environment but do lowest harm to it provide reference and green technology experience for the practice of modern ecological constructions and ecological living communities.



Fig. 6 - Earth villages with adaptation to natural economic conditions

3. THE STATUS QUO OF CHINESE EARTH CONSTRUCTIONS

Because China has a vast area with a huge population, and there is a huge difference between different regions in geographical climate, resource distribution, humanism and custom, as well as an imbalance in the economy and the living standards, the problems of living mode and existence style of the rural area have to be resolved flexibly by

accommodating them to the local conditions and avoiding stereotype. As the development of China's economy in recent years, the development of earth constructions is facing opportunities as well as challenges.

The first problem is recognition. Many people deem cave-dwellings and earth constructions to be an equivalent to "outdated fashion", "backwardness" and "poverty". With the progress of the era and the development of the society, adobe and earth tamped walls are replaced by adobe brick walls widely in the rural constructions in the northern part of China. This drives the old constructions wither away. At the same time, as the process of the urbanization speeds up, people focus on the development of the society but neglect the healthy development of the rural living environment, as a result, there appear some factors that restrict the sustainable development of the rural living environment.

Deserted dwellings in recent years can be found everywhere in all villages, especially relatively backward villages with inconvenient communication. Many farmers build brick and tile-roofed houses or two-storey house in new places, with most of these houses concentrating on both sides of roads or nearby the roads. Not only do these buildings occupy a great amount of arable land with flat terrain and fertile earth where communication is convenient, but also they do harm to the ecological environment to some extent owing to the garbage produced by the concentrated buildings that are not dealt with properly. As a result, the living environment has not been improved. Although these buildings make the rural area look "modern", the performance of these houses like heat preservation and heat insulation performance, etc, is very poor. What's more, they melt the rural culture to a great extent, and it is very hard to find rural pastoral scenery now, is show in fig. 8 the deserted earth dwellings.



fig.7 - Deserted earth dwellings.

In modern China, where the industrialization is basically realized and economic is developed rapidly, the lack of resource, the environment pollution and the ecological deterioration are the pressing issues faced currently. It compels China to change the ways of development gradually, pay more attention to the environment and ecological value. In living architectural design build principle .For the design and construct criteria, strategy of sustainable development is taken. The energy saving and efficiency, the green environmental protection and the environment-concerned treatment of residence and life style must be the choice. It has points in common with the traditional earth dwellings.

"The earth construction is not meant to backwardness, while cave dwelling is not equal to poverty. In nowadays when people are increasingly worried about the ecological environment and emphasize on the sustainable development, the earth construction shows its vitality increasingly. It hoped that governments at all levels can attach importance to its research, innovation and development. "This is the united appeal of the architecture specialists on the "the Seminar of Earth Construction and Ecological Environment Academic" in 2002.

4. DEVELOPMENT AND EXPECTATION OF CHINESE EARTH CONSTRUCTION

4.1. Reconstruct the earth dwelling, explore new way of sustainable development

The traditional Chinese earth construction can settle the relationship between human and nature appropriately; achieve higher living profits with lower costs. It can be used for reference for many residents in modern time. In rural area of China where the economy and technology are undeveloped, most of the existing and used earth constructions can basically satisfy the living requirement of the native residents after the elaborative renovation or reconstruct. The cost of it is lower than the brand-new residence. It is good for the native's ecological protection. This mode can also be taken as the intermediate phase in the process of shaking off poverty and setting out on a road to prosperity for the countries and towns. The excess consume of resource caused by dwellings constructed in one-shot move can be avoided. Meanwhile, it can utmost possibly preserve the native custom with bright features and living culture in raw type, which is important to explore the culture feature and ecological value of the earth dwellings and make it to be significant resource of tour and sightseeing in the future. It has an active meaning to improve the countrymen' living condition in the economy undeveloped areas in China the region' economy with high-efficiency environment protection is shown in fig. 8 Restoration of the earth dwelling.



Fig. 8 - Restoration of the earth dwelling.

4.2. Modernized exploration of the earth dwellings

With the advancement of the times and the development of the social economy, in north China, majority of the country's building adopt the clay brick instead of by the mud-brick and rammed earth wall, which leads to the vanish of this ancient construction material. In the arid and semi-arid areas of west China, the mud brick wall and rammed earth wall are still be used nowadays. When people review the ancient construction material "raw soil" from the social view of the ecological culture, they will clearly realize that it is the ecological construction material which had the brightest developing prospect in the west area of China. The earth dwelling shall achieve modernization by using the ongoing technology and develop synchronously with the living concept. We must learn and integrate the international existed experience and explore the earth dwelling system which is in conformity with the Chinese national conditions to achieve the modernization of the ancient construct mode "earth dwelling".

4.3. Accelerate the research and practice of the earth dwelling by the drive of development of the west regions.

Facing up to the world' environmental crisis, such as the population explosion, blind exploration, energy waste, environment quality decline and so on, people realize that there is only one earth and the sustainable development is the same future for us. The design is required to be integrated with nature. China is a developing country with a

large quantity of people and deficient resource, so the ecological design technique—having the least system affect on the non-renewable energy resource, make full use of the inexhaustible solar energy, take full advantage of the ancient and economical construction material, review and reconstruct the country architecture which meets the criterion of passive saving energy historically—must be emphasized in the process of urbanization.

Publicize and advocate ecological and civilized values vigorously to arouse people's attention to the ecological environment, make them consciously join the ecology and civilization construction. The specialists, scholars, engineers etc., who are engaged with the research and practice of raw soil architecture should take every chance to propagandize it perseveres through all kinds of approaches and media to make the ecological consciousness and green consumption concept entrench people's heart. Let more people know and join the earth dwelling architecture and make the Chinese earth dwelling architecture broadens its world influence.

CONCLUSION

As our country's traditional living construction, the earth dwelling is precious treasure in the process of the human architecture development. It is laden with the ancient human civilization and architecture culture for thousand years and is the crude construction with the rich experience accumulated for long time by the laboring people. It is originated from nature, measured suitable for the local situation, drawn on local resources, easy to construct, low in cost, warm in winter and cool in summer energy saved and also integrated with nature. When its lifecycle is to the end, all the materials back to the nature again which is propitious to the environment protection and ecological balance. Therefore, this ancient construction still possesses vitality in nowadays. The high-level attention to the ecology energy-saving and environment protection make the earth dwelling and its unique ecological charming regress and get developed ,which will be positive to the ecological balance, environment protection ,energy and land saving. Exploring and setting the splendid earth dwellings, earth-sheltered villages and cave dwellings in the history and rebuilding and renewing the traditional earth-sheltered villages are the historical mission for the modern China's architects.

Curriculum

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DEMONSTRATION STUDY OF EARTH-BASED REBUILDING OF EARTHQUAKE-STRICKEN VILLAGES IN SOUTHWESTERN CHINA

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Abstract:

After the earthquake in Sichuan of China in 2008, price increase of conventional materials, poor conditions in transportation and resources and low levels of economy and technology are the main challenges faced by villagers' home rebuilding. Under this background, a comprehensive demonstration village rebuild project was launched. Based on locally available natural resources and recyclable materials from collapsed houses, the local traditional earth-based technology got greatly improved in anti-seismic performance via experimental studies. By prototype-based training, the villagers quickly mastered these upgraded techniques and rebuilt homes by themselves with minimized input of manpower and material cost. Their new earth houses show a far better performance in cost-efficiency, sustainability and comfort than local conventional rebuilt dwellings. It demonstrated and conveyed an affordable, ecological, healthy and human way of post-quake village rebuild that local villagers could take, own and pass on.

1. INTRODUCTION

In May 2008, an 8.0 Richter magnitude scale earthquake hit Sichuan province of China. More than 60 thousands of people lost their lives, and millions lost their homes. Ma'anqiao is one of the poorest villages in this quake-stricken area. Most of the village houses, represented by the traditional rammed-earth courtyard dwelling, were severely damaged. Limited by local low levels of economy and technology and by the poor conditions in transportation and availability for conventional materials like concrete and bricks, it was difficult and unaffordable for villagers to rebuild their homes in conventional construction way. (fig. 1)

As these challenges are very typical in the entire rural Southwestern China, supported by Ministry of Housing and Urban-Rural Development (MHURD) of China, a post-quake village rebuild demonstration project was launched by a university-based joint team with a prototype of Ma'anqiao Village in Oct 2008. It aims to demonstrate and convey an affordable, ecological, sustainable, healthy and humane way of rebuilding post-quake village that local villagers could afford, own and pass on.



Fig. 1 - Overview of original Ma'anqiao Village

2. ISSUES AND CHALLENGES

The rammed-earth courtyard with a common living space for both human and livestock has been employed for thousands of years in the region where Ma'anqiao Village is located. The fact that most of rammed-earth houses were severely damaged during the earthquake made local villagers despair of the aseismic performance of their traditional earth-based building. For them, building with concrete and bricks seemed the only reliable way to rebuild their homes.

However, Ma'anqiao Village is isolated from outside by a river across which there is only one seasonal single-log bridge. It is impractical for villagers to input the industrial material as much as their home construction needs. Regardless of the transportation issue, since the earthquake the cost of manpower and materials on which the conventional construction relies has doubly increased, and becomes unaffordable to the villagers because of their very low incomes. Even though all rural families can get a government grant of 200 EUR, what they can afford, as the government proposed in most villages, is only a three-span house built with concrete and bricks for living, which however never meet villagers' demands like agricultural storage and husbandry. In

short, after the earthquake, not only was their building tradition being completely abandoned, but the peace of their original living being deeply broken.

From the environment of aspect, the villagers did not know how to deal with a large numbers of remnants of collapsed houses. What they could do was either to dump the “wastes” on the farmland, or mostly to retain the remnants and plan to rebuild new houses on farmland. Either way could cause serious adverse environmental impact.

Another issue, according to our initial investigation, is the insanitary living condition in their original rammed-earth courtyard with common living spaces for both human and livestock, though the villagers have been accustomed to it. Meanwhile, due to the limited anti-seismic capacity of their original rammed-earth wall, windows and other openings are greatly limited both in size and amount. Consequently, in the local subtropical climate the indoor space is always obscure and hot. (fig. 2)



Fig. 2 - Local traditional rammed-earth courtyard dwellings and damaged houses after the earthquake

3. STRATEGY AND METHODOLOGY

3.1. Strategy

In response to the above challenges and issues the villagers have to face, for villagers' home rebuilding it should be the most efficient and ecological way to selectively inherit and improve their earth-based construction tradition by utilizing locally available resources. It relies on whether suitable technical solutions could be found to restore villagers' confidence in anti-seismic performance of rammed-earth architecture. According to our investigation and field study, the answer is definitely yes. Therefore, the basic strategy for study and practice of the project should focus on two aspects:

Based on local natural materials and wastes from collapsed buildings, one consideration is to improve local earth-based architectural technology and design so as to upgrade their security of construction and living environment. The other is to guide and train villagers with enhanced earth-based technology, and facility them rebuilding their own homes according to their economical ability and demands. During the process, the working motto of “high science and low technology” needs to be followed both by employing the scientific research methods and tools, and by demonstrating and conveying an cost efficient, ecological, feasible, healthy and humane way of post-quake village rebuild that local villagers could afford, own and pass on.

3.2. Methodology

By integrating the above analyses and the local post-quake situation, the action plan of the demonstration project was proposed and implemented in three phases: prototype-based demonstration and training to local villagers; local extension and home rebuilding; technique promoting and regional training and extension. (fig. 3)

Firstly, facing those post-quake challenges, the villagers felt restless and confused about how to rebuild their houses. It was imperative to restore their confidence in earth architecture and demonstrate to them how to rebuild their houses with all resources they had in-situ. A rammed-earth courtyard, as a prototype, was therefore constructed by the team and villagers from each family. It provided them with a participative training on the basic techniques which was carried out from the latest researches (Tiegang, et al., 2008; Jin-Jie. et al., 2006), and can effectively enhance the structural stability and anti-seismic performance of their traditional earth houses.

In the early beginning of the second phase, by utilizing locally available resources a series of on-site experiments were conducted to further optimize those techniques for a most efficient and affordable solution and easy-to-follow technical guideline to the villagers. Meanwhile, based on the pattern of traditional courtyard with respect for local culture and livelihood, the team also carried out a numbers of design schemes, which can greatly improve their living environment and can selectively be employed in their house rebuilding according to their individual conditions and demands. Equipped with the design reference and techniques they learned in the prototype construction, all 33 families of the village rebuilt their houses by themselves within 3 months.

In the last phase, based on the research result, the team designed and mobilized the villagers to build a village centre to enrich the villagers' public activities and improve their service facilities. It also acts as a demonstration center of anti-seismic rammed-earth building technology. To further promote this method in other earthquake-stricken area in western China, an Anti-seismic Rammed-earth Village House DIY Construction Manual was compiled and published to provide guidance to laymen such as villagers and carpenters on how to build rammed earth village houses which are anti-seismic and economical.

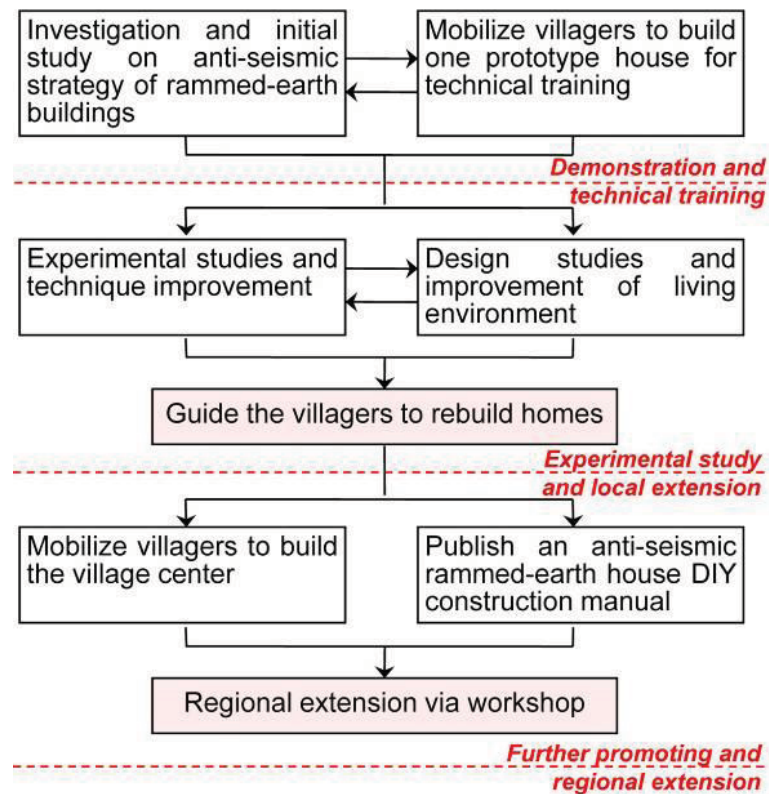


Fig. 3 - Methodology framework of the demonstration project

4. STRUCTURE EXPERIMENTS AND TECHNIQUE IMPROVEMENT

Enhancing the anti-seismic performance of the traditional earth-based building is one of core tasks and determines the success of the entire project. According to field investigation, it was found that the poor structural integrity of the house and mechanical quality of rammed-earth walls are the main reasons for damages of local rammed-earth houses in earthquake. Accordingly, the anti-seismic performance, based on experiments and analyses (Tiegang, et, al., 2010), has been improved in the aspects of the structure system, materials and tools of rammed earth construction.

4.1. Reinforcement of Structure System

Historically Southwestern China, where Ma'anqiao Village is located, has been a major earthquake zone. Meanwhile, building with rammed earth has been widely employed for thousands of years in this region. By utilizing locally available resources, people created a series of earth-based building techniques which are simple and effective against earthquake. (SONG, 1976) However, these traditional wisdoms were gradually being lost in past decades due to the lack of public attention and follow-up personnel. By comparison, the newly-built earth house gets higher and wider as the inhabitants pleased, but its anti-seismic performance turns to be worse. As investigated, it is one of core reasons for damages of local rammed-earth houses in this earthquake.

