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BIM models to manage and make use of cultural heritage

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***Abstract* – Survey and use of Historical BIM models (HBIM) as tools to make the most of historical and archeological heritage: different systems to manage and plan our use of local heritage.**
Case study of the project of the new lighting system for the cloister of the Basilica of Santa Croce in Florence.

I. INTRODUCTION

Why use Building Information Modelling (BIM) in the area of cultural heritage?

This is a crucial question and indeed a necessary starting point, in terms of methodology and operability, in each and every project requiring the use of an effective and feasible BIM process.

When we use what we call "BIM technology", what we are really saying is that we are going to adapt a particular technology, or software, to the BIM method. Without a solid strategy, technology might not give us real advantages and could easily become a reflected process that does not make the most of its actual potential.

It may well be suggested that cultural heritage does not necessarily need BIM for construction, at least not as a process to optimize the planning and building phases: aiming at reducing the construction stage (up to 30%) is clearly useless when it comes to historical buildings, which have existed for centuries.

In order to find a good reason for using BIM we need to deeply understand the "philosophy" behind the process. First and foremost, BIM consists in developing a virtual model enriched by integrated data, thus allowing to simulate and analyse different scenarios and strategies on a prototype, as well as testing it before actually building it.

Defining and testing the most appropriate strategies in matters as analysis, conservation or exploitation of a building is particularly important when we handle historical and archaeological heritage. BIM can help to optimize all the programmed and expected activities, reduce accidents, predict and evaluate critical situations, calculate timing, impact and cost of work, while essentially avoiding those situations when coping with the unexpected is left to the site work.

Fig. 1. Cloister rendered view, Santa Croce (FI).

II. SETTING H-BIM GOALS

This approach is important to understand how we can apply a typical BIM method to the specific area of cultural heritage, by adapting common technology and essentially mold the BIM process to meet our needs.

Current technologies are not completely suitable to these technical areas; as a matter of fact, they focus on a top-down logical process, in which details are treated as parts of a more general system, quite often a homogeneous system. A sandstone ashlar is a part of a macro-element: the wall. Likewise, a king post is part of a king truss.

These "detailed parts" cannot be taken into account during the first stages of the process, as BIM rather follows the course of a typical plan of work: from a Concept to a Developed Design, through a Technical Design up to a Construction Design [1]. As a result, many digital models (BIM) are often realised as non-aggregated parts, lacking a connective logic between them. Such models are built according to a non-conventional use of parameters, applying a "sum of exceptions" logic by which the detailed parts can be introduced as stand-alone elements, not necessarily integrated with data; although this kind of logic can generate a 3D model, this cannot be defined as a prototype of Building Information Modelling.

In this perspective, the use of BIM technologies does not offer particular advantages when compared to general 3D graphic models. On the contrary, it usually makes the job harder.

Limiting the approach to each area with regard to its own specifics (static/structural analysis, mechanical planning, management, survey and historical-archaeological analysis) is also not compatible with a BIM process.

As a matter of fact, operating on a single model placed "at the centre" of the process and shared between professionals does not automatically mean we are employing BIM: a necessary step is the capability of handling the integrated data, thus coordinating what will eventually become an integrated process. For the same reason, converting survey sketches in a BIM environment would not be considered good practise when not supported by a clear BIM management strategy. Strategy is a necessary key to the parametrization of the model and allows to maintain it and make the operative usage of the digital prototype successful.

III. USING A BOTTOM-UP APPROACH

Our recent activity of developing a HBIM model for the cloister complex of Santa Croce in Florence can today be used as a case study to analyse the applications of the BIM process to cultural heritage. In the following pages, we will describe the method adopted to build the 3D model in a BIM environment, using data and parameters, and the technologies used to simulate and render the new lighting system.

Primarily, the entire process was summarised in order to set up an effective operative BIM system, specific to the management of historical and archaeological heritage. We introduced some customizations into the typical top-down workflow, thus extending the process to a bottom-up approach.

With regard to the methodological point of view, we decided to focus the modelling approach on the photographical survey, comparing it to the graphic drawings and the additional descriptive information.

Even though the existing drawings (plans, elevations, details) have represented a starting point in our project, they have not been at its core. Rather, we used them as an aid to identify the architectural elements of the cloister and to retrieve the related hierarchical and constructive rules (proportion, module, rhythm…) [2]. Through this kind of analysis we were able to set up a system of rules and constraints for our parametric components and build them geometrically while, at the same time, making them suitable for hosting data (BIM ready objects) [3].

At a later stage, we focused on the texturing pattern of the cloister shell (walls, floors, vaults and roofs). Through the mapping of the cloister surfaces, we managed to obtain a vector geometric pattern, thus maintaining the functional continuity of every element by using the textures. This proved useful in order to obtain a unique model in terms of construction, structure and maintenance.

