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## 29th CIRP Design 2019 (CIRP Design 2019)

## A methodology for reverse architecture: modelling space and use.

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The historical restitution of demolished buildings requires the use of many sources of different nature, but no physical evidence of the element to be restored. In order to overcome this difficulty, this article intends to propose the use of virtual immersion of experts in the reconstructed space. This immersion makes it possible to evoke conscious or unconscious comments, in the sense of sensible response, of body postures, which are all additional sources that can guide or inform a process of historical reconstruction. We take as an example the theatres of the Foire Saint-Germain in Paris in the 18th century - for which important historical documentation exists, but no archaeological remains - with the aim of proposing a first draft of a methodology integrating the sensitivity of experts for a retro-architecture of these spaces.

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**1. Introduction**

Although it was not until the architect Louis Sullivan in the late 19th century that it was stated as simply as "form follows function", the question of the function and use of buildings has always been essential in the architectural design process. However, if the functional approach is one of the bases of reverse engineering, making it possible to redesign or improve the understanding of technical or mechanical systems that have disappeared or been abandoned [1], it is currently not very widespread in the reconstruction of spaces.

However, many of the buildings that have disappeared, particularly in the most recent historical periods, are known more by the description of their uses and customs than by the archaeological remains which, in many cases, are non-existent. This is the case, for example, of the theatre spaces of the Foire Saint-Germain in the 18th century, which serve as an experimental field for the purposes set out in this article, and of which only literary or iconographic traces remain today. This difference in treatment in reverse engineering and reverse architecture, which we will try to define, owes its origin to the very different way

in which the functions rendered by buildings and technical objects are modelled. While the functions performed by the latter can be based on services rendered (transmitting a couple), the former rely on social customs whose modelling can be more complex.

In this prospective article, we wish to highlight new ways of integrating the complex use of digitally reconstructed places into the reverse engineering process. It is a question of allowing architectural reconstructions to be compared with the physical and architectural reality, but also with the past use. Thanks to this, we will implement a digital reconstruction methodology that will allow us to work more finely on the question of the appropriation by Man of the spaces he creates, and thus to place it at the heart of the historians' concerns.

**2. State of the art**

There are many experiments in reverse engineering of historical objects, ranging from mechanisms related to ancient buildings [2], war machines [3] or industrial era machines [4], in order to improve our knowledge of technical objects of the past and possibly to exhibit them in a museum setting. Industrial archaeology itself seeks to restore the functioning of the various components that formed the industrial units or objects of the past, relying on many sources and sometimes on the components themselves. The study of a 19th century forge site could thus focus as much on the flow of goods as on the mechanical

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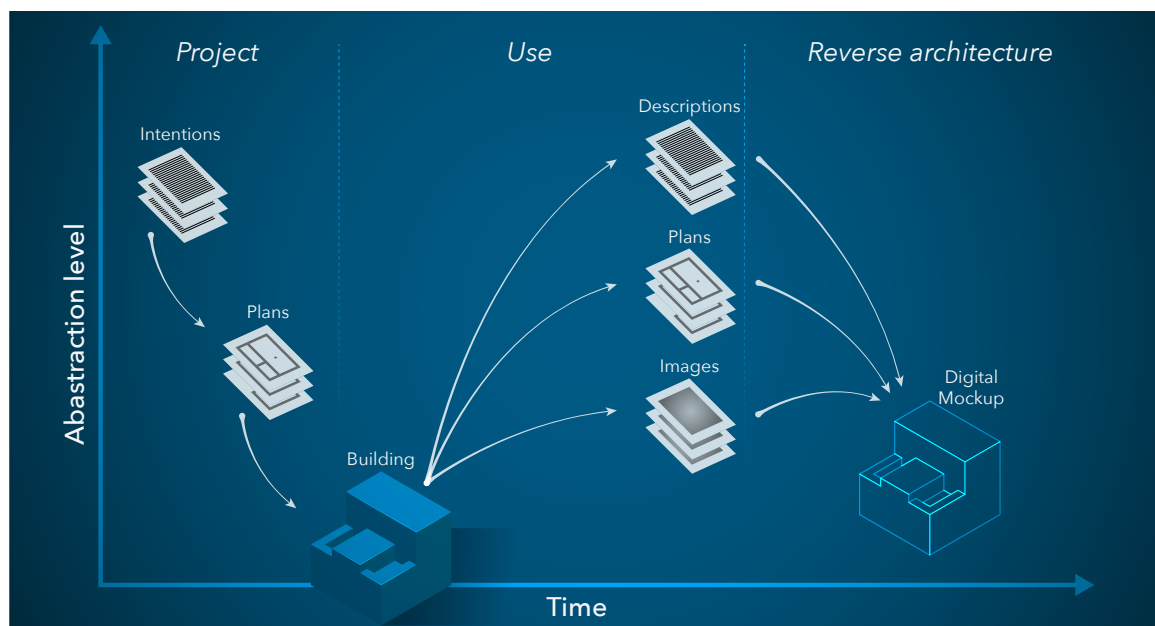