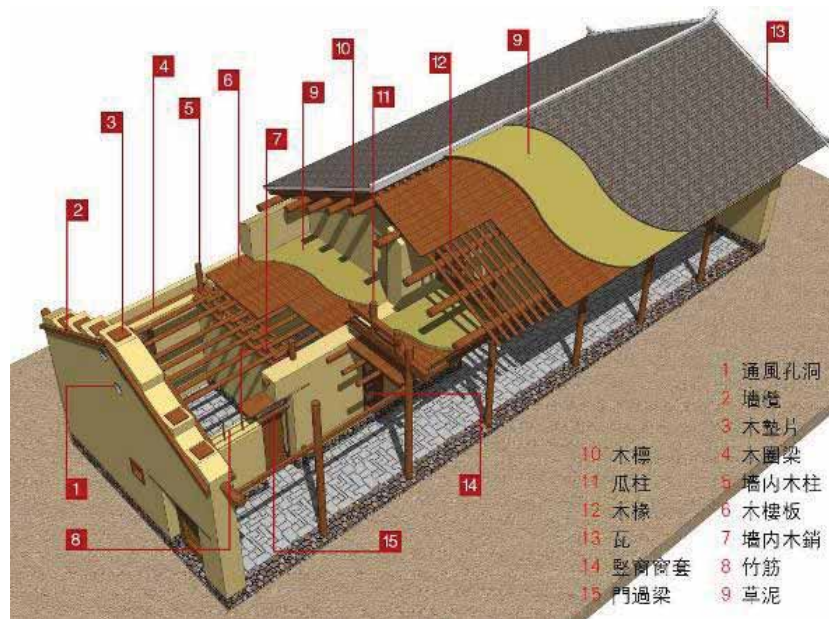


Fig. 4 - Optimized structure system of the local rammed-earth house

Under this situation, local traditional building techniques were excavated and sorted out by interviewing local old craftsmen and by reviewing literature and the rammed-earth buildings survived in the earthquake. Utilizing local natural resources and recycled materials, these got further filtered and optimized by theories of anti-seismic design, so as to carry out a series of technical solutions for reinforcing local rammed-earth houses. These can be summarized in three aspects:

1) Capping the span, storeys and floor height of the local rammed-earth house to reach a reasonable shape coefficient for seismic resistance; 2) involvement of timber-made structural columns in wall corners and bamboo-made ring beams on both top and bottom of earth walls; 3) improving structural measures for joints between walls, roofs and walls, and foundations to further enhance the structural integrity. (fig. 4)

4.2. Methods and Tools of Rammed-earth Wall Construction

Mechanical performance of rammed-earth walls is determined mainly by three elements: composition of earth mixture, ramming method and drying process, which need to well adjust according to local soil property and the level of economy and technology. (Walker, 2005) Therefore, a series of experiments and scientific analyses were conducted not only in the laboratory but on the site are conducted. It was found that the original rammed-earth wall can be greatly reinforced in mechanical performance by mixing 5% of lime with on-site soil. More significantly, the mud from the damaged house can also be reused in the same way. (fig. 5)

Since there is great randomness in earth ramming of local traditional architecture, the team also standardized the earth-ramming procedure to ensure a unitary quality control of the earth wall. Meanwhile, their traditional wood hammer is replaced by an iron hammerhead so as to obtain a more powerful ramming effect. By attaching two pieces of angle steel on both sides, the original wood mould also got effectively reinforced against transformation during ramming. (fig. 6)

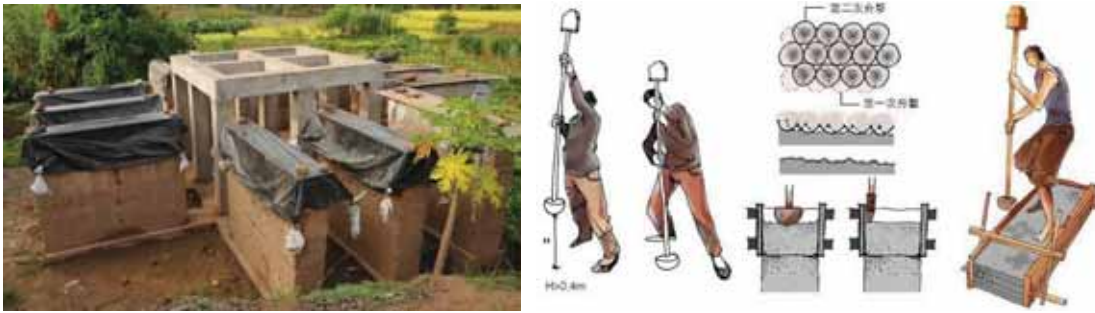


Fig. 5 - Experimental studies of rammed-earth wall construction in the laboratory and on the site (Left); Fig. 6 - Improved and standardized earth-ramming tools and procedure (right)

All the above technical solutions were simplified mainly by utilizing “wastes” from damaged houses and local natural resources like bamboo, timber, stone, straw, etc. so that the villagers can learn and easily handle with minimized increase of cost and manpower. Those outcomes were also translated into the form of easy-to-understand guidelines to tell the villagers what they have to follow in house rebuilding and what is selectable according to their financial situation.

5. DESIGN STUDIES AND IMPROVEMENT OF LIVING ENVIRONMENT

As mentioned, the poor insanitary conditions and indoor comfort are two of the main issues which reconstruction needs to overcome. It could be reached respectively at two scales of the functional layout of the courtyard and building design. Firstly the team interviewed all 33 families of the village to adequately understand about their livelihood, living and production habits, culture and expectations for home reconstruction. In response to their various family sizes, site conditions, earthquake damage features, financial statuses and demands, 12 design schemes got carried out by the team together with those families, based on the original courtyard pattern.

In those schemes, at the scale of the courtyard, the function and spatial layout were optimized so as to involve maximum solar radiation and wind into the courtyard and as well as to enhance space utilization for various functions. Especially, the spaces for agricultural storage and animal husbandry are spatially isolated but functionally connected with the living space to ensure a healthy and hygienic living environment.

Though the earth wall, as optimal thermal mass, can effectively balance the indoor thermal environment, the indoor space of local traditional rammed-earth house is very hot in summer due to the lack of windows and openings for ventilation, which are limited in area and amount by the poor mechanical performance of the traditional earth wall. There is even no window on the back wall of most houses. Therefore, via the prototype construction the team demonstrate to the villagers various feasible methods of making windows and openings in terms of nature of rammed-earth walls. These methods include digging round holes in the dried earth wall, ramming metal pails in the wall as openings, utilizing the gaps between rafters on top of walls, etc. The use of log-made window frame, which is inserted in the earth wall as ramming and whose area is maximized by lengthening the height, was specially recommended so as to effectively improve indoor ventilation and daylighting with little impact on mechanical integrity of earth walls.

By employing the software of TAS (ETSL), a series of thermal simulation experiments were conducted to compare locally familiar architectural forms in their thermal effect on

the indoor environment. It was found that in some traditional rammed-earth houses with pitched roofs, the garret for agricultural storage works as a thermal buffer to effectively insulate the living space below against solar radiant heat. Therefore, in design schemes several forms of garrets which are adequately ventilated by openings, are highlighted and combined with existing functions.



Fig. 7 - Two of design schemes recommended to villagers

All these design schemes are the output of exchanging between the team and villagers. Those work as not the conventional construction drawings the builders have to follow, but optional references which could be selectively employed by the inhabitants to improve their living environment as they expect and afford. (fig. 7)

6. HOME REBUILDING

Equipped with the technical guidelines, design schemes, and more importantly the experiences from prototype construction, two months after the earthquake all 33 families started to rebuild their own houses by utilizing locally available natural resources and “wastes” from damaged houses. The team also provided each family with several levels of financial support to encourage them to rebuild on the original site. The construction of all village houses was completed by villagers themselves only in 3 months. No extra farmland is occupied. To be pleasantly surprised, villagers show their creativity and wisdom in their home rebuild. After all they know best about their lives and demands.

7. VILLAGE CENTRE CONSTRUCTION AND DEMONSTRATION EXTENSION

The earth-based technology upgraded by the team provides the villagers with a suitable solution of rebuild for their current poor conditions. However, with their economy developing and living demands diversifying, will the villagers in future abandon this earth architecture, which is always regarded as a symbol of poverty, replaced with “modern” one made of concrete and bricks? Further demonstration is needed. Therefore, the team designed and organized the villagers to build a village center providing clinic, kindergarten, library, shop, guest room, etc., to improve local public service facilities and enrich their lives. The building has two stories and a curved plan, which seemed impossible to realize with traditional earth-based technology from villages’ point of view. By employing locally available resources and “wastes” from damaged houses again, the centre got constructed by the villagers themselves under

supervision and guidance of the team. Most research achievements from the project were involved to demonstrate to the villagers that their tradition can also be built in a “modern” form. Now the centre together with the whole village has been appointed by MHURD as the demonstration centre in which training workshops, for the villagers and craftsmen from the regions with earth building tradition, will be organized regularly to spread the earth-based technology and conception of sustainable architecture. Meanwhile, a DIY construction manual about construction of anti-seismic rammed earth village house was published. All related techniques got summarized and illustrated with photos and drawings so as to be easily understood and learnt. The book has been distributed by MHURD to villages and Governments at the grassroots level in Western China to enhance local traditional rammed –earth architecture.

8. PERFORMANCE

By monitoring the construction process and newly-built houses by villagers, a comprehensive evaluation has been conducted.

The upgraded earth-based technology is easy to handle with simple tools so that the house of each family could be rebuilt within 1-2 months by only relying on one or two employed craftsmen and free helps from several neighbours. Over 90% of materials are “wastes” from damaged buildings and natural products sourced from the village. Therefore, its averaged construction cost is only 15 EUR per square meter, which is one tenth of the one of local newly-built houses with concrete and bricks. (Fig. 8) Construction of the whole courtyard with living and husbandry spaces can be covered only by the financial support and their savings. Meanwhile, the indoor ambience of the new earth house, as Figure 11 showing, is far cooler and stabilized than that of the latter. Moreover, energy consumption and CO2 emission caused by the whole lifecycle of the new rammed earth houses are greatly minimized and hence it shows a far better ecological performance than local conventional buildings. To villagers, their living needs got entirely satisfied with more healthy and comfortable living environment. By now the village has come back to the original peace and harmony. (fig. 9)

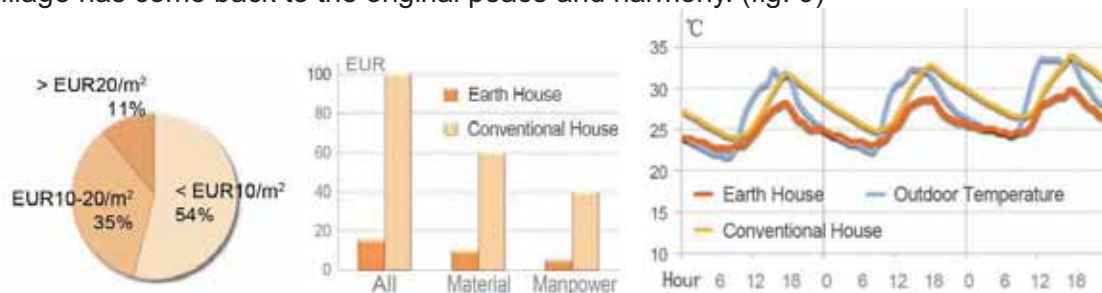


Fig. 8 - Stat. of construction cost of all families (left); Comparison in construction cost (middle); Indoor temperature comparison between the newly-built earth house and the local conventional house(right)



Fig. 9 - All 33 families rebuilt their homes with upgraded earth-based technology

9. CONCLUSION

In Southwestern China, vernacular architecture is the fruits of thousands of years of local people's practices in terms of locally available resources and special natural conditions, and hence is always one of most efficient and ecological solutions especially for rural construction. Though some of its inherent disadvantages cannot meet gradually varying demands of today's people, ecological potentials and technical experiences embodied in vernacular architecture is playing a significant role to the exploration for a really feasible ecological architecture.

At this point, Ma'anqiao demonstration village project gives a clear illustration. Based on the innovation of local earth-based traditional technology and utilization of available natural resources and recyclable materials from collapsed houses, it demonstrates an affordable, ecological, healthy and humane strategy of post-quake village rebuild that local villagers could take, own and pass on. It is also evident that the methodology of research and project management also shows a most practicable and effective way towards ecological architecture suitable for rural Southwestern China. During the process, the principle of "high science and low technology" needs to be highlighted and well followed so as to ensure a sustainable development.

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UNDERGROUND CONTEMPORARY BUILDINGS, PORTUGAL AND TURKEY

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world

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Abstract:

Using nature itself - on prehistoric caves - or as inspiration for their artificial constructions, man always looked for underground earth shelters. The North of Portugal is characterized by a disperse territory occupancy, what is problematic due to infra-structures and transport environmental costs. This reality has diverse causes: accented topography, division of soil due to multiple transmissions of property, an intensive labor and delocalized small industry. The generalized access to individual transport in the last 30 years accentuated this phenomenon, that is now irreversible, but economic paradigm is now changing drastically, with small industries closing and increasing unemployment, what is now impelling the return to individual means of subsistence, such as private poultry. But a lot of soil surface is now blocked for agriculture; due to the existence of small disperse buildings that pop up on territory, limiting accesses and insulation to potentially productive soils. This is especially critical for South oriented slopes, more adequate for agriculture. Increase density is now utopia for this region, so a strategy proposed for dealing with this reality can be to integrate new constructions on terrace slopes, leaving the housing immediate vicinity soil and even roof more easily available for agriculture or at least reducing visual impact of buildings on landscape. The advantages and disadvantages of underground buildings are discussed, with some examples comparing Cappadocia in Turkey with Portugal. Portuguese underground contemporary housing buildings are presented as case studies.

1. INTRODUCTION

Underground housing is usually associated with archaic, unhealthy, poor conditions. However, underground buildings have many qualities including low temperature oscillation, better acoustic performance and higher protection against intruders in comparison with conventional upper ground buildings. Global warming and violent social convulsions announce a forthcoming era where security and protection will become major concerns. In this paper different types of underground housing are presented and some contemporary examples in Portugal are analyzed.

Villages began to develop during the Neolithic age, in Minor Asia, such as Çatal Hüyük in Turkey (6.700-5.700 B.C.). This settlement consisted of houses joined together so

that the roofs formed a continuous surface from which the interior could be accessed by stairs. In fact this was not an underground village, but most of the houses of this village behave as being underground, as they are protected by other attached houses from all sides. Underground settlements are characteristic of several regions in the world. The most abundant examples are located in China, in Hunan, Shanxi, Shaanxi and Guansu provinces with approximately ten million people living in underground houses. Dwelling caves are found mainly in northern Shaanxi Province, in Yan'an and Yulin. They are built in the Loess mountain slopes. Cappadocia in Turkey is also known by its underground constructions which are still being built nowadays using the same constructive system as in the past. Figure 1a shows an example of a recently built hotel in Göreme, Nevşehir province in Central Anatolia. Other important examples of traditional dwelling caves can be found in Iran, Tunisia and Spain.



Fig. 1a - Underground Hotel in Cappadocia

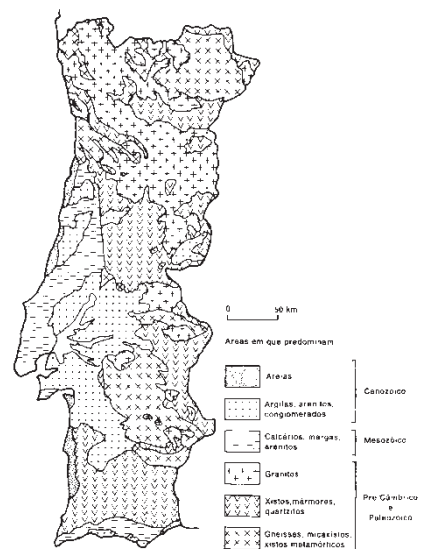


Fig. 1b - Lithological diversity in continental Portugal (Brito, 1994)

2. GEOGRAPHICAL CHARACTERISATION OF PORTUGAL

Geographical physical characterization is important to understand the possibility of using underground housing, especially regarding the climate and the soil properties. In terms of climate there are three regions in Portugal: Atlantic (wet Iberia, at the Northwest), *transmontano* (dry Iberia, at the Northeast) and Mediterranean (arid Iberia, at the south of the Tagus) (Ribeiro et al., 1987). From the topographical point of view the Tagus river separates two regions: the northern (with predominance of high relief) and the southern (with a predominance of plains). The lithological characteristics of the soil are also important to understand the feasibility of underground construction and the most suitable types to be adopted. Seven tenths of the Portuguese territory belongs to the "Hispanic" massive. It presents erosive and metamorphic rocks such as: granite, schist, marble and some quartzite outcrops (Brito, 1994). This massive contacts only with the Atlantic Ocean in the west coast, from Ovar to Sines and in Algarve, as it can be seen in Figure 1b. The rest of the territory present two distinct types: in the west and south predominates calcareous, margin and sandstones, but also clays and

conglomerates; in the basins of the Tagus and Sado rivers predominate clays, sandstone and conglomerates.

