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Towards a Digital Twin model for Building Energy Management: Case of Morocco

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Abstract

During successive industrial revolutions, the objective has not only been for industry to improve and satisfy its direct needs, it has also been to improve society's standard of living and make life easier for the consumer. Therefore, economic growth should always go hand in hand with each industrial revolution. The medical industry, energy conservation and, in particular, production technologies will be transformed through new value chain models. Globalization, urbanization, demographic change and energy transformation are the transforming forces estimating the technological impetus for a better identification of solutions for a world on the move. In recent years, successive revolutions have made remarkable contributions to a person's quality of life, safety, industrial economy, comfort and health. This work aims at improving the energy consumption of buildings. To achieve this goal, we have created a Digital Twin that accurately reflects the behavior and characteristics of a future or existing building. To reproduce a copy of the future or existing building, we chose to use the Autodesk REVIT solution to meet several constraints. These have a significant influence on the energy behavior of the building.

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1. Introduction

The digital twin, collaborative robots, data processing algorithms, energy challenges and advanced technological tools must collaborate to re-found the industrial model. They represent an opportunity to improve the attractiveness of different industrial applications. As for the impact of this evolution on a country's economy, several examples show that modernizing and digitizing industry contributes, in a significant and sustainable way, to improving the economy. The Chinese and Japanese models illustrate the virtues of this industry of the future on their economic strategy [1, 2 and 3].

However, the digital transformation of companies is today a crucial step for the development of the industry as well as the economy. This industrial digital transformation was initiated by the German government through the fourth industrial revolution known as "Industry 4.0" or "Smart Manufacturing" [4, 5]. This transformation has been the source of inspiration and change for other global initiatives, including the Chinese and Japanese economic forces. This revolution is bringing radical changes to systems and processes, but also ultimately to management strategies, business models and workforces.

In 2019, the American analyst firm Gartner ranked Digital Twins as a strategic technology trend. The Digital Twin concept is based on the development of multi-physical modeling of a complex system, taking into account the integration of real objects for real-time monitoring [6, 7]. Applications include production infrastructures (factories, rail networks), machine tools, robotic systems and complex components. Today, digital twins represent a key element for the development of the industry of the future. They provide information on machine behavior, identify when equipment is at risk of failure through preventive maintenance strategies based on collected data, increase productivity gains and optimize processes.

In this global context, the power sector has concentrated the main efforts as the main source of energy consumed in urban areas. This is prompting urban planners to reorient the city's intelligence towards the concept of the Intelligent Energy City. Electricity generation has undergone several changes over the decades, moving from decentralized to centered generation to move towards distributed generation with the integration of renewable energies. The implementation of renewable energy sources has been considered by governments as an alternative option to the modernization of traditional power plants [8, 9 and 10]. This is due to the increased availability of renewable energy sources and the advantages they offer, including cost effectiveness, inexhaustibility and reduced greenhouse gas emissions [11, 12].

This paper aims to improve the energy consumption of buildings, to achieve this goal we have created a digital twin that faithfully reflects the behavior and characteristics of a future or existing building. To reproduce a copy of the future or existing building, we chose to use the Autodesk REVIT solution, this allows us to target several disciplines that significantly influence the energy behavior of the building. The first discipline is the architecture, in addition to being essential for the construction of the building, it plays a very important role in the energy envelope of the building which has a significant impact on the energy demand of the building, we will see this in more detail in the following sections.

The paper will be presented as follows: in the second part, we will discuss the usefulness of energy management in the building sector. A state of the art concerning the evolution of digital twins will be the subject of the third part. A discussion concerning the implementation of the building model will be discussed in the fourth part. In the end, a conclusion and perspectives.