Once aware of which parametric components should be used and of the way to embed them in the model, we moved on to developing the BIM model for the entire complex. By employing all the typical procedures of a BIM environment, we carried on to modelling the complex, paying particular attention to the descriptive fields (notes, marks and specific parameters) and filling them in with the corresponding data from both the survey and the new project.

We included most of the architectural elements into a rule-based system, and were able to leave just a small number of elements as non-indexable parts (a mere 5% of the model). This percentage takes into account the elements lacking a corresponding parametric component, such as sculptures and sinuous streamlined forms, which are not strictly related to the simulation model.

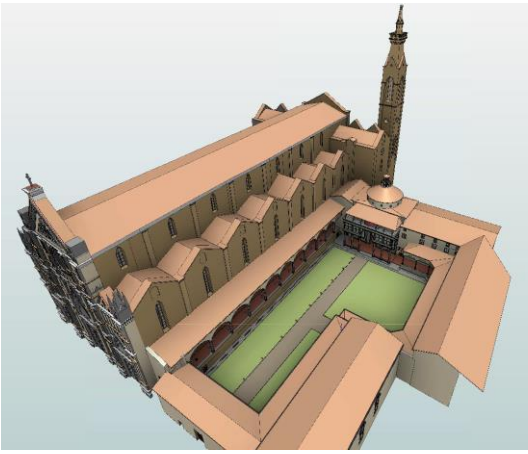

Fig. 2. HBIM model, Santa Croce – full view.

IV. MAPPING FIRST

Keeping into consideration the overall complexity of this project, in terms of technology we chose to launch a "medium-request process" in order to avoid excluding non-IT skilled professionals from the collaboration.

A reverse engineering technique significantly contributed to our approach to component analysis and parameter setting. Using perspective rendering from non-fiducial photograms in a 3D graphic environment, we were able to "read" the visual parameters of the image and evaluate the geometry necessary to assemble the 3D generic models that have been used as a later input for the actual parametric components. Therefore, through a first analysis of the photograms, we managed to retrieve the essential data to kick-start the BIM specialists' job, providing them with the necessary framework to treat each and every BIM component.

For easy usage in a BIM environment, we used a photo-editing software and proceeded to cut out the photographic mapping textures according to the model's geometric surfaces. We introduced some automatized procedures for image vectorisation and referencing -

particularly useful for the larger surfaces of the shell - in order to easily create graphic geometric patterns as similar as possible to the original textures. What we essentially did, was using such patterns as an innovative mapping system, configured as a sort of a second layer added to each single element in the model. This mapping system can, on the one hand, preserve the constructive continuity of all the components in our BIM model, while on the other hand it gives us the interesting possibility to link a single detail to the model through the usage of mesh and tag indexing for every detail and every "surface exception".

This method has the potential to be used to build both simple and detailed models, in which many useful data can be added and inserted in their exact position upon request, reflecting the existent conditions of the cloister even though the model surfaces are treated as continuous faces. Our procedure was a clear improvement when it came to validate the project and simulate the new lighting system, as it reduced timing and returned accurate results using an agile model.

At SPraUt, we decided to adopt these procedures as an operative standard for our activities and we are currently working towards optimizing the process, applying it to further studies in industrial archaeology and infrastructure.

Mapping the cloister in Santa Croce presented particular advantages, which led us to shift our focus to the prototyping theme. As a first advantage, the exact knowledge of the geometry and the architectural components helped us prioritize structural interventions such as laying a new electrical system, inserting supports, planning scaffold etc. This makes it particularly easy to plan and schedule the site in a non-restricted area.

Secondly, it represents an invaluable tool in simulating lighting effects within the model: light is not only a requirement affecting safety as well as usability, but it is essential in order to maximize the historical and artistic value of the site. A correct use of the lighting system plays a crucial role both in technical terms and in formal and communicative terms.

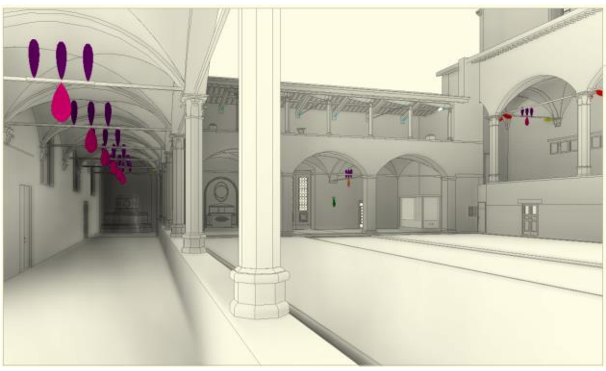

Fig. 3. IES photometric curves.

