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Generator of Hypotheses for a Digital Restitution of Built Heritage: Case of Roman Imperial Baths of North Africa

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ABSTRACT

In this paper, we present an approach for developing a tool for the restitution of built heritage and we take as a case study the Roman imperial baths of North Africa. This type of building responds as far as their architectural design is concerned to a universal model widely distributed throughout the Roman Empire with significant variations. We suppose here that this tool allows us to generate automatically the hypotheses of restitution (2D and 3D) facilitating the work of restitution for specialists in the field of archaeology and built heritage. The generated models can be refined and completed in order to obtain the most plausible simulation. This tool is obtained following architectural, theoretical, and historical analyses. Our study will focus on the elaboration of data model according to an architectural approach of Architectural Modelling Information (AIM).

KEYWORDS: Generator, Hypotheses, Digital Restitution, Roman imperial baths, AIM.

1 INTRODUCTION

The restitution of the built heritage poses enormous problems as far as the method is concerned more precisely the technique employed and, the lack of information on the monument to resituate. Some methods are opting to rebuild what is known (archived) and / or what is existing (visible) and seek to hide the unknown. Other methods launch hypotheses of restitution based on facts and similarities. In any case, each method requires a selection of a technique, which, in turn, determines the duration of the execution of the operation and influences the information resituated in terms of quantity and quality. Technological progress has given more precision to information and reduced the time compared to previous techniques of restitution. However, the reconstruction of heritage using computer (CAD tools) remains a difficult task in terms of time and energy. The introduction of new techniques (the phase of the survey and the phase of the interpretation and graphical fitting of monument to rebuild) has reduced execution time and increased accuracy. The automatic generation of architectural data is considered as a real progress in the field of reconstruction of cultural heritage but some problems still remain unsolved. Beyond the technical issues addressed by (De Luca, 2006), we discuss here two other problems:

- The first is that all developed approaches are oriented to reconstruct and represent the existing intact or partially damaged built heritage. So how can we proceed the restitution of lost heritage?

- The second is that the reconstruction of heritage through parametric tools is simply an adjustment parametric element to an obtained digital survey. However, this architectural heritage is not only a set of architectural elements to be adjusted. It meets during its design (plan and elevation) a set of relationships and specific rules of composition.

In this article, we will try in the first part to present a state of the art in the field of digital heritage reconstruction. In a second part, we explain our approach for digital restitution and we study Roman imperial baths of North Africa. These will be studied in the third part. Then, we will conclude this article with our perspectives and future work.

2 STATE OF THE ART

2.1 The architectural survey level:

The classic method of reconstruction of heritage is increasingly abandoned in favour of the introduction of new survey techniques and computer interpretation. The based images and photogrammetry survey method allows the return of the general appearance of the monument with a degree of precision in texture and not in the details such as mouldings (De Luca, 2006). The technique of laser - photogrammetry has solved the problem of accuracy and runtime problems but grateful complex objects still persist. It offers a high accuracy with a reduced time compared to technical based images where only simple objects are recognized. (De Luca, 2006) has developed a hybrid approach that combines the architectural survey technique of photogrammetry sorts with laser-grammetry which allowed the design of a platform for multi- architectural representation. However, this approach is inadequate in terms of precision. For that, this method has been consolidated by the development of parametric tools for the return of architectural elements (De Luca, 2006 ; Chevrier &al., 2008 ; Chevrier &al., 2009 ; Chevrier &al., 2010)

2.2 At the level of parametric tools

New survey techniques do not enable a high-precision representation of the built heritage. For this, several digital platforms have been designed with the objective of creation of historic and architectural object libraries. Take the example of Nubes (De Luca, 2006) and GOP (Chevrier &al, 2008) that have been developed from the description treaties architectures and analysis of existing cases in the form of plugin in Maya. Their operating principle is to adjust the architectural element automatically generated as point clouds (example of *the base of the column at the front of the "Convento della Carita " in Venice* (De Luca, 2006) and *the dome " Sulaymanïyah mosque" in Turkey* (Chevrier & al , 2009). Meanwhile, BIM (Building Information Modelling) platforms have been developed as Revit and ArchiCad containing a library of parametric architectural elements. But this library was not specific for the representation of cultural heritage in this context and with this BIM technology, a library of historical architectural elements (HBIM: Historical Building Information Modelling) was created from architectural treatises (Dore & Al., 2012 ; Dore & Al., 2013).