2. Energy trends in Morocco

Morocco is a middle-income country with a population of about 34 million [13]. With these two parameters, Morocco's energy sector will face double challenges: meeting electricity demand and regulating the supply of raw materials. Morocco's energy sector is dominated by the state-owned utility, ONEE (Office National de l'Electricité et de l'Eau potable). The ONEE acts as the sole purchaser of electricity in the territory. The ONEE acts as the sole purchaser of electricity and produces about 41% of Morocco's electricity in its own power plants, the rest being imported (18%) or purchased from Independent Electricity Producers (IEPs) [14].

According to IEA the contribution of each source in the country's production shows that Morocco relies on more than 80% of its production from non-renewable sources. On the other hand, Morocco is a net importer of energy.

Indeed, in 2013, energy imports accounted for about 90% of national energy consumption [15]. Electricity is the major source of consumption of energy imported by the country. This is demonstrated by the fact that until 2000 the country relied significantly on fossil fuels to meet the demand for electricity.

In order to achieve the national renewable energy and energy efficiency targets, several legal reforms have been implemented, namely Law 16-09, 57-09, 13-09 for the creation of ADEREE (the National Agency for the Development of Renewable Energies and Energy Efficiency) amended and supplemented by Law 39-16 and operated since 2016 under the AMEE (Moroccan Agency for Energy Efficiency), the creation of MASEN (Moroccan Agency for Sustainable Energy) and the standardization of the use of renewable energy in Morocco, respectively. According to this awareness of climate change, Morocco is committed to keeping global warming below 2 degrees at the 21st session of the United Nations Climate Conference (COP 21) held in Paris in December 2015 and in Marrakech in 2016 for its next session, applicable to all countries. Morocco has a great potential for the exploitation of renewable energy sources, which would help solve two major problems of the country: energy security and climate change and achieve its national objectives including the use of renewable energy and energy efficiency through the obligation of energy audit on industrial buildings following the law n°47-09 [16, 17].

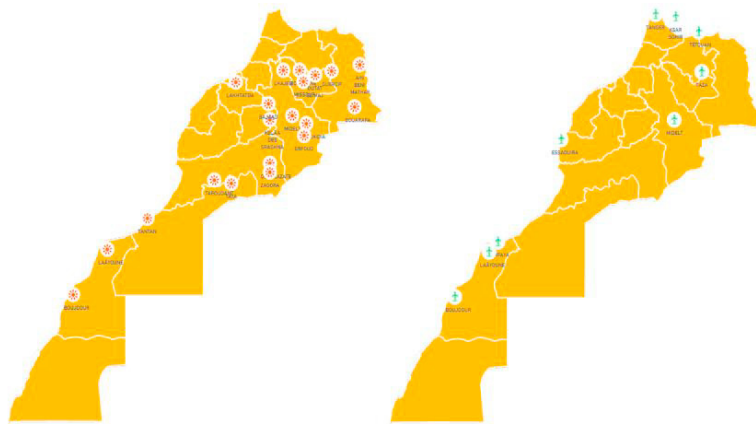


Fig. 1. Solar and wind projects in Morocco

3. Digital Twin

There are several definitions of DT in the literature [18]. In [19], the digital twin is defined as a computational model of an equipment or system that represents all the functional characteristics and links with the actual element. In [20], the authors defined the digital twin as a dynamic model of a real system, which continuously adapts to operational changes based on data and information collected online and can predict the future of the corresponding physical counterpart. In [21], a digital twin is defined as a set of virtual information that fully describes a potential or actual physical output from the micro-atomic to the macro-geometric level. According to [22], a digital twin is a digital representation of a physical element or assembly using integrated simulations and service data. The digital representation contains information from multiple sources throughout the product life cycle. This information is continuously updated and visualized in different ways to predict current and future conditions, both in the design and operational environments, to improve decision making. The authors in [23] show that a digital twin is a virtual instance of a physical system that is continuously updated with performance, maintenance and health status data throughout the life cycle of the physical system.

All these different definitions lead us to differentiate between 3 terms that are similar:

- The first term is the digital model which is described as a digital version of a pre-existing or future physical object, with no automatic exchange of data between the physical object and the digital model.