3. UNDERGROUND CONSTRUCTION IN PORTUGAL: VERNACULAR ARCHITECTURE

In recent years, the growing energy efficiency requirements led to a new approach, focusing less on the economic cost per se and more on environmental and material costs. Using local heavyweight materials, needed to increase thermal inertia and acoustic protection, begins to be considered in order to allow a compromise between pre and post occupancy environmental costs. As referred previously, intensive labor can be interesting not just for environmental reasons but also because it stimulates local economy. So, it can also be a more sustainable approach from the social point of view. Since the first buildings documented in the Portuguese territory, and until at least 50 years ago, the constructive systems used in housing buildings in Portugal were mostly mixed in terms of weight. These were characterized by heavyweight envelope structural walls, i.e. with approximately 1000Kg/m² considering an average thickness of 0,40m of massive stone – like an evolution of natural caves. In areas where the stone was not available, adobe was used, what could be considered as an evolution of artificially dig constructions. The floors and roofs were lightweight, made of timber - about 50Kg/m² the floor and 50 to 150kg/m² the roof. By the lack of efficient means of transport, materials used in the walls of traditional houses, were closely associated with the local availability of raw materials and manpower. Thus, the materials used for its construction correspond directly to the lithological characteristics of the soil, shown in Figure 1 b). Apart from the materials, with particular emphasis on the characteristics of the envelope, the morphology of housing contributed significantly to the evolution of the thermal performance of houses.

All primitive buildings were no more than shelters in the current sense of the word. It should however be made a distinction between shelters and primitive buildings. According to Veiga de Oliveira et al. (1969), shelters are buildings with very limited occupancy, temporary or even occasional, in some cases mobile, with rudimentary forms and systems or styles with regional characteristics; the primitive buildings had permanent occupancy, well defined building systems with sharp typological or regional differentiation. Construction progressed to a traditional architecture, gradually from the sixteenth century until the mid-twentieth century, when the presence of a uniformity of typologies could be verified. Some typological differences grew between North and South and between costal and inland, beyond the inevitable differences between urban and rural areas that could be noticed. The first shelters that man used to protect against the harsh climate and weather, present themselves in various forms, corresponding to different stages of evolution. Some examples remained in Portugal until today, or until the last century, including the following types:

- natural shelters - caves, grottoes and limpets;
- Semi-natural shelters - take part of rocks or soil and build inside these, as in the example shown in Figure 2 a);
- Artificial shelters - in stone, in stone and vegetable materials, entirely with vegetable materials.

The artificial shelters in stone with roof also in stone, appear in some areas of the country, like Trás-os-Montes, Beiras and especially in mountainous areas. These are small buildings in overlapping stone, as shown in figure 2b, used as shelters for shepherds, farmers or camp guards. This type of construction is based on the dolmen, and eventually stones or parts of these constructions may have been used. In some cases the artificial shelters with stone take advantage of walls and terraces for at least one of the walls. Artificial shelters of stone in circular or square plan exist also with false dome. The coverage was made with rows of stones that get closer to the centre as they develop to the upper part, to form a false dome. Constructions of this type can be seen on figures 2c and 2d, with circular and rectangular plan, respectively. Huts, with circular plan in stone walls and conical coverage made of vegetable materials still exist in some areas, particularly in Algarve mountains and in Alentejo. They are used now as barns, but there are still reports of some been inhabited till about 100 years. "(...) These are very poor forms of housing, where people lived in large - sometimes total - discomfort, that could be hardly accepted today, and are therefore doomed to disappear, voted in the general contempt that they deserve, or integrated into contexts that have evolved beyond" (Veiga de Oliveira et al., 1969).

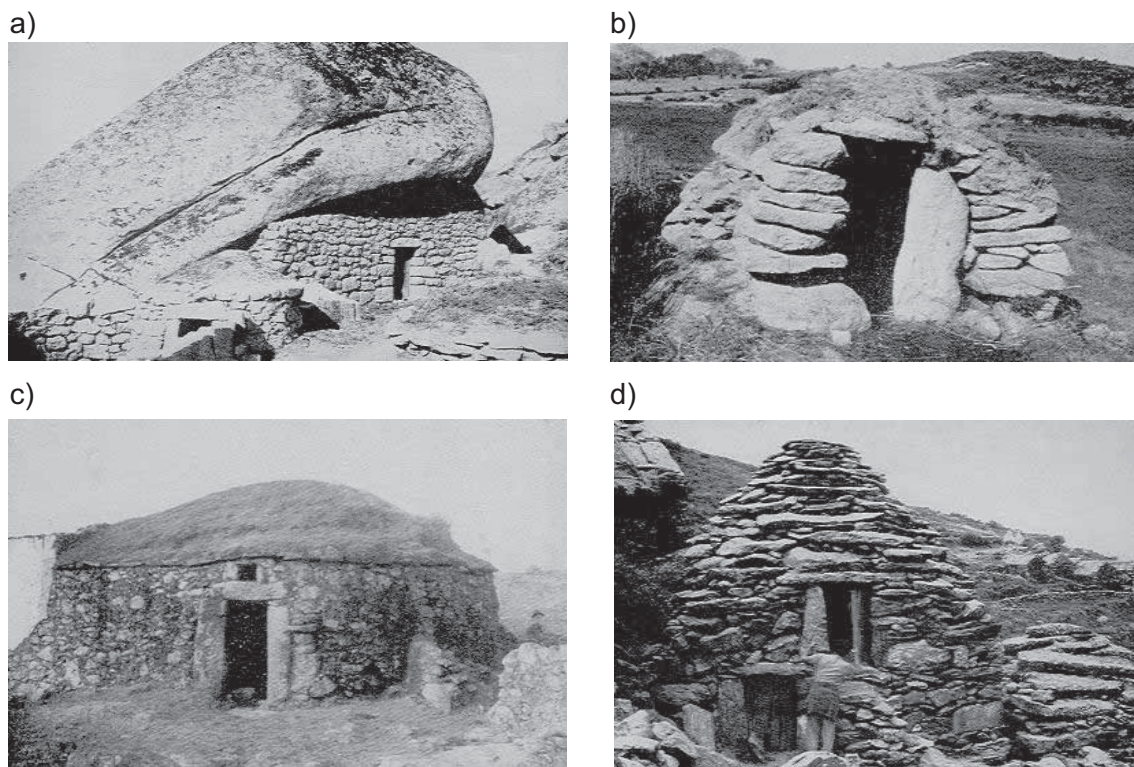


Fig. 2a - Semi-natural shelter: Monsanto da Beira; b) Artificial shelter with coverage: Leboção, Chaves; c) Primitive circular house of stone: Chafurdão in Ribeira da Amieira, Castelo de Vide; d) Stone primitive square plan construction: two floors oven in Branda do Real, Serra da Peneda (Veiga de Oliveira et al., 1969)

The relationship between housing and the immediately available resources only has an absolute value in the early stages of human habitat. Moreover, even at those levels, there are always plenty of scope for architectural changes, giving freedom to the conventions and local ideas to find their own expression (Keesing, 1961). The relationship between materials' availability on soil and primitive buildings is direct although, according to this author, leave some space for maneuver. What allows the

presence and determines the types of underground construction are mainly the characteristics of the soil, as well as the culture and climate.

4. UNDERGROUND CONSTRUCTION - NOWADAYS

With industrial revolution the transport of people and goods generalized. Building materials started to result from industrial processes taken up in factories and then transported to store places and to site works. Because of this fact, the link between the availability of materials in the soil and their use in construction changed, becoming significantly diluted. Economic issues are those that almost exclusively began to influence the types of materials used and thus also the constructive systems. Industries started to be located near raw materials extraction, more for economic than environmental reasons. This centralization of production increased the average distance of building products from the extraction to the work sites – with consequences on transport energy costs. Also the industrialization of construction materials, though more economical, is actually much more energy demanding and pollutant than the construction using intensive manpower and local materials. This happens in traditional underground constructions in Cappadocia / Turkey. Using only a digging hammer, one man can take between two weeks to eight weeks (depending on the hardness of the soil) to dig a compartment for a 20m² dormitory. The economical cost for constructing a compartment of this size using a conventional constructive system (hollow brick / concrete) is approximately 500€/m², not considering the cost of soil. Following a survey that the author took on Cappadocia recently, considering only handwork, the cost of digging an underground compartment is between 50 and 250€/m², meaning that this type of construction can be significantly more economical. The same comparison could be made about constructions in South of Spain (for example in Guadix), where the soil and the dryness of climate, allow the use of directly excavated spaces. Underground buildings can be found in: different urban layouts (from entire neighborhoods to isolated dwellings), with different uses (houses, hotels, offices, museums, libraries, etc.), and in several topographies. In relation to this last issue, it can be stated the existence of at least four types:

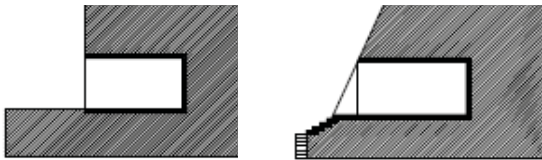
- Type 1: Underground building in a vertical plan - Figure 3a. In Cappadocia, Turkey, people lived for many years in underground cities. In a very mountainous region and with the enormous power of adaptation of human beings, started up to inhabit the caves and develop techniques of excavation, and thus shape their habitat. In this type of construction, the rock generally serves as a structural element. No example of contemporary houses of this type was found in Portugal;
- Type 2: Underground building in the horizontal plan - Figure 3b. There is a relevant example in Cappadocia, Derinkuyu, an entire underground city from the 8th–7th centuries B.C. In Portuguese territory, this type of construction is more adequate to the southern territory geographical conditions. Although the example presented here is a house in the north: “Bouçós” farm house (2007) in Valença do Minho, by Arch. Nuno Brandão Costa;
- Type 3: Constructions integrated on terrace slopes - Figure 3c, where ground and roof of sometimes intermingle. It is typical from the northern Portuguese territory, because of its topography. “S. Torcato” house is a project by the first author - Paulo Mendonça. It results from the excavation of a very inclined slope, forming a sequence of ra

mp roofs that allow the access to the upper part of the property. “Tóló” house in Vila Real, by Arch. Álvaro Leite Siza Vieira is a house located in a hill that instead of “fighting against nature”, absorbs it. The main entrance is at the top and the house develops its program down the slope;

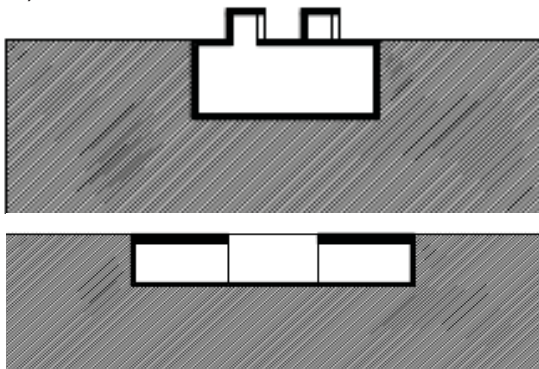
- Type 4. Constructions that simulate artificial topographies - Figure 3d. Guadix, an entire village in Granada, Spain and Future Systems’ house in Wales - England (1994) are international examples of this type. The authors from this last example referred: “Our objective has been to minimise the visual impact of the building and to site it in a way that makes the house appear a natural part of the landscape” (Future-systems, 2009). This type adapts to almost the whole portuguese territory. One example is “Labruge” house (1989-1994), Vila do Conde, by Arch. Carlos Prata. It is a small holiday house near the sea, with just 70m². It has only one facade to the outside, facing west, to the sea. “Dune” house (2009), from Pereira Miguel Architects is also an example of how to minimize the visual impact near the sea, integrating the house in an artificial dune.

The idea of underground building appears under the primary concept of shelter, based on the protection that it must provide. An underground construction uses the directly excavated ground to protect itself from the outside elements. It offers additional benefits when compared to conventional upper ground buildings.

a)



b)



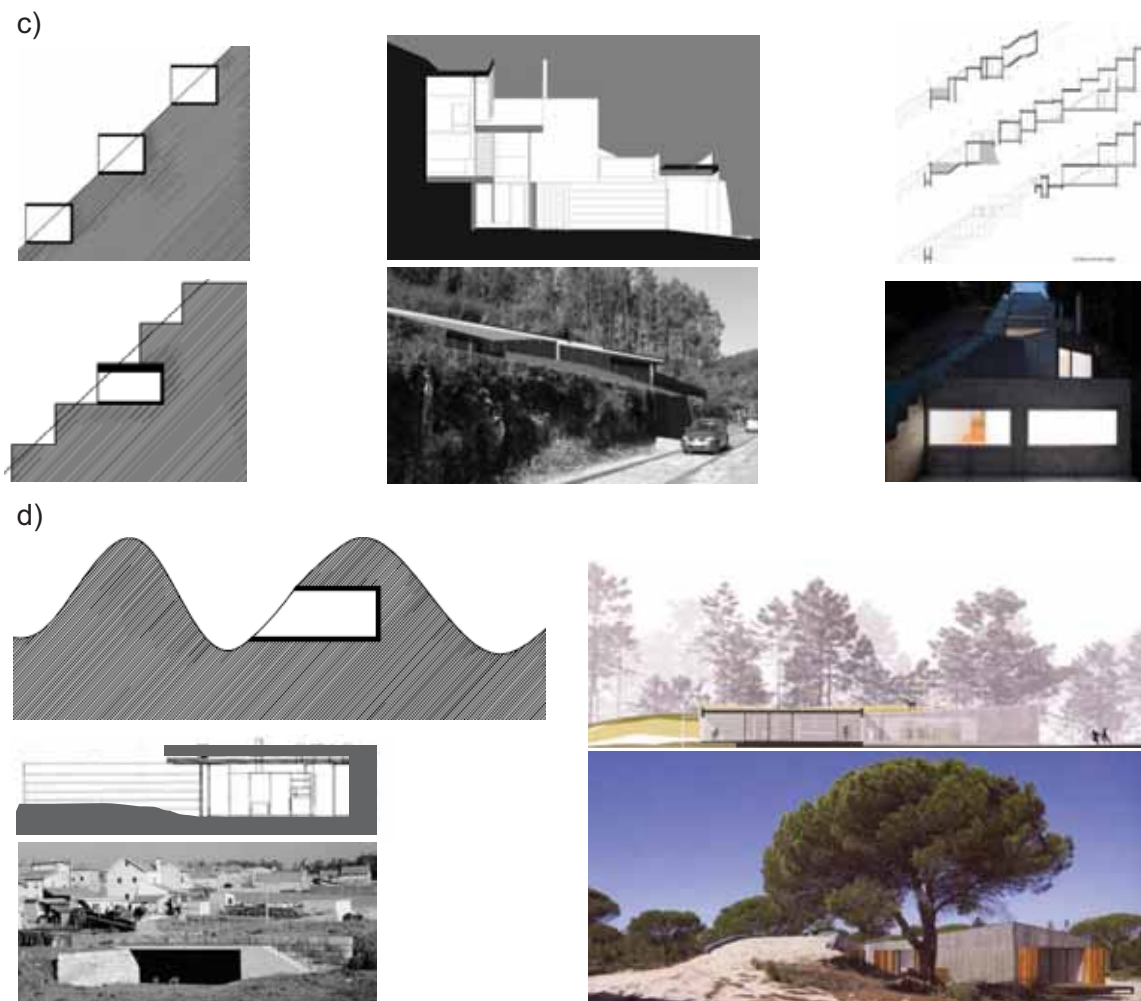


Fig. 3a - Scheme of Type 1; b) Scheme of Type 2 (left), “Bouçós” farm house section and plant (right) (FG, 2008); c) Scheme of Type 3 (left), “S.Torcato” house section and view (center) and “Toló” house section (Alvaro Leite Siza Vieira) and view (right) (FG, 2008); d) Scheme of Type 4 (left above), section (left center) (Carlos Prata) and view of “Labruje” house (left down), “Dune” house section (right above) (Pereira Miguel) and view (right down) (FG, 2008).