2.3 The approach - procedure relation of reconstruction level

2.3.1 Approach based on the description of the elements

The tools mentioned above are tools for the automatic generation of architectural elements. For the reconstruction of the entire monument, its generated elements will be adjusted to a digital reading (De Luca, 2006 ; Chevrier et al., 2008 ; Chevrier et al, 2009 ; Chevrier et al., 2010). Otherwise, the operation to rebuild the monument was studied throughout its decor (element) and was treated as a set relations of part - whole architectural elements (De Luca, 2006).

However, we assume that this reconstruction method is valid only for:

• Reconstruction elevations (interior and exterior elevations) and not for the plans.

• Reconstruction of existing buildings totally or partially and not for monuments totally or partially missing.

2.3.2 Approach based on the theoretical and historical description of the monument

(Pauwels et al., 2008) developed a similar approach to BIM which is AIM (Architectural Information Modelling). It's an approach based on modelling architectural information that describes more theoretical and historical knowledge of the monument instead of explicit descriptions and basic components within BIM elements. This approach is to develop a 3D information model of a building from its architectural, theoretical, and historical analysis. This model will contain information on the scale of the building (set) and across its constructive elements (Decoration). From this approach, the reconstruction of heritage can be achieved even for the type of buildings for which we have little information. This approach was tested on the Casino Gent (Pauwels et al, 2008). Beyond the development of the information architecture model, this approach gives the possibility to develop applications that can detect similarities between two monuments reconstructed virtually.

3 APPROACH ADOPTED FOR THE RETURN OF BUILT HERITAGE

For our current study, we choose to work at the scale of the building. At this point, we opt for the AIM as a restitution approach and we will use procedures of parametric modelling in design study. We are interested in modelling architectural knowledge across the building that allows us to " redesign " and virtually reconstruct an existing or a monument that disappeared.

Our approach is essentially based on the collection of theoretical and historical data on a class of buildings: the (traditional and / or digital) survey, an architectural analysis to develop the architectural model of this class at the 2D and / or 3D building and space level. Once the model is obtained, we assume that any operation of restitution is possible even if we have only fragments and that restitution can be adjusted and completed in accordance with the model raised and in cooperation with subject matter experts.

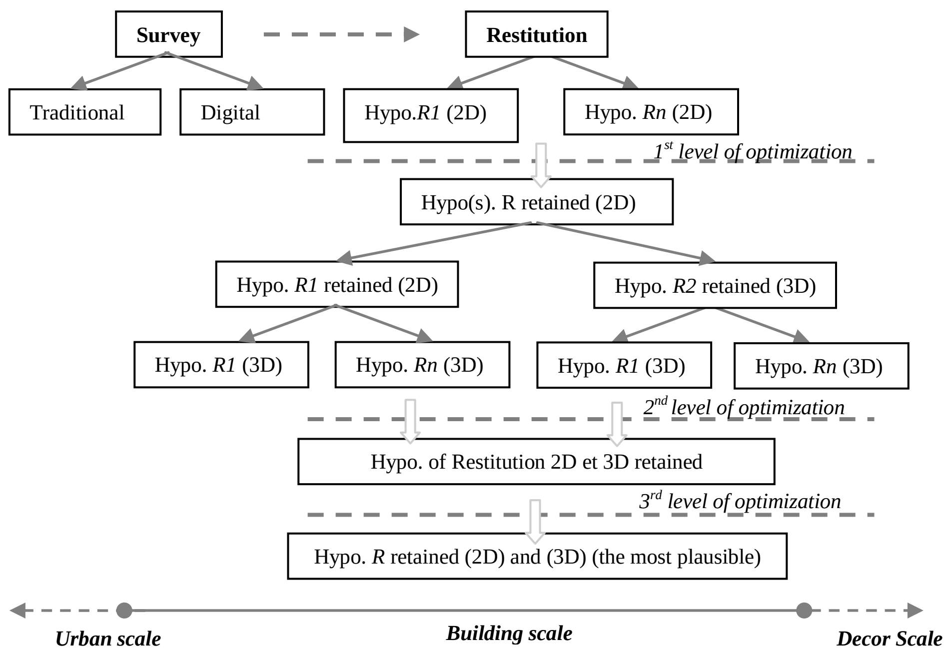


Figure 1: Flowsheet of the operation of a restitution at building scale

At this level, we offer three types of optimizations:

- Manual: manual selection of the most logical hypotheses by the user (the specialist).
- Semi -automatic: a first automatic pre selection in reference to a predetermined architectural model, then passes a final selection of the most logical hypotheses by the user (the specialist).
- Automatic: automatic and final selection of the most logical hypotheses by the computer in reference to predefined architectural model.

At the architectural space: we assume that this approach allows the recognition of architectural space as a whole (its position and its qualitative and quantitative characteristics). In case of lack of information, we assume that this approach will provide automatically a restitution by referring to similar cases or simply by referring to the theoretical model (Fig.2).

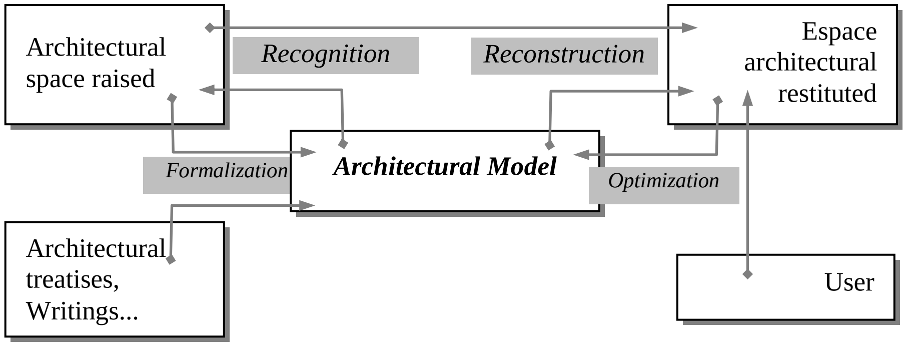


Figure 2: Flowsheet of the architectura space

4 CASE STUDY: THE IMPERIAL ROMAN BATHS IN NORTH AFRICA :

4.1 Presentation of the imperial roman baths

Roman imperial baths represent a masterpiece in which the Romans experienced their creative genius. They are considered as a true " People's Palace " and are a great "showcase" of the ideal Roman life and an object of propaganda showing the power of the empire Romanized people. Architecturally, these baths are distinguished by their monumentality. They respond at their level of architectural design to principles of axiality and symmetry with a duplication of warm and cold spaces. In North Africa, the imperial baths or symmetrical baths reach the number of twenty-three built in twenty different cities.

4.2 Architectural analysis

To identify the architectural model of thermal baths, we conducted:

- A theoretical and historical analysis from treatises on architecture (Vitruve, 1969) and texts and writings that describe the architecture of Roman baths such (Thébert, 2003) (Lézine A. , 1961) (Lézine A. , 1969).
- A Reproduction the survey of archaeologists to analyses it.
- An architectural (qualitative and quantitative) analysis of baths space from surveys and on-going input descriptions in the literature (Thébert, 2003) (Lézine A. , 1961) (Lézine A. , 1969). At this level, we studied :

• The frequency of spaces to identify the program of each category baths.

• The geometric level of each category of baths to identify the dimensional rules producing the architecture of these baths. At this level, we also analyzed the relation between the length and width of the components and of the building.

• The ratio of the area between the two (warm and cold) sectors and between components in the same sector in order to identify the principle of equilibration. At this level, we analyzed the relation between the useful area (excluding material), components and their respective heights.

At the architectural analysis, we used the method of (Dhouib, 2004) and precisely we used the structural analysis method (SM). The SM is the result of crossing structural and functional hierarchies (Fig.3). At this level, we performed several types of analysis to extract the generative grammar (set of geometric physical rules) of this architectural system.