Fig. 1. Cycle of abstraction levels from project intentions to the physical building, then during the use phase and up to the reverse architecture process.

operation of machines dedicated to production, as is the case, for example, at the Brest forges [5]. This last project shows the interest of taking into account the knowledge and know-how of blacksmiths in the process of returning industrial buildings and machines.

The use of three-dimensional digitization technologies (via the obtention of point clouds) has enabled the definition of digital threads allowing the structured acquisition of knowledge through and for reverse engineering [6]. The objective of this type of approach is to produce a numerical model that can reflect different levels of abstractions, from the most physical to the most conceptual, each allowing us to improve our knowledge on different aspects of the object under study. It is based on five levels of abstraction: physical (what is the materiality of the object?), logical (how the object behaves?), functional (what is the function of the product?), conceptual (how is the product defined?) and objective (what is the context of the product?).

The refinement of this approach is generally not reflected in the way traditional "architectural" archaeology is approached, since it is based above all on the physical level, i.e. on the geometric and constructive information related to the building. The other levels are addressed within a macroscopic framework that can prevent us from grasping the diversity of the functional level, that of spatial use. By spatial use or custom, we mean the way of behaving in a certain space and the different possibilities that a particular space offers for physical or social interactions.

In the case of the reconstruction of the streets of Ancient Rome, carried out by the CIREVE laboratory in Caen [7], immersion in virtual reality has enabled researchers to understand the essential function of the street: being able to move around in the city. Immersion thus makes it possible to measure travel times between different points of interest in Rome, and thus add a perceived dimension to the size of the city. The authors stress

the importance of this type of observation since "understanding travel time is important for understanding events and ways of thinking".

The project to restore a Compagnie des Indes ship in the 18th century, La Boullongne, also illustrates the importance of focusing on the functional spatial level [8]. This project aims to reproduce a ship in virtual reality and allow it to be manoeuvred in a virtual marine environment, based on period plans. Nevertheless, the realization of this experiment has raised important issues concerning the space use of the ship. The authors thus suggest that the size of the decks raises questions about the ability of sailors to move around them, and even to use guns.

### 3. Definition and problem

In the light of the problems posed by the reconstruction digital of destroyed historic buildings - whose sources deal mainly with the question of uses or customs - and classical reconstruction methods focused on historical remains, we believe that new tools should be put in place that are adapted to what we are tempted to call "reverse-architecture". Reverse engineering can be defined as a process of analyzing products and objects to find the design and manufacturing techniques that made it possible to build them, or to reveal their secrets, in order to identify their weaknesses and exploit them [9]. By analogy and contrast, "reverse architecture" could be defined as a process of analyzing traces and images of a disappeared building in order to recover its design and construction techniques, and to produce the most accurate digital model possible. In the same way that reverse engineering is based on the physical object to be understood, reverse architecture can be based on images or descriptions of

the building and the practices that took place there, thus on all the traces left by the use phase.

A significant difference between these two approaches is therefore the physical existence or inexistence of the object itself: in most cases of reverse engineering, the object or system to be studied is directly accessible. In the case of reverse architecture, making this object accessible through a digital model is one of the objectives of the approach. Figure 1 therefore shows how this process should be based on the traces produced during the use phase and possibly during the design phase of the building in order to design a new virtual model. The latter is supposed to crystallize the sum of knowledge about the building and is therefore at a higher level of abstraction than the building itself. Reverse architecture thus defined, we wish to focus on how to integrate the question of the uses of space within a process of reverse engineering and architectural visualization. The uses that concern us in this prospective article are mainly social customs, because they are predominant in our case study (the performance venues of the Foire Saint-Germain in the 18th century). We will first show the mechanisms to be put in place to successfully integrate these social models into the retro-architecture process, then we will focus on its future application to our case study.