- The second term is the digital shadow which is defined as the digital representation of an object that has only one direction of data flow: the change in the state of the physical object implies a change in the digital object.
- The third and last term is the digital twin, the difference this time is that the data flow between the existing physical object and the digital object is fully integrated in both directions.

The digital twin should have [24] three main parts: the physical object, its virtual model, and the data and information connections capable of linking the physical and virtual objects together. In [25 and 26] the authors defined in more detail the theoretical foundations of digital twins applied to industry, and most of the work highlights the following key technologies:

- Modeling: physical and virtual models must describe the main characteristics of the system.
- Connection: the physical and virtual system must be constantly connected. This concept includes data transmission, conversion, storage, protection, etc.
- Advanced data analysis: to obtain information from a database, it must be pre-processed (cleaned and filtered) and exploited by data analysis techniques and artificial intelligence (AI) algorithms.

4. Discussion

The characteristics that interest us in our quest are mainly heat transfer coefficient (U in $watt \setminus (m^2 \cdot kelvin)$), thermal resistance ($m^2 \cdot kelvin \setminus watt$) and thermal mass ($kj \setminus kelvin$) as far as walls and floor are concerned. What influences these values are the number of layers used as well as the constituent materials (tiles, marble, reinforced concrete, wood, thermal and acoustic insulation ...) and their thickness. These specificities influence, in one way or another, the behavior of the thermal envelope of the building. A good thermal insulation avoids us to have thermal bridges between the different rooms, and the one that is the most answered is the insulation concerning the external walls which are always subject to thermal exchanges between the room and the outside world. This unfortunately leads to an abusive use of HVAC by the inhabitants to achieve their desired thermal comfort, which considerably increases the electrical load consumed by the building.

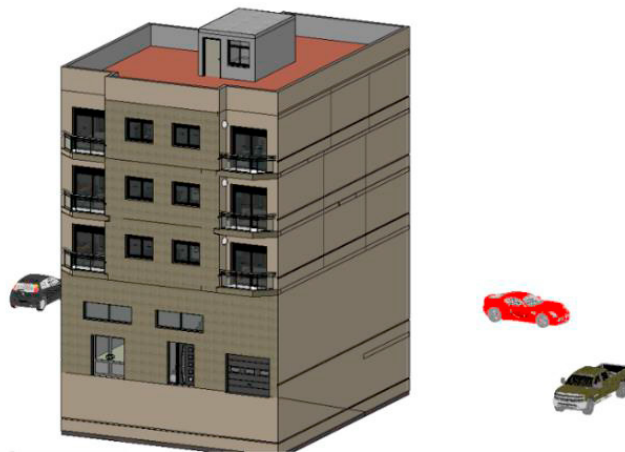


Fig. 2. The proposed model

The choice of construction materials plays a very important role since we can notice that there is a difference in the value of thermal resistances for the two doors (metal and wood). Windows and patio doors have, in addition to the factors seen before, the solar heat gain coefficient and the transmission of visible light. The latter allows us to reduce the energy demand of the building by reducing the electrical load necessary for a good lighting that meets the needs of the inhabitants. The quality of the glass also has repercussions on the energy demand of the room since it allows a heat transfer between the two different spaces (interior and exterior), without forgetting the noise reduction. This now

brings us to our study model which is a building consisting of a garage, a ground floor, three floors and a terrace, as shown in the previous figure, we will see this in more detail in the following parts. We decided to design a R+3 to be able to analyze the impact that each variable can have in interaction with our model, including the number of rooms in each apartment, the characteristics of its walls, windows, doors ..., the location of the apartment (1st,2nd,3rd floor).