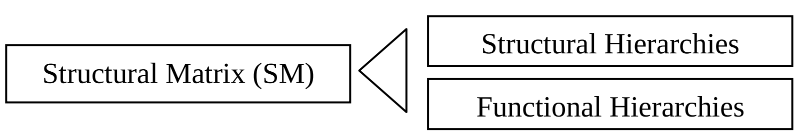


Figure 3: Diagramme of the structural matrix SM (Dhouib , 2004)

4.2.1 Classification of baths

(Thébert, 2003) classified the baths into two categories (medium and great). To better understand the Roman thermal model, we tried to refine this classification, all in accordance with the first classification (Thébert, 2003) as follows:

Table 1 Classification of Roman Imperial baths of North Africa

Categories		Nbre of baths	
Cat.1	The area is more than 1000m ² and less than 2000m ²	5	Medium
Cat.2	The area is more than 2000m ² and less than 3000m ²	4	
Cat.3	The area is more than 3000m ² and less than 4000m ²	4	
Cat.4	The area is more than 4000m ² and less than 5000m ²	2	Great
Cat.5	The area is more than 5000m ² and less than 6000m ²	3	
Cat.6	The area is more than 6000m ²	2	

4.2.2 Program of baths

For each category of baths, we deduced the *fixed program* or essential components in the seaside building and additional spaces that vary depending on the surface of the building

Table 2 Program baths according to the categories

	Program
Cat.1	*Fixed Program* - (missed spaces in the cold sector)
Cat.2	*Fixed Program* - (missed spaces in the cold sector)
Cat.3	*Fixed Program*
Cat.4	*Fixed Program* + (added spaces in the cold sector)
Cat.5	*Fixed Program* + (added spaces in the cold sector)
Cat.6	*Fixed Program* + (added spaces in the cold and warm sector)

The *"Fixed program"* is composed of:

• Warm Sector: Tepidarium input, Destrictarium, Laconicum, caldarium, tepidarium output, Praefurnium (or warming area).

• Cold Sector: Lobby, Apodyterium, Frigidarium, Natation, Hall of distribution.

- Spaces to add in the cold sector are the Palestra, the gymnasium, the exedra, annexes and halls distribution (used as regulators spaces).

- Spaces to add in the warm sector: the warm pool.

4.2.3 Geometric level of spaces

At this level, we analyzed the relations between the length and width of the components and the bounding shape of the building to identify the limits or upper and lower bounds (*lmin and lmax*) of each dimension and the ratio between the dimensional values of the space. These values are used to facilitate the primary morphological restitution of spaces. Then we calculated the ratio between the thickness of the natural casing (walls) and the respective heights. We assume that the ratio allows us to distribute primitive forms generated within the bounding shape of any statement or generated in accordance with the rules and principles of the architectural design already modelled. The generated forms of spaces or buildings can be adjusted according to the survey model.

Table 3 Example of analyses of length / width ratio of the components of the warm sector

	Cat.1	Cat.2	Cat.3	Cat.4	Cat.5	Cat.6
I	1,40	1,31	1,27	2,03	1,32	1,84
II	1,29	1,54	1,63	1,16	1,54	1,01
III	1,47	1,33	1,96	1,10	1,27	1
IV	1,58	1,27	1,16	1,07	1,17	1
V	1,98	1,67	2,34	1,38	1,54	1,09
VII	-	-	-	-	-	1,24

4.2.4 Geometric level of areas

At this level, we studied ratio between the areas of the two (warm and cold) sectors and between the components of the same sector in order to identify the principle of equilibration. The maximum and minimum raised surfaces (*S.min* and *S.max*) will be stored in a database. We also analyzed the relation between the useful area (excluding material), components, and their respective heights. The values obtained at the geometrical and dimensional analysis and help to deduce and optimize the number of shapes to be generated automatically.

Example:
If L/l≈1; A (m²) ϵ {*Smin; Smax*} = {*20; 25*} then L≈1= {*20, 30*} = {*4.47; 5.47}* (m)
If we add that L*r* = 5 (m) and L / L ≈ 1 then b = {4.47; 5} (m) (We design by L*r is* raised length).

4.2.5 Physical level of materiality

At this level, we studied the ratio between the useful area and the physical envelope of each space and for each sector in order to extract information about the thickness of the walls, the amount of material ... and to define the principle of equilibration between the quantity of material and the lived space.