#### 4. A methodology for the integration of uses in a digital model

Since the dual objective of retro-architecture is to design a three-dimensional model of the building under study and to improve its overall understanding, it is advisable to start by accumulating data allowing for restitution. After that, not one but two models are to be designed: one is geometric and takes the form of a virtual mockup, the other is a set of relationships that define social customs and interactions.

##### 4.1. Sources available

The sources called upon for reverse architecture are diverse and reflect the range of documents that can be used by archaeologists or historians. We propose two ways to distinguish these sources, either by their medium or by the elements they provide. The graphic medium makes it possible to group together all sources in the form of plans, images, photos, paintings, point clouds, etc. Textual media, on the other hand, includes scientific, technical or journalistic descriptions, which are intended to be factual, monographs and all literary works which, by their context or their descriptions, can evoke or inform about a building and its uses. For example, novels, poems or plays can be confronted, even though these documents are not instinctively summoned in a restitution process.

A last type of medium is human, in the form of one or more experts, each one capitalizing on a wide range of knowledge and capable of providing solutions or insights to a reverse architecture project. By using the annotation of models, and recording the comments of experts, it is thus possible to treat the historians' intervention as any other source. This can be pre-

served, inventoried, commented, criticized or defended, thereby increasing the robustness of the models designed.

These sources can inform many of the aspects that interest us in this process: the history of the object of reconstruction, its form and its uses. Let us consider only the form and uses: if the form is naturally better described by graphic sources, it remains that textual sources can bring the precision of colors and materials that can be lacking on old photographs or plans. A thorough study of the plans can provide information on the use of the spaces they describe, either by comparison with other buildings or with the help of experts. Photography, like painting, can inform both form and use, depending on the way in which the author or artist has chosen to include his subject.

In all cases, these sources must be carefully analysed, considering that texts and images reflect the intentions of their authors, and not the truth itself. The indexing and preservation of all these sources should also be considered in order to be able to maintain a link between the interpretations of these documents (in the form of models) and the documents themselves.

##### 4.2. Models to build

The first model to be designed is the spatial model, in the form of a virtual mockup. Many softwares already make it possible to design virtual architectural models, but the challenge here is to link the geometric model with the sources that made it possible to create it. Ideally, we would like to be able to identify, for each element, the documents that made it possible to specify its position, shape and dimensions. However, none of these properties are the result of a "true" or "false" binary choice based on documents, but rather a decision made by the designer, with or without the help of experts. This decision-making process can also be recorded [10]. Similarly, on the basis of this documentation, it is possible to imagine a confidence index, based in particular on the principles of fuzzy logic, to establish the degree of certainty of representation of an element in the virtual model [11][12].

The second model associated with retro-architecture is that of uses and customs. In this case, it is a question of accounting for the different human and social practices, their spatial scope and their temporality. Social interaction models remain difficult to address, and even if several formalizations based on UML have already been carried out [13], a simplified ontology making it possible to link situations (a moment associated with a temporal extent), places, protagonists and actions remains to be stated. The modelling of the social customs that are associated to a place is mainly based on written sources, which can provide information on expected (scientific or journalistic descriptions), typical (literature) or exceptional (police reports) behaviour. Images, such as paintings or more recently photographs, can also be used to inform customs. The integration of temporality is important in this modeling, since it will eventually make it possible to visualize whether different practices avoid or overlap (for example, the repetition of a play does not involve the same protagonists as an ordinary performance, they do not take place at the same time but are done in the same space).