5. ENERGY EFFICIENCY IN CASE STUDIES

One of the main advantages of underground construction is energy efficiency; due to the large heat store capacity of the soil it presents a high thermal inertia. The soil temperature remains relatively constant throughout the year, near the average annual outside air temperature, so the building does not present large daily and even seasonal temperature lags. Bury the buildings also creates high acoustic protection from the outside. This yields a more protected environment inside, which makes possible to build in places near sources of noise, where conventional buildings would be unviable or too expensive to give them the same level of acoustic insulation. Another positive aspect to consider is the integration that this type of construction has with nature. It hardly emerges as a strange element in landscape, presenting a neutral integration. It is however important to use an efficient ventilation, since the relative humidity is always high. The Portuguese climate and soil characteristics need waterproofing of walls on excavated constructions. This creates vapor barriers, not allowing the recommended

absorption / dissipation of humidity that soils rich in clay or conventional breathable walls can provide.

Day lighting

The visual comfort can be considered as a psychological factor that reflects the degree of satisfaction of individuals with their visual environment. The existence of natural light is essential, it is appropriate if it allows the development of visual tasks that are performed during the day. Together with acoustic and thermal comfort is one of the fundamental aspects that contribute to the overall feeling of comfort inside buildings. There are many advantages by using natural lighting in buildings. It presents a graduate and continuous variability that helps to create a more pleasant environment than the monotonous one produced by artificial lighting. To evaluate the natural light available inside the buildings, should also be considered the availability of natural light outside. Daylight factor (DF) describes the ratio between outside illuminance and inside illuminance, expressed in percentage. A higher DF represents more natural light available in the room. It is expressed as such:

$$DF = 100 * E_{in} / E_{ext}$$

Where:

E_{in} - inside illuminance at a fixed point

E_{ext} - outside horizontal illuminance under an overcast (CIE sky) or uniform sky.

The levels of natural light indoors depends on the conditions of cloudiness in the sky, on the time of day and year, the geometrical characteristics of the building and compartments, the size and spectral-photometric characteristics of glazing, the external obstructions, and the reflective properties of interior finishing surfaces. There are several ways to take advantage of natural light to illuminate the interior of buildings, especially in underground buildings, which by principle represent a higher difficulty in getting natural light, as there present less exposed areas available to place natural light capture devices. In all the examples presented there are similar façade exposure then in conventional buildings, and in most cases conventional direct gain windows are explored to achieve a good penetration of natural light. These systems are especially interesting for Types 2 and 3 presented, and are explored in “S. Torcato” house – Type 3. Measurements of DF in the middle point of main compartments were made on the case studies and presented on Table 1. The results were satisfactory on “Labruje house” and excellent on “Dune” house - both Type 4.

	“Bouçós” house Type 2A	“Labruje” house Type 4A	“Dune” house Type 4B
DF	1,2	2,9	5,1

Table 1. Daylight factors on case studies (measured on the middle of compartment)

In what concerns the south vertical openings, shading devices should be placed horizontally. In high windows it is recommended to have overhangs above the line of sight, dividing the glazing in two sections, one on top, called "daylight opening" and one at bottom, the "open vision". The top should have a high reflectance finishing: such as glass mirror or highly polished metals to be more efficient. These can be used for types 1, 3 and 4. The “Labruje” house – Type 4 and the “S. Torcato” house – Type 3 uses simple forms of this system – external venetian blinds and fixed overhangs. North

vertical openings don't need shading devices, and other orientations should be avoided, but when it is necessary they should present vertical shading devices.

Another option is the skylight. It consists of an opening located in a horizontal or slanted roof. The skylights allow natural light to reach the spaces below; however it is necessary that the building has the roof in direct contact with the outside. This system was explored in "Labruje" house – Type 4.

But even in more deep underground solutions, there are devices that can allow the entrance of natural light. Lighting ducts are the most used system to capture natural light in these cases. The lighting ducts (and its variants) allow the capture of daylight and their conduction to areas and interior spaces of buildings not directly connected to the outside environment. Generally, the interior surfaces of lighting ducts are coated with materials with high reflectance in order to direct and spread the natural light "down" with some effectiveness, including mirrors and prismatic components.

From a previous study by the first author (Mendonça, 2005), it could be concluded that higher values of daylighting does not mean better overall energetic efficiency. The central question in this issue is to decide between direct gain strategy and indirect gain strategy:

- Direct Gain - the estimated values for thermal gains are usually higher in a direct gain strategy, but the temperature and glare due to the excessive solar radiation penetrating occupied areas can be a source of discomfort. On the other hand, the excessive solar exposure can lead to furniture and other equipment degradation. Additionally, with this strategy it is normal to have a great asymmetry in the radiant temperature between the exposed glazing and the interior walls, which is also a cause of discomfort. These facts can lead the building occupants to constantly operate the existent shading devices and, consequently, block the required thermal gains, as well as the natural illumination;
- Indirect Gain - in spite lower thermal gains estimated values, an indirect gain solution can, more effectively, guarantee that the forecasted values are closer to reality, since there is a more efficient control of the thermal gains. Then, the strategy chosen for the proposed design was an indirect gain strategy.

Thermal efficiency

Thermal fluctuations in the ground are minimal, guaranteeing not just a reduction of daily, but also of annual thermal lags. This is due to the great thermal inertia assured by the thickness of soil. This means that almost no thermal insulation is needed and the needs for mechanical equipment are reduced, especially for cooling. In cases where thermal gains are needed, a greenhouse can be created in direct contact with the construction, allowing heat to be later retained inside the building – this system was explored in S. Torcato house bedroom areas – Type 3. This type of solar passive heating works as an indirect system, with lower theoretical gains than direct gain systems (used in all other case study types presented). However it guarantees a better compromise between thermal and natural lighting comfort. As there is no direct radiation penetrating the compartment – there are no need to close shutters for lighting comfort when there is occupancy, what could compromise project predicted gains (Mendonça, 2005).

The acoustical insulation is also assured by the existence of buffer zones, what is intrinsic to the indirect gain system. This system pretends also to explore a greater

flexibility in the use of interior spaces, allowing a 30% increase in flexibility, when compared to a conventional system. This system was explored on “S. Torcato” house.

Measurements of temperature were made on “Bouçós”, “Labruje” and “Dune” house, between March and June 2009. Results of these measurements are presented on Table 2. As it can be seen, ΔT (daily thermal lags) on the interior were just between 1 and 2,5 °C, what is specially relevant on houses located more far from the sea, what was the case of “Bouçós” and “Dune” house. “Labruje” house is very close to the sea, that’s why the exterior ΔT was very low.

		“Bouçós” house Type 2 Temperature (°C)	“Labruje” house Type 4 Temperature (°C)	“Dune” house Type 4 Temperature (°C)
exterior	min	12	16	8
	max	27	20	18
	ΔT	15	4	10
interior	min	16	18	13,5
	max	17	20	16
	ΔT	1	2	2,5

Table 2. Measurements of temperature on case studies

Relative humidity

Humidity is a major problem on underground buildings. To prevent problems of durability of materials used inside and on the air quality, ventilation strategies should be used for reducing the moisture content in the interior environment. However, despite the high humidity, it does not mean that there is cold condensation in walls, because these cool very slowly (due to high thermal inertia) assuring these don’t easily reach dew point. Apart from a good ventilation, the best way to assure a low relative humidity is the election of a soil type that has significant amounts of clay (35% or more). This kind of soil is very rare in the Portuguese territory, so the excavated buildings are in general inserted on rock soils. In this context, and before proposing an underground construction in Portugal, it is recommended to make a study of groundwater level of the site, what must force to use materials like asphalt for waterproofing. In this case the excess of humidity should be expelled in the form of water vapor. It is therefore very important that the other surfaces, including walls, roofs and windows can breathe, and to use materials to facilitate this phenomenon. Sheet metal, waterproof concrete or windows without ventilation grids are solutions to avoid the other elements that confine the underground space. It should be considered the use of some vapor permeable façade and vapor absorptive interior dividing walls. In the “S. Torcato” house – Type 3, adobe walls and ceilings are used. The lighting and solar passive gains systems, mentioned above, may also function to create air pressure differences over the housing (solar chimneys and other openings). In “Bouçós” house – Type 2, the high opening ventilation allow the dissipation of humidity. Relative humidity was measured in “Bouçós”, “Labruje” and “Dune” houses, and in all cases it was between 60% and 70%, what is similar to conventional Portuguese buildings, as presented by Mendonça (2005).

6. CONCLUSIONS

The advantages and disadvantages of underground constructions were discussed. Some existing examples of North Portuguese contemporary houses were presented as case studies. Some of these examples were measured regarding thermal comfort

parameters. The results were used for optimizing an underground housing unit project, "S. Torcato" house, projected by the first author. It pretends to be a future model occupancy strategy for urban sprawl territories, such as the existing in the north Portuguese territory.

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Curriculum

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EGYPT AND HASSAN FATHY'S IDEAS AFTER THE 25TH OF JANUARY 2011 HOW CAN WE WRITE THE HISTORY OF THE FUTURE?

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world
Sub theme 2.2: Architectural design and sustainable development

Keywords: Hassan Fathy's ideas, sustainable future, Egypt

Abstract:

The first step towards writing the history of the future is to gather the nation around a national project that keeps pace with the revolution of January 25, the new concepts, the new constitution and the new human being who derives his heritage from the ancient Egyptian civilization and the language of modern technology, with emphasis on that 7% of the valley is no longer accepts more and Egypt needs to build on 93% of the desert outside the valley.

In spite of the existence of the proposed desert development corridor as one of the suggested scenarios and the acceptance of all other scenarios, on one hand the first step requires an initiative that exceeds feasibility studies and inspires the desire, potential energy and new non-conventional ideas. On the other hand there is no need to invent the wheel we could learn from past experiences many principles and ideas for the future. The experiment of Hassan Fathy to build a New Gurna still could give ideas and principles in different levels. New Gurna could be the beginning of a new venture for Egypt to build new communities. For many years Hassan Fathy's project and ideas which covered through his book "Architecture for the poor" were a matter of dialogue.

New Gurna was a pilot project and it showed the way to rebuilding a community, with cheap but good houses, and it was a great test of do-it-yourself through a system of planning and control for a village whose inhabitants gave their work free. It gave definite and useful data to the people who administer schemes of "aided self-help" to peasant communities. The project used unique architectural techniques of vaulted-roof construction, based on orthodox materials. The design and plan of the village were based on traditional principles. The costs were low, and the village is considered beautiful, in contrast to concrete buildings. Hassan Fathy wrote that "I always say that we benefit more from failures than from successes. Failure makes us consider every aspect of a situation. But success has certain hidden dangers which, when repeated on a large scale, become a disaster. Only by knowing the mistakes in an idea can you find a solution to it and save it from the beginning" (Steele, 1988, p. 10). This paper would like to discuss the experiment as a process rather than a product and to what extend the developmental process

of Hassan Fathy with the new trends of green/ earth/desert architecture and sustainability still could be used for architectural design to build new Egypt and write the history of the future.

1. INTRODUCTION

The recent revolution in Egypt aimed for a national development which seeks to get rid of corruption and to create a better and prosperous lifestyle by reducing disparities within the different strata of the Egyptian society. The revolution was sparked by a group of young middle class through the digital social networking across the different regions of Egypt. The social networking led to an organized action against the ruling political system in Egypt, this action was transformed into a physical action by going on protests.

The main problem in Egypt is that only 7% of the total area of Egypt concentrated mainly in the Nile Valley and Delta leaving about 93% of the desert undeveloped. This leads to several problems such as the settlements expansion on agricultural lands, concentration of high population densities in urban centers and the inequality and imbalance in investments (Serag, 2008).

2. HYPOTHESIS

- The need for futuristic visions and programmes combining the present and future of Egypt that would provide practical scenarios rather than setting unreachable plans.
- Prediction in the midst of regional and global variables as well as scientific revolutions is very difficult. Studies of the future depend on the thought (the survival of the fittest) which means who is the first to reach scientific and technological applications that would change the face of the world.
- The issue of population and resources is a strategic issue to be considered in the long term, and therefore after the 25th of January getting out from the 7% of the Nile Valley and spreading to other areas either the Developmental Corridor or Toshka is a major development of resources.
- The desert and Egypt of the future need a construction, not only new in its version, but also new in its philosophy of development (but still could use idea similar to Hassan Fathy's).
- The responsibility of the architect/engineer stems from his message of reconstructing the land, and the attempt to change the future and sustainability of the development of Egypt of tomorrow through work and out of equal competition so that self building and implanting moral and ideological values and self education of the items of a sustainable environment could be achieved concurrently with technical components.
- Ethical, religious, artistic and architectural values of the heritage of ancient environments and what they contain of ideas, solutions and lifestyle compatible with the environment and not the desire to return to the past is the justification for deducting a

uturistic architectural way of thinking of a sustainable development.

- Dialogue and studies that discuss issues of reconstructing the future of Egypt and the future of today's children, men and women of tomorrow, will not bring any new ideas through the traditional routine and therefore the emergence of new ideas that may be in some cases non-stereotypical is essential.

3. THE PROBLEM: INVADING OR SETTLING IN THE DESERT

The ironic note that the ratio of the population of the Egyptian desert to the total population of Egypt is the same percentage as the Nile Valley area to the total area of Egypt helped in promoting the idea of invading the desert. Gamal Hamdan, in his book "Egypt Personality, a study of the genius of the place" about the invasion of the desert says:

"It is not easy, however, to invade the desert, because it is not a geographical or cultural picnic, but it is a struggle against nature and a real battle against the element. The process may take the risk failures and setbacks as much as possibilities of success. It is regrettable that the first three attempts to reclaim and reconstruct desert lands in the last two or three decades (this meant 1950s, 1960s and 1970s of the past century), whether on the edge of the valley itself or in the oases, Al-Natroun Valley and they are the project of El-Tahrir Directorate, and the New Valley. They stumbled by varying degrees, and got many losses and did not achieve the desired or remarkable success."

The research here refers to the development of the desert as the invasion of the desert. This term was also found in many of the scientific and cultural circles, and in this regard the research point out that we have to change the concepts of developing the desert as well as the requirements necessary for this development. Therefore, the research found that it's necessary for us to change the operative word if the goal is to change the requirements of its significance. As the word invasion origin is (invaders), which means that the settlement is illegal with reparation of force and coercion.

The aim of invading a place is to deplete the resources and potential wealth in the desert, whether agricultural or mineral depending on a limited source of water and eventually leaving the place once the stock and resources are depleted. It is noticed that in Islamic history, the word Conquest was used instead of Invasion because the goal was not only to reconstruct the land, but also this reconstruction should be sustainable. Therefore, the actual meaning and significance of moving towards the desert is to develop and sustain it through making settlements and social communities.

After all, the old word (Conquest) enhances the concept of sustainable development and the deliberate settlement and the way of dealing with the desert environment from the perspective of coexistence, and not based on the ideology of invasion that will neglect any sustainable aspect. Changing the way of thinking will have a direct impact on the way we deal with the desert resulting in a developed sustainable second Egypt.

4. IMPACTS ON THE BUILT ENVIRONMENT

Spatial impacts have several tangible aspects on the built environment. The two most tangible aspects are: the illegal urbanization on agricultural lands and regional planning and development (Serag, 2011).