Table 4 : Example of Analysis of surfaces

	Total Area (%)		Area WS (%)		Area CS (%)	
	US	QM	US	QM	US	QM
Cat.1	75	25	70	30	80	20
Cat.2	71,5	28,49	60,35	39,64	80,36	19,63
Cat.3	63,81	36,18	62,47	37,52	64,36	35,63
Cat.4	69,07	30,92	65,50	34,49	71,10	28,89
Cat.5	79,57	20,42	69,09	30,90	83,52	16,47
Cat.6	66,45	33,54	50,9	49,09	72,76	27,23

US is the useful Area and QM is the quantity of material.

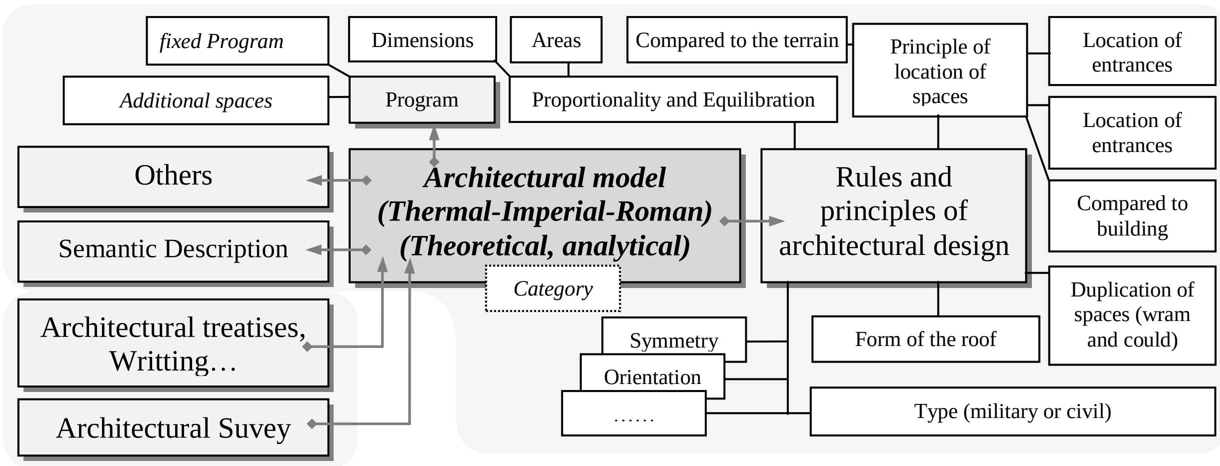


Figure 4: Development schema of architectural thermal model

4.3 Example of analysis for the regeneration of bath space: the Frigidarium

In this section, we present an example of our analysis and explain the operating procedure of regeneration or restitution. We took the Frigidarium space as an example. It is a central space placed on the axis of symmetry. The results below are obtained from an analysis of twenty baths (Tab.5).

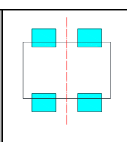
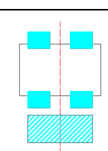
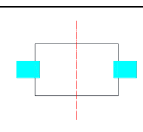
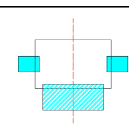
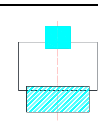
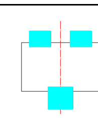
Table 5 Example of analysis of the circulation and basins area of Frigidarium.

	Area en %		Length / width ratio		Nbre of basins	Cover	Height
	Circulation	Basin	Circulation	Basin			
Cat.1	86,00	13,99	2,10	1,29	1*sb* +1*bn* ou 2 *sb+1bn ou 4sb*	cross vault	h*max*
Cat.2	68,78	31,21	2,89	1,09	1*sb+N* ou 2*sb+N*	cross vault	h*max*
Cat.3	80,82	19,17	1,83	1,27	4*sb* ou 2*sb+N*	cross vault	h*max*
Cat.4	84,43	15,56	1,88	1,55	2*sb+N*	cross vault	h*max*
Cat.5	86,84	13,15	1,56	1,3	2*sb* ou 2*sb+N*	cross vault	h*max*
Cat.6	82,80	17,19	2,2	1,78	2*sb+N ou 4sb+N*	cross vault	h*max*

We note by *sb*: the small basin and *bn*: basin-natatio.