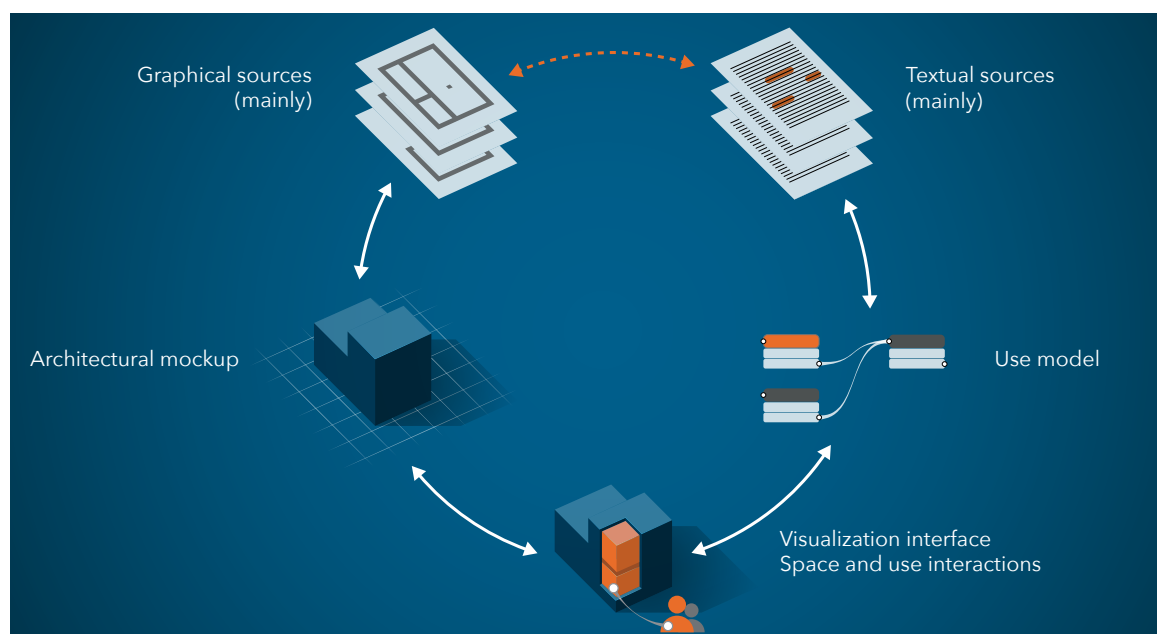


Fig. 2. Links between graphic and textual sources and associated models, and integration of the whole model in a visualization interface.

## 5. Methodology

As the models to be designed and the documents useful for this design are detailed, it remains to define a methodology allowing the synchronous design of the two models, and their use to enrich and complete the historian's work.

### 5.1. Synchronous design of the models

The spatial model and the custom model are not separated: the architectural model is the framework of the custom model since the latter takes place in the former. From the moment it is possible to replace the geometric boundaries of the spaces used in the usage model in the digital model, it is possible to schematically visualize the interactions between the spaces, but also between the different protagonists within these spaces. This implies being able to assign a use to each place, and to each use a place, but there is no bijection between the spatial model and the use model, for several reasons. First, some uses can take place in several spaces (it was thus possible in the 18th century theatre to drink and eat both in the café and on the parterre), then, because of the absence of sources, some spaces can remain of unknown, or anecdotal use (documents relating to the use of certain technical or maintenance rooms may not exist, as they are considered trivial). It is therefore necessary to accept that certain areas of the spatial model are not subject to any use, or that uses cannot be associated with any particular space.

The synchronous design of the two models makes it possible to spatialize most customs and the contribution of this spatialization is twofold: it makes it possible to strongly orient the restitution of the building by verifying that the uses to which it must conform are indeed possible. It also makes it possible to visualize, if not experiment, the way in which space makes pos-

sible, encourages or refrains from certain practices. A process of retro-architecture from the most important uses to the most trivial would therefore make it possible to iteratively complete the knowledge about a given building. In the case of a factory, we can thus focus successively on production flows and tools, administration, maintenance, etc.

It is therefore necessary to imagine in the long term an interface to make the link between the two models, and to visualize within the digital model the physical and social interactions of the usage model. This interface would also make it possible to visualize the documents used to design all the models. Figure 2 represents the interaction between models and their sources and, since links between sources and interpretations are systematically maintained in the process, how documents and their information of different types and destinations are transitively linked.

### 5.2. Using the product of reverse-architecture

We have previously insisted on the benefits of the realization of these models to increase knowledge about a building. But the very product of reverse architecture, namely a digital model combining space and use, makes it possible to imagine new forms of interaction with historical restitution. Indeed, if it is already possible thanks to virtual reality immersion technologies - via headsets such as HTC Vive or Oculus Rift - to move into buildings of the past. Informing cultural practices in these buildings would also make it possible to represent these practices in immersion. Avatars, designed with the same scientific requirement as the spaces themselves, could be used for the occupations dictated by the usage model and thus give more life and realism to the immersion experience.





Fig. 3. Miniature of Louis-Nicolas von Blarenberghe (Credits : Metropolitan Museum of Art, New York), and corresponding digital mockup.

Taking the form of a kind of time machine, such a tool would allow historians and experts to evolve in a virtual situation at the heart of their subject of study. Having simultaneously become a guide of disappeared buildings and a witness to a simulated story (based on scientific sources), the expert would not only provide feedback on the relevance of what he sees, but also information on the postures, trajectories and ways associated with the spaces visited. Such information acquired by the experts could only be reproduced by in vivo practice.