4.1. Illegal urbanization on agricultural lands

It is well known that the agricultural lands in Egypt are under continuous threat of being run by the urban expansion and sprawl. Therefore, to protect these lands there had been several laws and regulations to protect the depletion of such valuable lands. The ministry of housing and the General Organization for Physical planning, produced a strategic plans for the villages and cities of Egypt, according to which, the urban expansion on agricultural lands is limited to specific cases.

4.2. Regional planning and development

Since human settlements are concentrated on only 7% of the country's total area as shown below in (fig.1), mainly the Nile Valley and Delta. This leads to settlements expansion on agricultural lands, concentration of high population densities in urban centers and the inequality and imbalance in investments (Ibid, Serag, 2008). There had been several regional planning attempts proposed before the revolution to increase the inhabited areas and redistribute the population in Egypt.

Among those projects was the development corridor initiated by Prof. Farouk El Baz (fig.2), where the intention was to construct a national road spanning from the west of Alexandria in the North to the southern borders of Egypt with transverse roads linking this corridor with existing settlements in the Nile Valley, and initiating the establishment of new human settlements, and also the establishment of new industrial areas (Ibid, Serag, 2011).

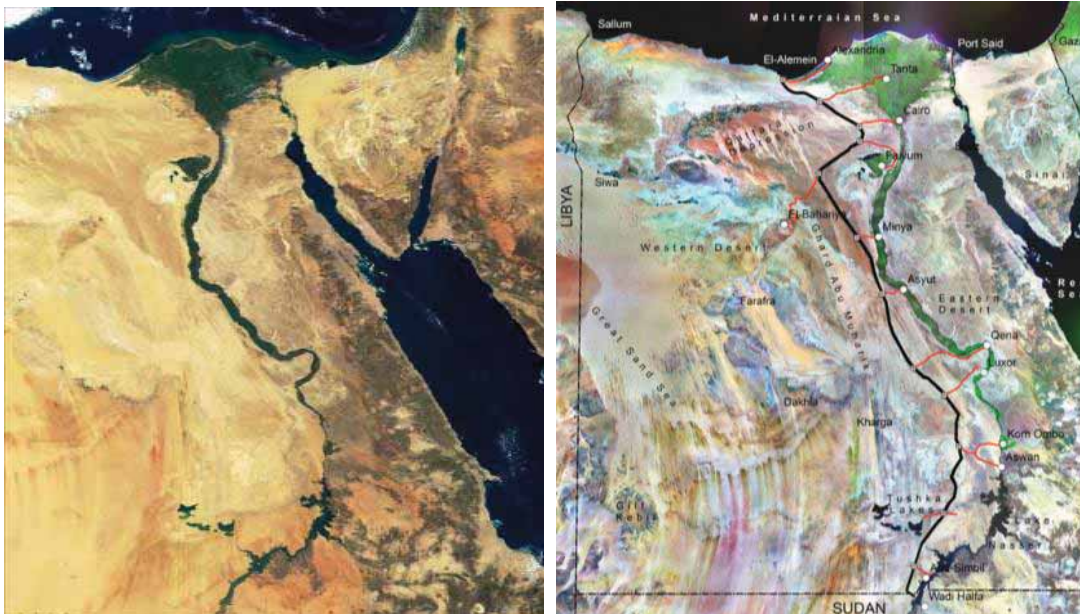


Fig.1: Only 7% of Egypt's area is populated, with a clear imbalance of population distribution
Fig.2: The Development corridor showing the transverse roads as links with the Nile Valley
(Elbaz, 2011)

5. HOUSING DEMANDS

Almost about 25% (15.5 million) people are living in informal settlements. This problem has been growing over the last few decades; in fact it became evident in the spatial structure of Egyptian cities, as an informal solution to the housing problem. There had been several attempts by the successive governments to solve this problem by focusing on providing public sector housing affordable to large sectors of the society to meet the housing demands.

After the revolution, the government aim to improve the situation among the different critical sectors in Egypt including the housing sector. A project to construct one million housing units within the next five years was proposed by the government. These units are to be constructed along governorates and to be strictly distributed over the slum dwellers. Thus, a great challenge for planners to find proper locations within the Egyptian cities to locate these units (Wahab and Sheta, 2008).

6. THE DESERT AND THE STRATEGIC ENVIRONMENTAL ASSESSMENT

"Strategic Environmental Assessment" (SEA) can be defined as the process of a preliminary environmental assessment of the general objectives of the development related to major projects in the stage of setting Policies, Plans and Programmes (PPPs) of these projects so as to ensure the environmental feasibility of these policies, plans and Programmes. The research finds that to achieve a kind of developmental integration on the national, regional and local levels for settling in the desert from the environmental perspective there should be a "Strategic Environmental Assessment" to be the first steps to change the concept of the desert invasion to become desert development, and then laying the foundations and the basic principles of the desert development which is considered as an initial phase of decision making, completed by the Environmental Impact Assessment of the projects (EIA) which comes in later stages to ensure the integration of projects at various levels and the sustainability of the aimed development. Here, we must point out the four elements concerned with the raised environmental issue about settling in the desert: firstly, the population and what is related to this element regarding spatial issues, water, energy, food and other requirements. Secondly: the technical contents such as the food production techniques, disposal of waste, industry, energy and other methods of coexistence with the environment and affecting it. Thirdly: consumption; which is the ability of all parties to participate in the environmental benefit of the resources available which include water resources, agricultural lands, riches mineral and even the air itself. Fourthly and lastly: sustainability and networking which is the ability to build systems of land use and to exploit the riches that would attain environmental balance without draining them. Therefore, the objective of assessing the environmental strategy is to make an attempt to ensure the sustainability of the aimed development and perform comprehensive studies of all aspects of desert development.

There is no doubt that the availability of information and different studies and the use of satellite images and geographic information systems (GIS) is the central axis and the cornerstone of the success of the presumed objectives of the "Strategic Environmental Assessment", in order to support the decision makers to take the right decisions. This may require rearranging and making comprehensive regulation for all institutions and bodies concerned with these studies, as well as to renew and reconcile all laws and legislation governing these fields.

7. HASSAN FATHY'S PHILOSOPHY AND THE FUTURE OF EGYPT

Prospective studies and the future of Egypt isn't just a theory. It is the responsibility of current generation to think and work hard towards enabling future generations to achieve their objectives. Over the years a variety of national projects have been started with optimistic expectations and ended up with limited results or frustrations. It is noteworthy that Egypt has lots of potentials based on its civilization and its human resources. However, these potentials should be utilised in an innovative and efficient way to reduce or eliminate waste of time, cost and effort. From the Egyptian History Hassan Fathy was a visionary person who tried to change Egypt future about 70 years ago by inventing a mixture of ideas included Egypt civilization, Earth architecture and Architecture principles. The question is it still valid for Egypt after the 25th of January revolution?

Fathy realized on 1930-40 that to have a new Egypt we need to start with the cell to assure a healthy body and the cell at that time was the village with most of the people was poor. Therefore, by upgrading the village through the "Architecture for the Poor" it could be the only option for Egypt to be modernized. The experiment had its merits and failure. Fathy's vision was to understand the importance of restoring the harmony between people, artifacts and nature, by which the basic theory of regionalism was articulated. Fathy philosophy contains a moral plea in favor of preserving age old adaptations from rural culture". This is why Fathy's breakthrough must be considered in a broader context of emerging regionalism in many parts of the world.

Fathy's ideas are to explain the importance of the architecture of the past and in responding to the crises of modernism in architecture. Moreover, Fathy concerned human needs and requirements. This attitude towards humanistic architecture began to be felt with the development of the post-modern movement in the early 1970s (Rashed, p. 113).

"I always say that we benefit more from failures than from successes. Failure makes us consider every aspect of a situation. But success has certain hidden dangers which, when repeated on a large scale, become a disaster. Only by knowing the mistakes in an idea can you find a solution to it and save it from the beginning" (Ibid, Steele, 1988, p. 10).

Hassan Fathy describes his experiment to build "the New Gournia Village" in his book "Architecture for the Poor". He tells the story of the birth of the idea, the decisions, the reasons behind them and the social and economic contexts. Fathy also known by his strong social involvement through their nationalist feelings, and to work on adequate low-cost schemes inspired from the place.

8. NEW GOURNA SUCCESS OR FAILURE

Fathy's work in New Gournia exhibited an extreme responsibility toward authenticity in architecture which can be the basis for today's aspiration of an architecture rooted in local heritage concerning with vernacularism, contextually, metaphor and symbolic architecture.

The main objectives of this project were to preserve and conserve the urban heritage from the destruction, caused by the squatter villages and the pilfering of antiquities, by providing the population with their own village. These two objectives were never achieved. Only about fifty buildings and most of the public buildings were built. A few people moved from their original houses and lived in New Gurna. The rest continued to live on the archaeological heritage sites. They did not establish a new economical base. About forty years have passed, and still the question of conservation of a tradition is unanswered. It is not enough to judge the experiment as a failure, as a great number of detractors did. It should be considered as a struggle between ideals and practice, dreams (professional) and reality (public), and to avoid as much of this conflict as possible in any future issue.

The simple architectural role is to build suitable shelters to house people. Many issues are involved in any architectural decision, in this example, Fathy as the architect, chose a form of participation in which the people themselves would build their own houses. Such a participation of the peasants in the creation of the new village solved two problems. First, the preservation of the peoples' tradition and culture, and second their participation as labourers. In addition, he chose mud brick as an environmentally sound material to build the village. This approach gave hundreds of families the chance to make their houses as efficient and as beautiful as possible, each family made their house to suit their needs. Thus, although Gurna has nothing of the colorful and imposing architecture of Nubia, or perhaps the same pride in really beautiful craftsmanship, yet there are occasional buildings that show a certain purity of form and that were free from the artistic corruption that degrades village building as one proceeds northward (Ibid, Steele, 1988, p. 108).

Gurna was a pilot project and it showed the way to rebuilding a community, with cheap but good houses, and it was a great test of do-it-yourself through a system of planning and control for a village whose inhabitants gave their work free. It gave definite and useful data to the people who administer schemes of "aided self-help" to peasant communities. The project used unique architectural techniques of vaulted-roof construction, based on orthodox materials. The design and plan of the village were based on traditional principles. The costs were low, and the village is considered beautiful, in contrast to concrete buildings (Fathy, 1989, p. 60). But The Gurna experiment in one way failed. The village was never finished; the principles did not succeed in practice. After a continuing series of obstacles and frustrations that are well documented in Fathy's own account of this project, construction was halted after three seasons of work, with only about 20% of the total plan completed.

9. HASSAN FATHY IS NOT ONLY NEW GOURNA

Soon after the New Gurna experiment, Fathy developed his ideas by having different designs and cooperation such as his works with Doxiadis Associates in Athens who offered him an opportunity to tackle larger-scale planning issues. Through his collaboration with Doxiadis, Fathy had the chance more systematically to contemplate the interrelationships of local knowledge systems with dominant demands for standardisation and mass production (Pyla, P., 2009, pp. 715-730). The positive reviews of Fathy's ideas over time came in much more massive numbers after publishing the Book *Architecture of the poor* in 1969, and by portraying the book as offering a way out of the dilemmas of a modernising third world where 'from Baghdad

to Benghazi, look-alike blocks of dreary high-rise buildings rose along drab, dusty boulevards.' Even the few book reviews that expressed unease with Fathy's nostalgia hailed New Gurna as a 'superb example' of 'indigenous vernacular architecture. Fathy explained his experiences as the following:

"Sixty years of experience have shown me that industrialization and mechanization of the building trade have caused vast changes in building methods with varying applications in different parts of the world. Constant upheaval results when industrially developed societies weaken the craft-developed cultures through increased communications. As they interact, mutations create societal and ecological imbalance and economic inequities which are documented to be increasing in type and number."

Today, with the challenges of Egypt, Fathy's work is reframed as an environmental strategy. His ideas included the issues of sustainability, green architecture and appropriate technology. Furthermore, from sustainability debates he was based his studies on local materials, low technologies, local knowledge systems and the economy of means, allows the integration of social, cultural and economic concerns within a definition of environmental sustainability. The readily obvious explanation is that Fathy's designs using mud-brick structures fulfill many criteria for reducing both the energy consumption and the embodied energy of buildings. The participatory approach and participatory design of his works reflected the social responsibilities of architecture and its democratization.

One of the critical issues of Hassan Fathy's works and had kind of debate is that the irony behind the fact that the proponent of 'architecture for the poor' ended up designing luxurious villas. But the fact that the lesson learned from New Gurna was that the only way to reach the poor was first to collaborate with the rich to establish a trend which the lower classes would then feel compelled to copy.

The 'alternative histories' explored here remind us, first of all, that the social impact of architecture and of the architect is neither singular nor uniform. Concepts such as 'tradition' or 'locale' are proved to be far from neutral, and any binary opposition between 'traditional' and 'modern' or between 'local' and 'global' misses the fact that these concepts are not only intricately intertwined but also that their very definition is part of processes of selection and contestation. To situate these 'histories' into the larger socio-political realities that shaped them is not simply a matter of historical research or historiographic critique; rather, these histories and the rigorous reflections they cultivate can introduce useful complexities into contemporary architectural concerns about the social, political and ideological uses of concepts of 'tradition', 'place' and 'environment' in a globalised world: where the dilemmas of developmentalism, cultural identity and environmental protection are ever-more powerful.

For all of the above reasons, it is logical to draw parallels between Fathy's work and the current situation of Egypt and the strategies in sustainability. So the use of Hassan Fathy's designs was used in many touristic villages with the concept of 'eco-lodges' in (Siwa oasis at the western desert, Qusier and Hergada at the Red Sea, The North Coast, Sharm Elskikh at Sinai and more over within Luxor and Aswan at the Nile Valley). To conclude Fathy's designs and principles could play major role in future of Egypt.

10. THE DESERT AND THE PROPOSED PROJECTS

The implementation of other experiences are all mechanisms that allow the creation of multiple and different scenarios that vary in how they fit with the private sector participation, the goals of the state, the target time and place and the quality of the

settlers. It is necessary to stress once again on the need of studying similar experiences in the world and the diversity of the studies and development of ideas in accordance with modern technologies. Also, it is important to study local materials of the Egyptian desert and the possibilities of their use in the construction and the construction systems appropriate to the desert in terms of temperature and ventilation and then study urban planning to be compatible with the desert environment. Moreover, there is a need to create an integrated society that has factors of culture, entertainment, media, education, investment, crafts, transportation and services required.

Looking to the future, we see that the situation at any given time largely determines the coming stage in development and change. Thus there would be no problem were the present situation of architecture normal, that is to say, truly contemporary. The future would then take care of itself. But unfortunately that is not the case, and it is the responsibility of the modern architect to find a remedy. He must renew architecture from the moment when it was abandoned; and he must try to bridge the existing gap in its development by analyzing the elements of change, applying modern techniques to modify the valid methods established by our ancestors, and then developing new solutions that satisfy modern needs.

Heritage is what is automatically gained depending on the genes (qualities vertically inherited from one generation to another over the generations and civilizations). In the study of heritage and architecture there are things for granted that cannot be escaped and cannot be known if they belong to the Greek or Renaissance civilization. There are things that can be selected from traditions because it indicates specific architecture and distinct civilization and can be replaced by another meaning or different expression. As for modernity, it depends on the characteristics that circulated by members of one generation and produced in a creative way the meme-tics. The development of the fetus (meme-tic) may be affected by multiple inputs, including cultural, political, technical, or other factors, of different rates from one region to another and for different goals and according to the genetics credit and its impact. This is why the vision of the future process is incomplete.

In the presented theories and views, there is an invitation to re-visit heritage, and to re-read inputs and modernity and to use new tools that would allow us through wearing new spectacles to have our own reaction by the relationship between heritage and modernity to form the future in a time when speed and the growing change in the requirements and techniques drive us to think about the potential in dealing with both the self, the time and the place to create of a new map for the future and to accept that the future of Egypt desert has more than one scenario. The actual reality might be something different from what has been conceived.