The model shown in Figure 3, presents the energy model. This model is generated using the data and characteristics of the elements constituting our model (walls, floors, doors, windows...), this model is based on the volumes of the rooms, these spaces allow us to set up the areas where the HVAC systems are functional. After the generation of the energy model, a simulation of its performance is available thanks to the simulation in the cloud, which takes into account the data from the energy model and the location of the project, REVIT and allows you to specify the exact location of your project and then choose the nearest meteorological site to exploit its data during the simulation. This simulation takes into account the solar radiation, the outside temperature, the location, the operating time of the building (24H/7d, 12H/5d...), the type of building (residential, office, school, hotel...). This is possible using the integration of INSIGHT, in addition to this an Insight plug-in is available to further improve the building's performance by allowing to simulate HVAC systems and choose the zones where these can be active. As well as a simulation of the lighting behavior to achieve visual comfort without excessive consumption of the luminaires.

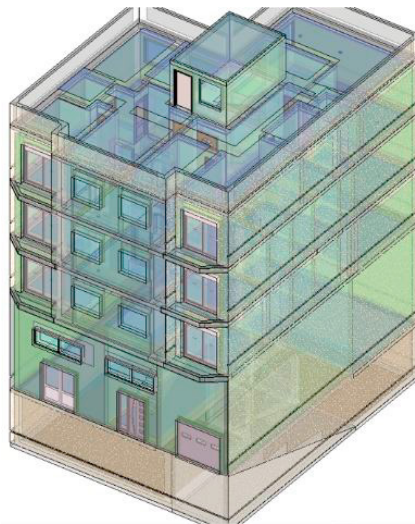


Fig. 3. The energy model

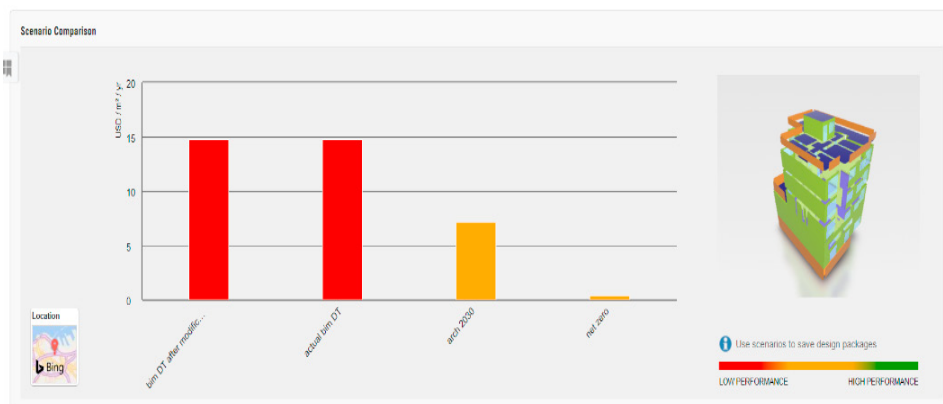


Fig. 4. Comparison between different Insight's proposed scenarios

The Insight platform provides us with two of the most popular and coveted scenarios (Fig.4.), which are Architecture 2030 and net zero. The first enables us to halve the energy consumption of our homes, by acting on the specific features we have discussed in the previous sections. The difference with net zero or commonly known as NZEB (net-zero energy building) is that it aims to produce the energy the building needs from renewable energy, such as PV.

5. Conclusion and perspectives

Today, the construction sector offers in Africa and more particularly in Morocco a real potential for development. The numerous infrastructure projects and the fight against substandard housing are strong signals of the commitment of public authorities in setting up structures that support the sustainable, economic and social development of the country. This sector in Morocco accounts for about 25% of the country's total energy consumption, including 18% for the residential sector and 7% for the tertiary sector. This energy consumption will have to increase rapidly in the coming years for two reasons: the first is the important evolution of the building sector following the major programs announced in the Moroccan tourist platform under the label "Plan Azur Maroc 2020", namely the emergency program of the national education, the program of 150,000 housing units per year, the program of rehabilitation of hospitals, etc. In this paper, we presented a model of the digital twins for a future building in Morocco. The results are very encouraging and have a direct impact on the energy bill. As for the prospects, the aim is to target the net-zero of the building and the integration of an IoT/Cloud model.

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