In the near future, the dual model produced by reverse architecture could make it possible to more accurately simulate the way the building behaved in a context of normal use, and to answer questions about the maximum gauge of spaces receiving the public, the temporality of certain actions, etc. In either case, the aim is to lay the foundations for an intelligent interactive simulation capable of reporting on the operation of the system under study, in the same way that the digital simulation of a mechanism allows it to virtually respond to all its functions.

## 6. An example: the Foire Saint-Germain theatres during 18th century

The reverse architecture process as described above was developed in order to respond to the specific issues raised by the VESPACE project (Virtual Early-Modern Spectacles and Publics, Active and Collaborative Environment), aimed at reviving a virtual theatrical evening at the Foire Saint-Germain in the 18th century. The theatre sites of this Fair disappeared in the early 1790s, but there are still iconographic traces (paintings, plans, sketches), numerous police reports and a very large literary production (plays, puppet plays or poems), all witnesses to the great inventiveness and dynamism of the Fair's theatre entrepreneurs [14].

The restoration of the theatre venues of this Fair cannot be based on any archaeological remains, due to the significant transformation of the district over the past two centuries, and the ephemeral nature of the materials used for their construction (wood, mainly). In the context of the restitution of a puppet

theatre, the use of which had spread at the Fair, we were able to rely on only one graphic source: a miniature painted by miniaturist Louis-Nicolas von Blarenberghe around 1760, which depicts the inside of a small puppet theatre and the crowd that came to attend the show taking place in the castelet. However, this image is not free of defects since it represents space from an impossible point of view and with a false perspective that distorts it. The miniature also represents several customs, from the most obvious, such as the representation of puppets on stage, to the most unexpected, such as the inappropriate way of standing of one of the characters in the foreground.

First, we were able to compare the spatial model based on the interpretation of Blarenberghe's work (Figure 3) with the simplest uses associated with this space: entering, moving and looking at the representation. This confrontation made it possible to question the position of the seats of the parterre and the entrance, which are not clearly legible on the miniature, thus maximizing the well-placed seats and preventing onlookers without tickets outside the theatre from enjoying the show.

Other sources can provide us with information on how to behave in a theatre in the 18th century and thus provide the basis for a model of social custom. Police reports were thus heavily used to study the behaviour of the audience in another major theatre in Paris: the Comédie-Française [15]. These reports make it possible to establish precisely the type of population that frequented the place, the way people accessed the theatre, how they bought their tickets, the risks due to pick-pockets, etc. Fortunately, similar documentation exists for the theatres and puppet theatres of the Foire Saint-Germain [16], so it seems possible to build the corresponding usage model. These social practices are highly spatialized, such as seduction and/or invective games between spectators on the stage and in the parterre, or interactions between the stage and the audience. Within digital models of theatres built on the basis of summary plans, paintings or descriptions, visualizing the adequacy of the space with the expected uses (and attested by police reports) would make it possible to ensure the relevance of the restitution.

In the restored puppet theatre, the model already reveals some difficulties in matching the proven uses with the morphology of the place. The immersion in virtual reality, through a HTC Vive helmet, highlighted the relative exiguity of space. This makes it difficult or even impossible for noble women to move between the rows, dressed in very large à la française dresses. This first observation was confirmed by the modeling of an avatar with such a dress, which can only move in this space with great difficulty. Such an arrangement may imply, for example, that certain privileged places should be reserved for this type of spectator, guaranteeing them sufficient space to move and settle comfortably.

## 7. Conclusion

In this article we tried to define a new discipline at the boundary between reverse engineering and building archaeology: reverse architecture. It is based on a set of abstraction levels to allow a building to be restored as a whole. Among these levels, the level of functional abstraction gives priority to uses within the space. We have therefore proposed a draft methodology that integrates the modelling of these uses, from very diverse sources, in parallel with the production of a spatial digital mockup, into the overall process of producing a digital model. At the end of the retro-architecture process, we thus obtain not only a model proposing the reconstruction of the state of a building at a given moment, but also a set of situations of use and customs. This whole model makes it possible to inform the building operation and to imagine simulating these situations.

As it is a use-centred approach, it obviously questions the sensitive relationship to space. However, it still remains to be possible to integrate this subjective but essential aspect of architectural perception into the reconstruction process, by means of immersion in virtual reality.

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