11. THE CITY OF 25TH OF JANUARY AND NEW CAPITAL CITY OF EGYPT

The first author of this paper suggested to have an international competition to have a new city named 25th of January "The Egyptian Dream" which could be the first future sustainable settlement on the desert. And one of the scenarios is to have a new capital city for Egypt with all different new ideas. Although the simplicity of the name, it has a deep meaning. Starting with the new Constitution to build a presidential palace that does not change with the change of the ruler, as the case of the White House or the Elysee Palace or Buckingham Palace. In addition, the presidential place is associated with the Parliament and Shura Council as well as ministries and government agencies, diplomatic missions, embassies, and other requirements for a quality of life such as markets, clubs, neighborhoods, airports, railway stations, transportation, clean air,

architectural and urban development projects that apply the principles of green architecture according to the National Organization for Urban Harmony and using clean and renewable energy. It is of prime importance to mention that streets and districts will be named with the names of martyrs of the revolution to mark them in the history of Egypt.

The city of January 25 is a national project that will develop and urbanize the desert and a step in the writing of history of the future. It will be at a distance of at least 300 km and could be reached by road and train (Average speed trains in Europe 300 kph) and is therefore linked to the valley in an hour time or less, and at the same time, this distance allows for stability and non-cohesion with the Valley, so it will not be an additional burden to 5% as is the case with cities 6 October and 10th of Ramadan and others.

Let the city of January 25 to be an opportunity for all ideas emanating from all the people, generations and experiences, and provide an opportunity for the government, scientists and researchers, to be parallel to the graduation project for students in all universities with the beginning of the second semester, where the integrated vision of planning and construction, architectural, engineering, agriculture, tourism, mining and renewable energies and all the science and research, depending on the terms of reference of Hassan Fathy, Gamal Hamdan, Farouk El-Baz, Ahmed Zewail, Rushdi Said, Mustafa El-Sayyid and all the scholars of Egypt and the civilization of 7 thousand years and all the studies and research available in the universities and bodies and the various centers in Egypt and the world.

12. CONCLUSION AND RECOMMENDATIONS

The research paper sought through scientific methodology addressing the research hypotheses, to discuss Fathy's Ideas after the 25th of January 2011 and how can we write the history of the future. Here a question arises, which futures are we making and how? Could we have a vision and a means to translate research papers, studies and conceptual thinking into applied reality?

The research here is primarily concerned with the desert, investment opportunities, reconstruction work and the role of architectural and architects as influential or being influenced by other factors. In the research a problem was reviewed: to invade or to settle in the desert and the environmental dimension of the desert and the importance of strategic environmental assessment studies, as well as the future of Egypt and the ideas of Hassan Fathy with other various proposals such as the corridor of reconstruction and document of the twenty-first century, projects of desert back villages and towns, and what could be the form of reconstruction product and desert society.

As a start, the transfer of patterns and styles that were applied for long time in the valley to the desert would be undoubtedly a historic mistake. We should not be hasty to imagine solutions to the quality of the architecture of the future (the product) as the issue is not easy or simple. What should we do? The right solution is the scientific techniques and capabilities to help solving the problem of determining the architecture and planning appropriate to the nature of the desert (Abada et Al Khorazaty, 1999, pp. 50-57).

Views and theories that can keep pace with development, modernity and speed were also discussed. They could play a role with understanding and awareness in assuring the role of applying this through distinct architects as Hassan Fathy who think and apply these theories in different projects, which allow positive influence instead of depending on receptive to turn the matter to a kind of contribution. With time, lost

leadership can be retained by experimentation and not reclusion and vague slogans. Findings and recommendations of the research paper can be summarized in the following:

1. Through an interdisciplinary outlook that integrates historical and theoretical perspectives on Egypt modern architecture with critical perspectives on the cultural politics of modernization, representation and post-revolutionary, the paper considers the role Fathy's ideas played (and still plays) in the formation of contemporary conceptions about local tradition and cultural identity, and about modernism, urbanism, technology or ecology.
2. The historic role of construction between heritage and globalization has been and still influential in the construction and settling in the desert.
3. Environmental dimension and Strategic environmental assessment is a necessity to ensure the developmental sustainability.
4. Penetrating the future can be achieved through self-understanding, education and focusing on the aimed steps and not to rush the product as practical aimed steps though they may take time but they shorten times instead of the trial and error method of the unstudied product.
5. What the architect needs today is more than a mere understanding of construction skills, it is to understand the development of the age and renewable techniques and try to create a space for understanding the mechanism of knowledge and techniques and factors of change. It is a must to gain a profound understanding of the heritage which he adds to or modifies through his works. Architectural education and training are the possible basis for a better future.
6. There is a need to spread awareness and the consolidation of the size of the architectural community participation, in particular, and the international community in general in the reconstruction of the desert.

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APPLICATION OF GEOTEXTILE REINFORCEMENTS IN A MUD STRUCTURE IN MOROCCO: MODELLING OF ITS SEISMIC MECHANICAL BEHAVIOUR

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world
Sub theme 2.2: Architectural design and sustainable development

Keywords: Earth architecture, *pisé*, geotextile reinforcement, Morocco seismic area

Abstract:

The construction of a mud structure using the *pisé* technique, localised in a seismic area in Morocco, needs a specific study for the elaboration of an seismic resistant project and the research of new reinforcement methods. This study was made by a technical office, specialised in mud construction and anti-seismic engineering.

Geotextile reinforcement in mud walls was chosen for economical and technical reasons. Wood is expensive and scarce in Morocco and, by the other hand, the use of metal and concrete are not easily compatible with the clay structure. It was thus necessary to find an innovative method, linked to a seismic resistant conception. The geotextile material, which qualities were verified on a shaking table in Peru is still experimental: it has been used in mud constructions in Peru and historical masonry constructions in Italy, especially after the l'Aquila earthquake. For Morocco, the use of this technique is innovative and validated by a French control office: SOCOTEC.

However, in order to underline the qualities of this reinforcement method by geotextile, as shown by the shaking table tests, a numerical modeling was produced by the CMGD, Ecole des Mines d'Alès laboratory, using finite elements and discrete elements (LMGC90). The results of this modeling are presented.

1. INTRODUCTION

The use of mud material for house building is a thousand years old tradition in the Berber tribes from south Morocco. Numerous *ksour* and *kasbah* from these areas were built with mud. Berber tribes produced an original rural building art, without any external influences from Arabic or Hispano-Moorish period. This art is very similar to Yemenite traditions, as Yemen is another important spot for mud construction in North Africa (Naji, 2008). This ancestral way of construction, now in danger because of the lack of maintenance, is nevertheless very efficient from a sustainable architecture point of view. For many years now some architects and the research laboratory (CRATERRE-ENSAG), throughout the world, have worked to promote this material and to benefit from the discovery of all the old building techniques.

In this context the project « Domaine Royal Palm », located near Marrakech in Morocco was conceived, partly in mud material, by Denis Coquard, architect of the project. Marrakech area is located in seismic zone 2 after the Morocco seismic zoning. For this reason, the building must be conceived according to the Moroccan antiseismic rules. Unfortunately, mud material is a traditional way of building out of modern normalisation. For this reason, antiseismic rules didn't propose any way of reinforcement. By another hand, engineers aren't educated for earth material resistance calculation. The rules elaborated in France after the Second World War (REEF DTC 2001, 2102 1945), concerning the use of mud material for buildings reconstruction, are now completely forgotten and actually people who want to build with this material meet a lot of difficulties and could be considered as pioneers in spite of the fact that this material was used from millenaries.

For these reasons, the construction now of mud towers in Morocco, in seismic zone 2, with a geotextile material used for reinforcement, validated by a French control office like SOCCOTEC France is a first time experimentation.

For the antiseismic conception study we used the Moroccan rules (RPS 2000) completed by the French PS92 rules. The Eurocode 8 was not yet official at the study's time. In order to complete and verify the good resistance of the structure after geotextile reinforcement, a numerical modelling was produced by the CMGD, Ecole des Mines d'Alès laboratory, using finite elements and discrete elements (LMGC90).

2. THE SEISMIC CONTEXT

The location of the "Domaine Royal Palm" is 15 km from Marrakech in the road to Amizmiz, in an area with traditional earth architecture. The area of Marrakech – Tensift – El Haouz is located in the central place of Morocco, surrounding a part of the High Atlas. The area represents 4,5% of the national territory with a population of about 3 million people. According to the RPS2000 seismic rules, the Marrakech area is located in zone 2 which is characterised by an average seismicity (fig. 1) with obligation for antiseismic construction.

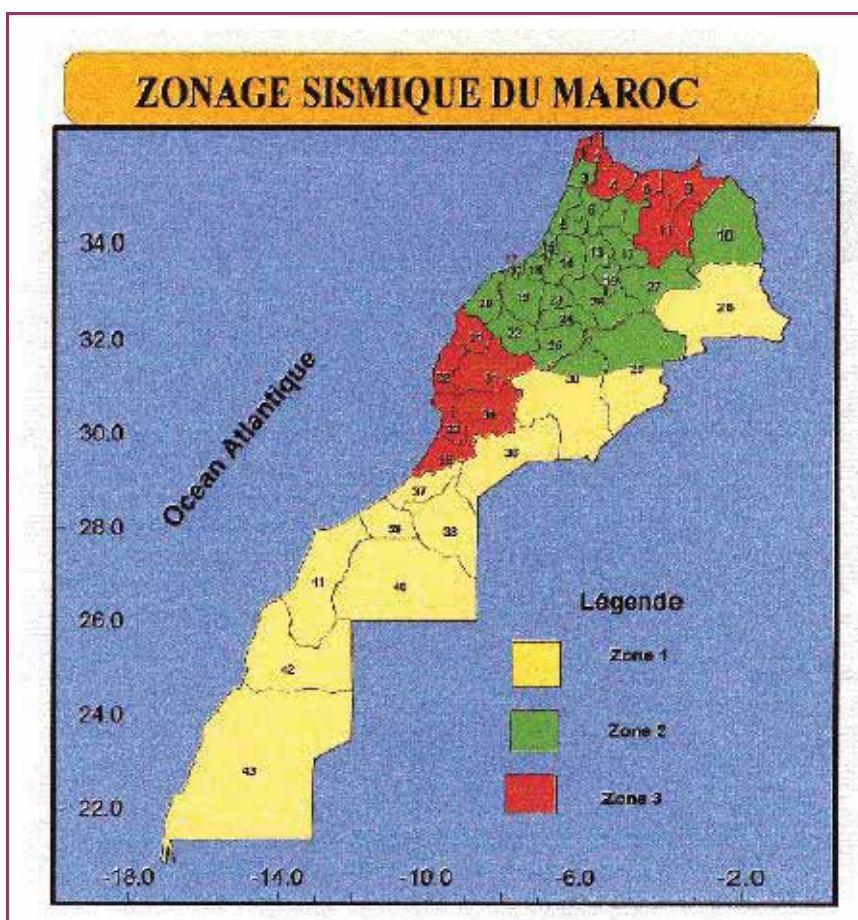


Fig. 1 - seismic zoning of Morocco

For this reason, the Domaine Royal Palm project was verified in order to be conform to the antiseismic Moroccan rules and resistant to the reference earthquake for this specific zone.

3. VERIFICATIONS AND PROPOSALS FOR ANTISEISMIC BUILDING

Because of the lake of specifications concerning the mud materials in the RPS 2000 rules as well as in the PS92 too, we just have to verify some important points for a good resistant conception: like the quality of site implantation, the regularity in plan and elevation of the building, an so on. Reinforcement proposals are selected after experiences of traditional earth architecture (CRATerre, 1995 ; G. Poursoulis, 2000) in world seismic areas, and after civil engineers experience (AFPS guide, 2005 ; M. Zacek, 1996, 2008).

3.1. Plan regularity of the Domaine Royal Palm

The Domaine royal Palm will be surrounded by *pisé* walls, 4m height, with four mud towers (also in *pisé*), consisting on a square of 8x8m with a height of 9m (fig. 2-5). All the walls (surrounding ones as well as towers walls) will be 0,8m large. The external walls will be separated from the towers by an antiseismic joint of 5cm. This square shape of the towers is compatible with the regularity criteria proposed in the RPS 2000 rules (chapter 4.3.1.1 regularity criteria, 1).

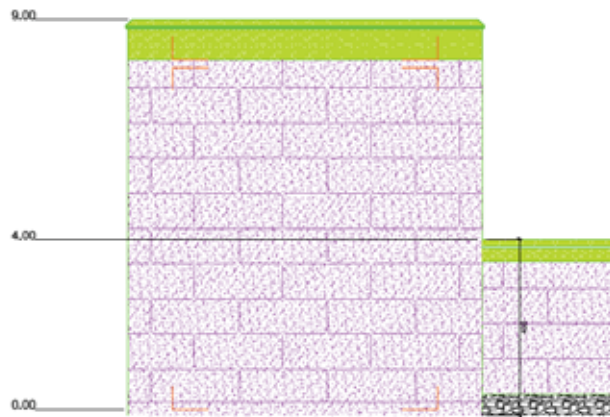


Fig. 2 : West wall

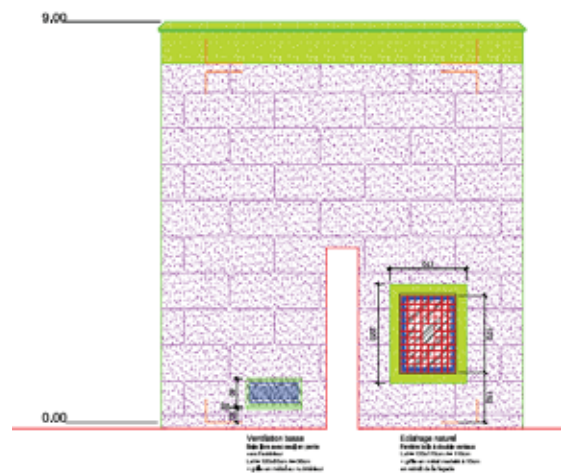


Fig. 3 : North wall

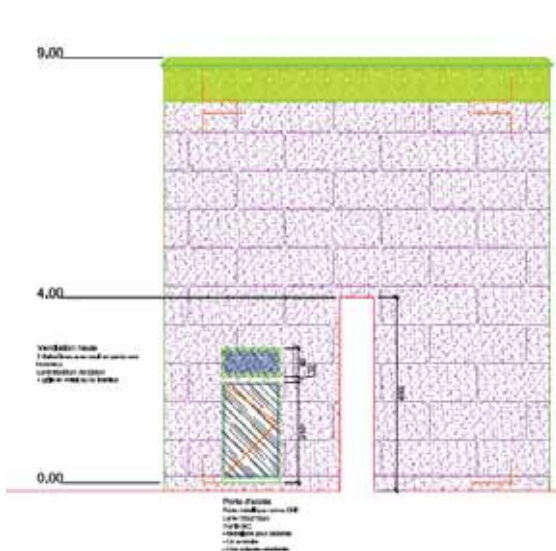


Fig. 4 - South wall



Fig. 5 - East wall

For a height regular construction it's necessary to have a regular distribution of load and rigidity in all the height (RPS 2000 chapter 4.3.1.1, regularity criteria, 2). For that, sudden differences of load and rigidity from one floor to the other must be avoided. A change of load must be progressive and the rigidity well-balanced at every floor in order to avoid the twisting effect. For that reason we propose the walls to have a regular thickness on all the 9m height of the tower.

3.2. Evaluation of structure fundamental vibration period:

According to the chapter 6.3. of the RPS 2000 rules, the fundamental vibration period of the structure could be evaluated from an inclusive formula :

$T = 0.09H/(L)0.5$, with H = height of the building, L = building dimension in seismic movement direction.

The total height of the tower is 9m for a width of 8m, so we have:

$$T = 0.09 \times 9 / 2,82 = 0,28s.$$

4. ANTISEISMIC BUILDING PROPOSALS

Proposals are made for all the elements composing the towers, from foundations to upper structure, but we will present here just what concern the geotextile reinforcement used as vertical and horizontal clamping.

Effectively, according to the location of the towers in a seismic zone 2, and in order to validate the project with mud material we are in the necessity to reinforce the mud walls. Many solutions are possible using ordinary techniques like: wood or metal reinforcement, concrete reinforced elements, and so on. But in the Moroccan context from one hand and for mud walls in other one, these materials are not so efficient. For these reasons, and after the experimentations and test on shake tables made in Peru on mud buildings by our colleagues of the Catholic university of Peru (Tarqué, 2009; Torrealva, Dusi, 2007) (fig. 6), we proposed the containment of the mud wall by a geotextile of a specific configuration and resistance quality, produced by the RichterGuard society, in order to avoid the cracks and walls destruction after traction and shearing off effects.