At the frigidarium level, we studied the spatial and dimensional relation between circulation space, basins and natatio (dimensions, surface and number). We highlighted six spatial configurations of frigidarium (Tab.6).

Table 6 The different configurations of Frigidarium

Configuration	 *Conf.1*	 *Conf.2*	 *Conf.3*	 *Conf.4*	 *Conf.5*	 *Conf.6*
Nbre	2	1	1	9	2	5

We try, here, to resituate the dimensions of the frigidarium of the Great Baths in Oudna. These are imperial baths with an area greater than 3200m². For these baths, we do not have any dimensional or graphic information.

We have *Sur.T=3200m²* ϵ {Cat.3} then *Sur.cir.fri* ≈ 207.87 (m²) and *Sur.Bas* (m²) ≈ 49.33(m²)

- circulation:
  R=L/l →L=R/l and S=L*l →L=S/l → R/l=S/l → l²=S/R → l=√(S/R)= √207.87/1.83=10.65 (m) then l ϵ {*lmin; lmax*} ϵ {*9.26; 11.74*}→L=R*l=19.48 (m)
- basin:
  R=L/l →L=R/l and S=L*l →L=S/l → R/l=S/l → l²=S/R → l=√(S/R)
  If it is in the case of two basins: l=√ ((S/2)/R) = 4.40 (m) ϵ {*4.03; 4.66*} →L=R*l=5.58 (m)
  If it is in the case of three basins: l=√ ((S/4)/R) = 3.59 (m) ∉ {*4.03; 4.66*} → to eliminate
  If it is in the case of four basins: l=√ ((S/4)/R) = 3.13 (m) ∉ {*4.03; 4.66*} → to eliminate
- Configuration
  According to Table 2 and 6, the frigidarium must have the configuration 4 or 6. In this case, we go to an other level of optimization to minimize the number of configuration. We refer to Table 6 and the similar cases (the conf.4 is raised at Cat.3).

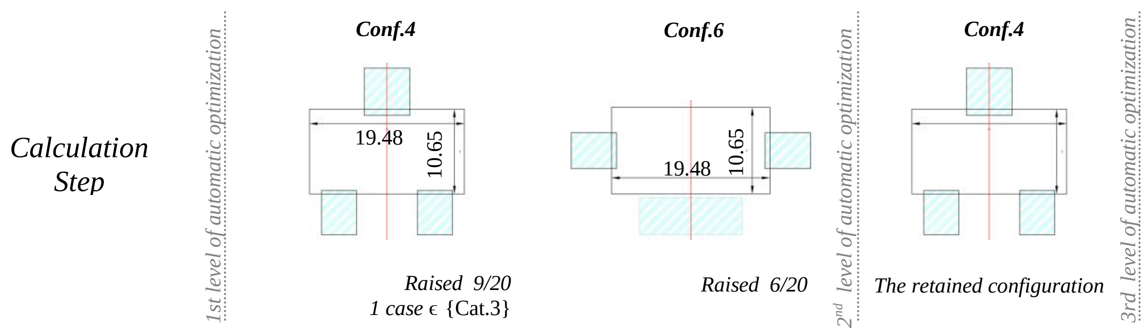


Figure 5: Automatic optimization of generated solutions

5 CONCLUSION

We presented our approach to developing a tool for the restitution of the built heritage from an architectural, historical and theoretical studies allowing the automatic generation of hypotheses of reconstruction. This cognitive tool must be finalized within a multidisciplinary framework (architect, computer engineer, archaeologist, historian...). For our part, as architect researcher, we studied the design process through the imperial baths architectural analysis and theoretical and historical study. This study aims to model the architectural knowledge of this type of buildings to be re -utilized in the process of re-design or regeneration. We assume that the digital model obtained can be updated whenever there has been a breakthrough in the field of archeology and the hypotheses generated can be adjusted according to the (traditional or digital) survey updated.
We have to finish our architectural analysis and especially at the heights level which we found a major problem in order to complete the baths and begin the phase of software development of the architectural model.

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