Fig. 6 - Model M075-T11: reinforcement arrangement and model during construction (PUCP shake table tests 2008)

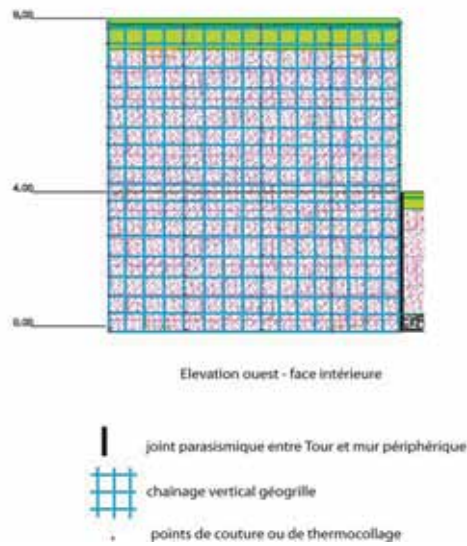


Fig. 7 - Vertical geogrid clamping

Vertically, the geotextile will be disposed on the two faces of the walls. On external face, at 15cm inside the wall for aesthetic reasons. On the internal one, against the *pisé*, and it will be recovered by mud mortar for a perfect grip with the wall (fig. 7).

Horizontally, the geotextile structure will be disposed on the *pisé* surface at every 40cm with an outflanking of 10cm in order to establish a junction with the vertical clamping (fig. 8) for a perfect containing of the wall. We also dispose this horizontal geogrid at lower and upper parts of the windows and doors openings.

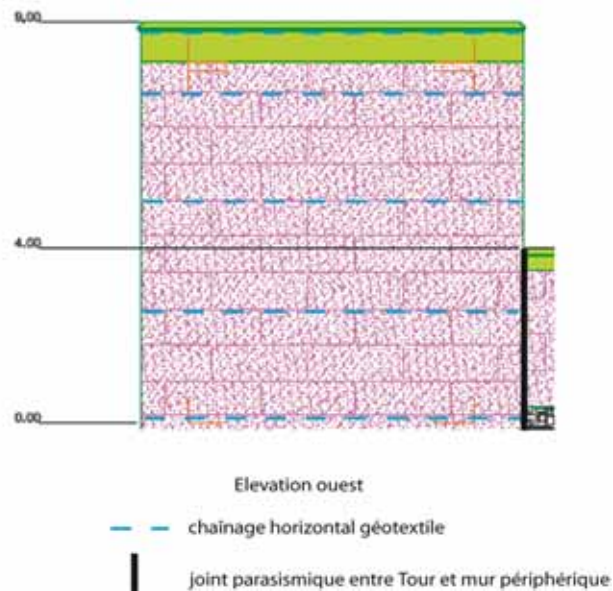


Fig. 8 - Horizontal geogrid clamping on west wall

This technique of horizontal clamping, disposed at regular heights on the wall and made with a different material than walls one, is a traditional method of reinforcement used in many parts of the world where earthquake recurrence was sufficient for people conceived “local seismic cultures”. The location of the horizontal clamping (made of bricks or wood beams), every two of three *pisé* layers, avoid the shirring effect (with cross cracks in the walls) (fig. 9).



Fig. 9 - Horizontal clamping in a *pisé* wall from an old farm (18th century) in South-West France (Klein, 1999)

5. PRELIMINARY RESULTS

The building presented in section 2, was modelled using in a first step a classical finite element analysis, with the presence of rigid concrete slabs representing the floors. The principal vibration modes of the structure were calculated.

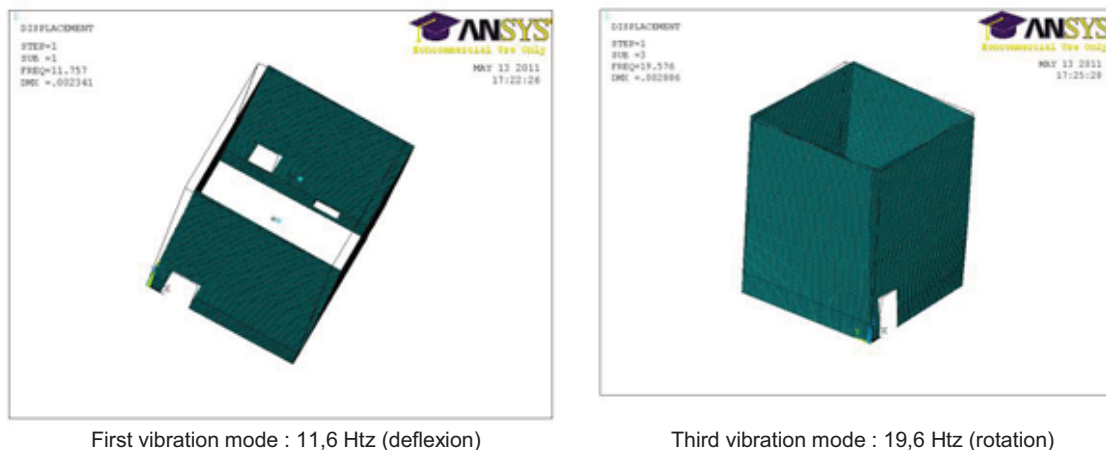
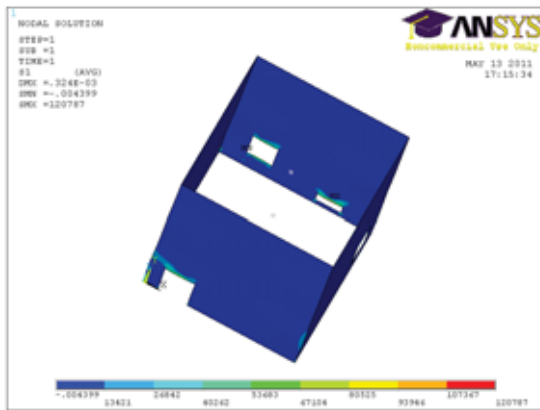
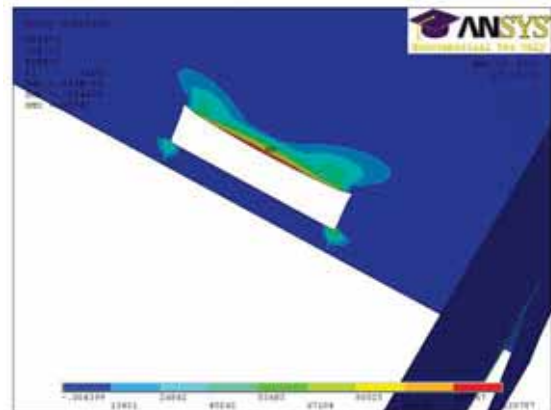


Fig. 10 - First and third vibration modes of the structure

This first model allows the detailed analysis of some stress concentration at the top and corners of the different openings in the structure, thus confirming the need to pay a special attention to these parts of the structure.



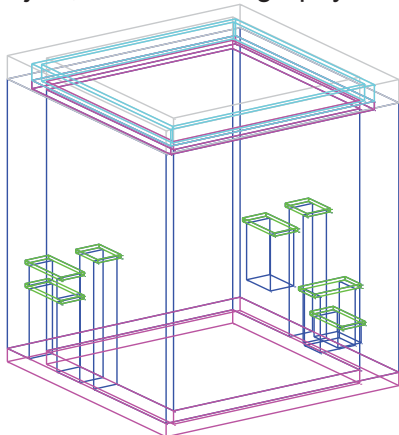
Principal stress : general view



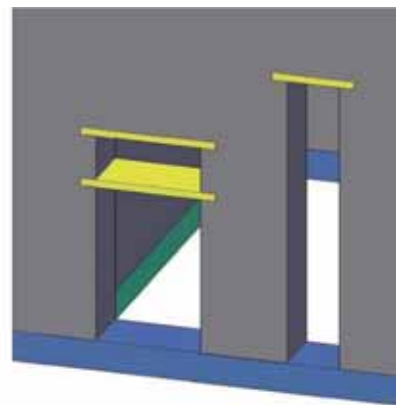
Principal stress : close-up view

Fig. 11 - Principal stress analysis at the top and corner of the openings

A second model using the capabilities of the LMG90 discrete elements platform (Radjai et al., 2010) was set up to analyse in detail the implications of the proposed reinforcements on the mechanical behaviour of the structure. Basically, the complete structure was decomposed into different entities that were meshed in 3D. The contacts between these entities are then given particular properties (contact laws) in order to take into account the essentially discontinuous nature of the building structure. The parameters of these contact laws were chosen, either from experiments available for the project, or from bibliography analysis (Rafiee et al., 2008).



Discrete entities: general view (transparent)

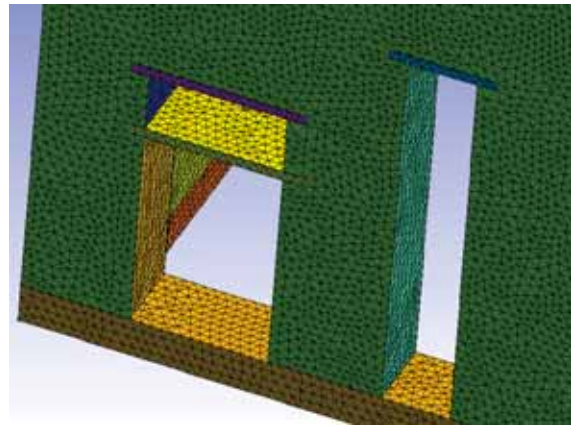


Discrete entities: close-up view (volume)

Fig. 12 - Details of the building decomposition in discrete entities



Meshed entities: general view



Meshed entities: close-up view

Fig. 13 - Example of meshed entities, the contact between the entities being governed by cohesive contact laws, or Coulomb friction

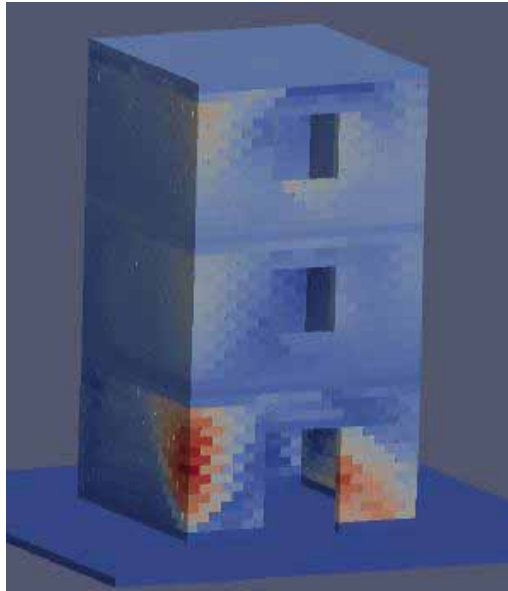


Fig. 14 - Example of the behaviour of a building modelled with discrete elements using the LMGC90 platform: displacement in an horizontal direction, during an earthquake. (extract from Vinches et al., 2010)

A complete study of the behaviour of the Domaine Royal Palm tower is now being performed. The complete results will be presented at the conference. Fig. 14 gives an example of the displacement calculations that are possible in the elements of a different, but structurally similar structure, after a simulated earthquake (Vinches et al., 2010).

6. CONCLUSION

The collaboration between architects, experts in seismic resistant local cultures, applied to vernacular buildings, and researchers in mechanics, allowed the design and calculation of the mechanical behaviour of the reinforced earth structure of the Domain Royal Palm tower.

The methodology described in this paper, and the advances now made in the development of the discrete element platform LMGC90, a free code, can now be extended to different types of buildings using earth, timber frames, concrete, or steel, or any combination of those materials, in different configurations: beams, slabs, volume elements ... The ability to describe the interaction laws, with the correct parameters, is still a requirement to obtain a realistic answer from the models. The description of the geometries of the different entities composing the structure is a task that is more easily managed. The correct tri-dimensional mesh of the entities is possible, and allows a correct transmission of forces between the different entities, with the possibility to describe the stress distribution in the whole structure, with an accuracy that can be selected to match the designer's requirements.

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SUSTAINABLE EDUCATION IN EARTH BUILDING – EXPERIENCES OF THE DACHVERBAND LEHM E.V. (DVL), GERMANY

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Theme 2: Actuality and prospects for earthen architecture in Asia and other regions of the world
Sub theme 2.2: Architectural design and sustainable development

Keywords: Education, target groups, curricula, Germany

Abstract:

From the end of the 1950s to the 1980s earth building materials were practically not used in Germany. During this period, technical developments in earth building were non-existent and professional and theoretical knowledge all but disappeared. Consequently, there were no activities in professional training or academic teaching in the field of earth architecture over a whole generation.

As a result of a gradual shift in the criteria for selecting building materials in the 1990s, an awareness of earth as an ecological, sustainable building material increased. It was “rediscovered” as a very suitable material for the restoration of historical earth structures. It soon became necessary to revitalise the practical skills and theoretical knowledge in earth construction by developing programmes for professional training and academic teaching.

This paper analyses current activities in the field of education in earth building in Germany in particular those of the Dachverband Lehm e.V. (DVL), the German national association of earth builders. This paper begins by identifying the different target groups and the differing kinds of information they require. For each of these target groups, possible forms of courses and training are described. Finally, the paper provides an outlook of priority areas of activity in the development of education programmes for earth building.

1. EARTH BUILDING AND EDUCATION – HISTORICAL CONTEXT

During the Second World War millions of houses were destroyed and millions of people made homeless and without shelter. The demand for new residential accommodation after the war to house the millions of refugees and homeless people was therefore very large. At the same time, the manufacturing industries had been completely destroyed and the only building materials available were those that could be locally sourced. For a short while earth became a significant building material. However, knowledge about how to use earth for building purposes had been largely lost during the war. The authorities, particularly in the eastern part of Germany, recognised a need to develop activities in the field of education in earth building and a series of State Schools for Earth Building called *Landeslehmbauschulen* were founded in several Federal states in Germany.

The school in the state of Thuringia was founded in 1947 by Hermann Henselmann, the first post-war rector of the University of Building and Fine Arts in Weimar, which later became the Bauhaus University. The school was led by the department of rural building and settlements at the university. The practical training of the apprentices was provided by foremen skilled in masonry and bricklaying (Schulze, 1993). Theoretical teaching and practical instruction were therefore closely related and attuned to one another. An Earth Building Primer, the *Lehmbaufibel*, was issued by the department and served as a reference book on building with earth at the time (Miller et al., 1947). In 1951 the first DIN standard on building with earth (DIN 18951, 1951) was issued.

None of the State Schools for Earth Building in Germany lasted longer than five or six years. By this time, the building material manufacturing industry had been repaired and concrete, steel and brick again became the predominant building materials, displacing earth. From the end of the 1950s to the 1980s, earth was rarely used as building material. In this time the practical skills and theoretical knowledge about earth building all but disappeared and as a consequence, the DIN-standards on building with earth were withdrawn without replacement in 1971. Similarly, all topics concerning building with earth disappeared from the curricula of professional and academic education. A whole generation of building tradesmen, architects and building engineers received no information or training on how to build with earth.

In the 1980s, new initiatives reviving the use of earth for building purposes began to surface in East and West Germany. At the same time a gradual shift in the criteria for selecting building materials came about with ecological requirements becoming increasingly important. Renewable, environmentally-sound and healthy building materials and construction methods were gaining in significance. This marked the beginning of a “renaissance” in earth building that continues to the present day.

In a situation similar to that after the war, the available practical skills and theoretical knowledge of building with earth were practically non-existent: most first-hand knowledge had been lost because a whole generation of craftsmen and architects had received no instruction in building with earth. The pioneers of the renaissance of earth building technology had to draw on information and documentation drawn up more than 30 years before. Step by step they applied the knowledge of the post-war generation to the contemporary technological context.

This could not have been achieved by a few individuals and in 1992 a national association – the Dachverband Lehm e.V. (DVL) – was founded to support all activities in the field of building with earth including education in Germany. Today the DVL is the German Association of Earth Builders with more than 250 members from a wide variety of professional backgrounds. The spectrum of occupations ranges from architects, planners, firms specialising in earth construction and those producing and trading earth building materials as well as ecologically orientated associations.

2. EDUCATION AND EARTH BUILDING IN GERMANY – PRESENT SITUATION

Today we can identify different target groups that require specific information about building with earth and their different curricula (Table 1, Schroeder, 2010). The DVL has developed special activities for each of these groups.

	Professional	Academic
Basic / undergraduate	apprentices of building trades (Initial education module)	Students of architecture and civil engineering (networking platform “uni-terra”)
Advanced	building tradesmen (training course “Specialist for Building with Earth”)	architects, planners, civil engineers, conservators, archaeologists (networking platform “uni-terra”; training course “Expert in Earthen Architecture”)

Table 1 - Target groups for activities in earth building education

There are also additional activities for special groups such as “Playing with earth” for children of all ages in collaboration with schools and kindergartens that consider pedagogical and educational aspects (Warzecha, 1997). There are also numerous offers for non-professionals (“laypeople”) with a general interest in earth as a building material.

2.1. Target group “Professionals / basic”

In Germany, the target group “apprentices of building trades” receive initial vocational training in professional schools and training colleges according to a specific curriculum which runs for a duration of two, sometimes three years. After completing their basic education, the apprentices receive a professional designation issued by the local Chamber of Trades and Crafts.

At the moment only very few professional schools offer specific teaching modules in earth building and they do not share a common coordinated curriculum. The most effective way to promote the culture of building with earth is to “plant the seed” and introduce the subject at the very beginning of professional development as part of initial vocational training.

The DVL has therefore initiated a pilot project in cooperation with the Knobelsdorff Training College in Berlin. The aim of this project is to develop a *basic education module “Building with earth”* that can serve as a model for all professional schools and training colleges in Germany. This module will be offered to apprentices in their final

year of professional training as an optional module. The module comprises 40 hours and provide apprentices with a foundation in earth building.

2.2. Target group “Professionals / advanced”

The target group “building tradesmen” comprises a number of traditional building professions such as masons, bricklayers, carpenters, plasterers and painters. At present there is no specific professional designation for “earth builders”. In Germany these professions are registered with the local Chamber of Trades and Crafts. The designations of these professions have a long tradition reaching back hundreds of years.

In previous decades, building with earth was only rarely or not touched upon in the basic professional training of “building tradesmen”. As awareness of using earth in restoration or new building projects grew, they began to look for ways of filling the gaps in their knowledge and sought information at a professional level.

In a pilot project undertaken from 1999 to 2001 together with the Environmental Centre for Crafts and Trade in Rudolstadt, Thuringia, and funded by the Thuringian Ministry for Economic Affairs and Infrastructure, the DVL developed a vocational training programme with a view to increasing professional know-how and acceptance in the building sector. It enables participants from related vocational backgrounds to acquire the qualification of a “*Specialist for Building with Earth*”. The certificate is recognised throughout Germany (Fig. 1). It is also of interest to those who have already been working in the field of earthen architecture but without formal vocational qualifications and who wish to improve their professional standing in dealings with clients and public authorities. Successful course participants are entitled to hold the title “DVL Earthen Builder” denoted by a special seal.

The approach of the course is to provide the participants with special information about building with earth which is necessary for building professionals today. The course programme summarises information about the most commonly used earth building materials and earth building techniques for traditional as well as modern earth building in Germany. The course contents conform to the stipulations of the *Lehmbau Regeln* (Dachverband Lehm e.V., 2009), the German standards for Building with Earth, also issued by the DVL. This standard serves as the statutory basis for building with earth in Germany in general. Professional education or qualifications in this field would not make sense without such a standard.

The course is led by qualified members of the DVL and supervised and invigilated by the Chamber of Trades and Crafts. The course involves theoretical sessions as well as active teaching practice such as the hands-on use of materials and practical application. The course programme encompasses 140 hours which are divided into 6 modules. The course is accompanied by a handbook for the participants (Dachverband Lehm e.V., 2005) (Fig. 2). This handbook contains background information about the different modules.

Since 2005 the course has become self-financing, i.e. it is financed only through the participation fees. It takes place once, occasionally twice per year in cooperation with the Chambers of Trades and Crafts in Ulm and Koblenz. Between 2005 and 2011 approximately 120 participants have successfully completed the course. Over the years we have received numerous requests from other countries. As a result, the “Building

with Earth” course was given in English for the first time in September 2010 with the same course programme and accompanied by an English version of the handbook.

In cooperation with the Chamber of Trades and Crafts Koblenz, the DVL has also elaborated a specialised curriculum for a “Building with Earth” training course for the Abu Dhabi Authority for Culture and Heritage ADACH. A special course handbook was developed for the course participants (Dachverband Lehm e.V., 2009).

2.3. Target group “Academics / undergraduate”

A number of universities and academic institutes around the world do already offer courses on building with earth. These offers can be classified into three types:

1. “Earth building” as a part or chapter of a “main” special branch such as building materials, ecological building, restoration of monuments etc.
2. “Earth building” as an individual special elective of a general curriculum for architects, civil engineers or planners.
3. “Earth building” as an individual Master course with a corresponding degree (Master of Arts M.A, Master of Science MSc. etc.).

At the moment, German universities offer only a comparatively small number of courses on “Building with earth”. Most of them can be classified as type 1 or 2. They are typically part of a *consecutive* Bachelor or Master course: concerning the contents there is coherence between the Bachelor and the Master courses. Each university or faculty decides individually whether or how they are integrated into the respective curriculum. At the moment, there are no specific Master courses on earth building (type 3) at German universities. Type 3 curricula require approval from the appropriate Ministry of Education.

A “type 2 course” was developed at the Bauhaus University Weimar for Diploma / Master courses in architecture and civil engineering. According to the European Credit Point System the students can acquire 12 CP.

The main idea of this course is to develop a general understanding of earth building as an individual discipline similar to other conventional building techniques such as building with concrete, brickwork etc. The course shows that the field of “earth building” can draw on the same theoretical basis as some of the other disciplines such as soil mechanics and building physics. But other aspects cannot be transferred from other disciplines and require specific solutions for earth building materials and constructions such as mechanical behaviour, thermal and hygroscopic parameters.

The course unifies all aspects of building with earth in one theoretical model: the *Life Cycle Assessment* of building materials (Schroeder, 2010). This model describes and evaluates all phases over the life cycle of an earth building construction by comparing the resources they require and their environmental impact: the identification and preparation of suitable soils, the production of earth building materials, their processing to building constructions, their maintenance, repair and conservation and finally their demolition and removal at the end of their useful lifetime. The cycle is closed “ideally” when the materials of the demolished constructions can be recycled as building materials and there is no disposal. Today this model is the basic principle of ecological building. Figure 3 shows the life cycle assessment of earth as a building material.

In the past few years an increasing number of universities and academic institutes have organised international conferences on building with earth. Until now, there is little focussed information on these activities. Similarly, there is little harmonisation with regard to the timing of such conferences. Here too, the DVL has taken the initiative to fill this gap in the provision of information. In order to promote knowledge and information transfer about activities in the field of earth architecture at an academic level, the DVL set up a *networking platform* entitled “*uni-terra*” (www.uni-terra.org), open to all university-level establishments and institutes offering courses on and/or research, PhD theses etc. on building with earth.

2.4. Target group “Academics / advanced”

In Germany, architects, civil engineers and planners are registered with the respective national/local chamber of architects or engineers. They are required to keep their professional skills and knowledge up to date by undertaking continuing professional development. This is assessed by the respective chamber. During their studies at universities most of architects and civil engineers received little to no information on building with earth. Postgraduate courses on earth building are, therefore, a suitable measure to fill this gap.

Postgraduate courses can be offered by the chambers or in cooperation with other organisations such as industrial sectors or universities. Many universities have established specialised departments for postgradual qualification. These offer courses only for graduates. The course types are similar to types 1 and 2 as described for the target group “Academics / undergraduate”.

At the Bauhaus University Weimar, the “Further Education Academy” offers a postgraduate course on “Building Maintenance and Conservation” with a chapter on “Earth Building” as constituent of the curriculum (type 1). In cooperation with the Further Education Academy the DVL has elaborated a curriculum for a course “Planning and Building with Earth” (type 2) for the Abu Dhabi Authority for Culture and Heritage (ADACH). The course is specifically directed towards architects, engineers, archaeologists and conservators and a special course handbook was also produced for the course participants (Dachverband Lehm e.V., 2009). A first course was carried out in March 2011 in Al Ain, Abu Dhabi.

On the base of this course the DVL has developed a similar course offered and certificated by the Further Education Academy of the Bauhaus University Weimar for architects and planners addressing regional problems in Germany.

3. EARTH BUILDING AND EDUCATION – FUTURE OUTLOOK

Building with earth is a part of the entire building branch. In 2009 the German building sector had a total volume of about 250 billion Euro. Of this, the earth building industry accounts for around 30 million Euro – about 0.1% of the total volume of the building sector in Germany. While this may seem very small, the annual rate of growth was more than 10% at a time when the growth of the remaining building sector is stagnating⁴. The earth building sector in Germany comprises the preparation of suitable soils, the production of earth building materials, their processing to earth building constructions, their maintenance, repair and conservation as well as demolition and recycling. All these steps require standardised solutions.

The requirement for education offerings in the field of building with earth depends on their need in building practice. In order to create a need for earth building materials in building practice, building tradesmen and architects and engineers with appropriate skills and theoretical knowledge must be available. They have to be able to advise potential clients on the use of earth building materials in constructions. All partners in the building process – producers, tradesmen, planners and clients – also need to have a clear legal standing. Without earth building standards, the possibility of building with earth is very restricted or even impossible. In Germany, the earth building branch is recognised as a distinct branch by the State Building Authorities on the basis of earth building standards developed by the DVL (Dachverband Lehm e.V., 2009).

Based on the experience in Germany, the following general recommendations can be made with a view to developing sustainable activities in the field of education in earth building:

1. A careful analysis of different target groups requiring education in earth building is necessary (see Table 1). Courses for architects communicate different information to those for tradesmen or laypeople. Each curriculum should have a logical structure and also address regional problems. The courses should consist of different types of training methods including active teaching with experiments, hands-on use of materials, and practical application on site as well as theoretical lectures and case studies in the form of lectures and excursions.
2. Education offerings in the field of earth building for professional as well as academic graduates should be developed by appropriate organisations such as the national earth building organisations in cooperation with the appropriate state bodies which are responsible for awarding the certificates. The resulting qualification or certification needs to be of a recognisably high standard, ideally conferring the ability to register with the Chamber of Trade or to set up a business of one's own etc.
3. The teaching staff for the courses must be highly qualified and have appropriate experience in practical skills, theoretical knowledge and pedagogic background. The technical infrastructure of the course centre and the course organisation must be of a high level.
4. To be sustainable, earth building courses need to have a solid financial basis, ideally covered by participation fees alone. External financial support by funding organisations is helpful but should be limited only during the implementation phase. Undergraduate and postgraduate education is a "free market" and "consumers" will compare different offerings.
5. Educational offerings for earth building must be announced in appropriate media such as websites, national / international earth building conferences etc. To be used effectively, they need to be offered at fixed dates in the calendar. Similarly, the actual demand for education offerings also needs to be analysed very carefully. An excess of courses can saturate the market place and endanger the financial viability of all courses who may no longer be able to attract sufficient numbers to sustain their course.
6. A programme of postgraduate events for successful course participants should be organised such as annual meetings, internet platforms with special access etc. These

events allow course organisers to acquire feedback from building practice. The postgraduates can be kept informed about recent developments in earth building standards, earth building materials and technologies.

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Fig. 1: Certificate “Specialist for Building with Earth”

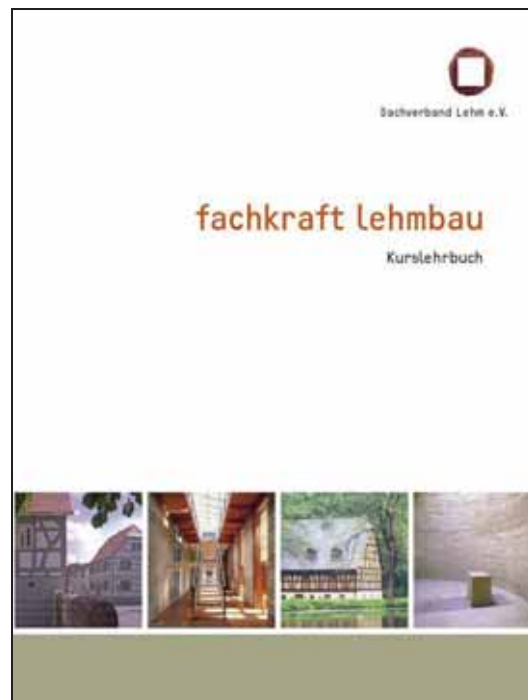


Fig. 2: Course handbook for the participants

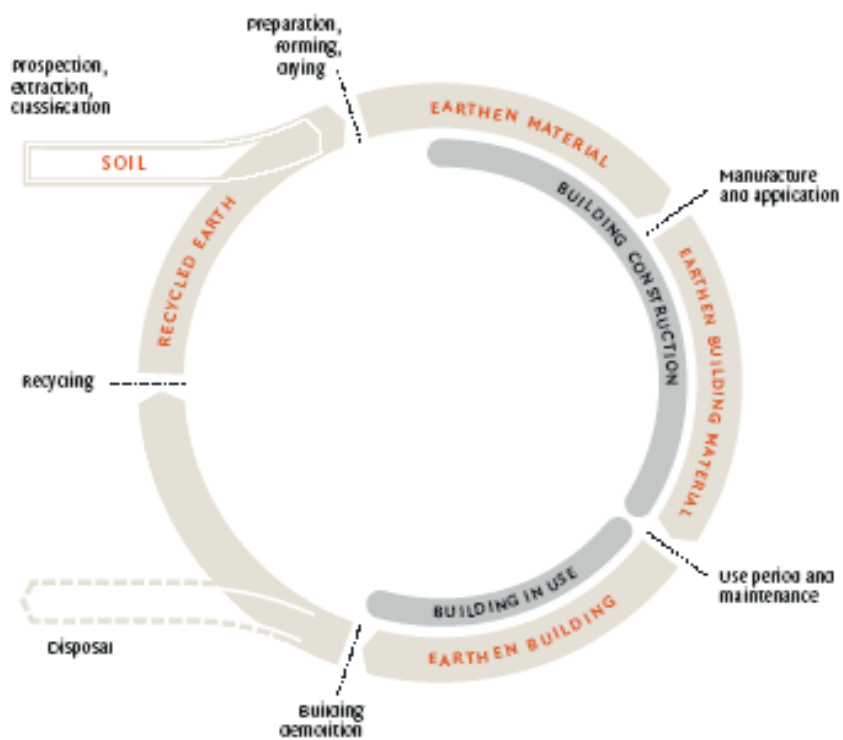


Fig. 3: The life cycle of earthen materials

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This book contains 29 proceedings of the International Conference on Earthen Architecture in Asia, TerrAsia 2011 that was held in Mokpo, Republic of Korea, from October 11th to 14th, 2011, bringing together participants from 15 countries. 64 authors, professors, researchers, and professionals addressed the state of research and study activities on immovable earthen cultural heritage, earth materials and earth construction techniques as well as the revival of earthen architecture in the Asian region, comparing it to the situation in other world regions.

TerrAsia 2011 is organized by the Department of Architecture of Mokpo National University, in association with the National Research Institute of Cultural Heritage of the Republic of Korea (NRICH) and the Institute of Earth Architecture in Korea (TERRAKorea), with the support of Changpyeong slowcity and Jipyeongseon school. The conference was organized under the aegis of the UNESCO Chair Earthen Architecture, building cultures and sustainable development of the National Superior School of Architecture of Grenoble, France, the International Centre for Earth Construction of Grenoble of the National Superior School of Architecture of Grenoble, France (CRATerre-ENSAG) and the International Scientific Committee on Earthen Architectural Heritage of ICOMOS (ICOMOS-ISCEAH).



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