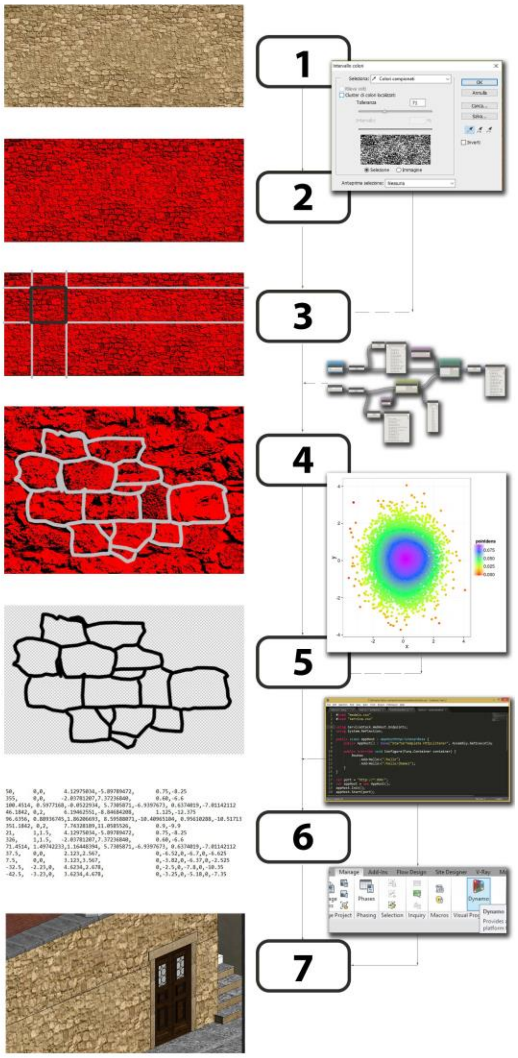

Fig. 4. Mapping and texturing.

1. *Referenced Hi-Res acquisition*
2. *Polarized contrast imaging (BW)*
3. *Surface meshing*
4. *Searching for black coloured accumulation points*
5. *Lines as connectors through pre-determined nodes*
6. *Identifying vector patterns*
7. *Inserting and aligning patterns into the model.*

V. COMBINING SIMULATION ANALYSIS WITH PERCEPTUAL FEATURES

In a digital environment, there are two different technologies available for lighting simulation:

- Algorithms based on lighting curves and grid references, are useful for both direct and diffused light. They return an accurate and detailed analysis in technical terms, although their communicative and descriptive capabilities might not necessarily prove effective. Professional knowledge, as well as high expertise, are necessary requirements in order to avoid unsuccessful results.
- Photo-realistic rendering software are very effective at making light look real on images. They compensate lack of precision with enhancement of the formal and narrative aspects.

Typically, the professionals in charge of the project layout choose one of the aforementioned approaches and begin a second rendering process by “duplicating” the 3D model. Although this can bring valid results in terms of layout, we encourage to use a full BIM process, as in any case such approach does not fully reflect the BIM logic.

BIM is a unique environment that includes activities such as modelling, prototyping and simulation, but also scopes, performance and functional levels: the aspects addressing performance, function and perception of the cultural site should not be left behind.

Furthermore, non-material elements like air, heating and lighting, deeply impact the dynamics between a building and the environment, and such influence can strongly depend on how professionals set up the scene and its properties. Moreover, minimal changes to those values can lead to different results, which can produce reactions not necessarily compatible with the original purpose of the project.

It is our opinion, therefore, that the implementation of a BIM process can prove particularly useful in regards to these elements, thanks to its capability of mirroring the exact and real state of things before building new simulating scenarios.

BIM can represent a reliable tool to keep all these aspects connected, thus avoiding unexpected and unreal occurrences that are common when we employ 3D model generated rendered views that may often result in a discrepancy between the building model and the rendering model.

There is no sole strategy when deputing layout and rendering to the BIM prototype, as it is possible to use different technologies.

Focusing on current technologies and referring to what is usually intended as *virtual reality*, there are three different and available methods:

- Perceptive similarity approach
- Over-realism
- Pseudo-physic simulation.

In a perceptive similarity approach, the simulation only focuses on some of the macro-aspects of virtual images, emphasising their similarity with reality and leaving the rest to a level of lower precision. It concentrates on the quality of diffuse radiations and uses stochastic algorithms for scene balancing. Due to their accessible programming and considerable speed, these kind of engines are the most common. Additionally, we can rely on a considerable quantity of technical papers available to the users to help them configuring and adjusting the simulation.

Over-realism technology usually employs smudge and halation to focus on the realistic textures of physical objects, or glaring and other filters to enhance the background, so that the viewer attention is moved away from details that are left imprecise, especially in terms of lighting effects. This kind of engines take advantage of powerful computers and therefore are very quick, which makes them widely popular in the gaming industry.

Pseudo-physic simulation technology employs algorithms derived from mathematics and physics laws (Maxwell’s electromagnetism theory) and it elaborates accurate models, until reaching a programmed minimal range of discard in regards to analytical results. This kind of engines need high level technological resources and return high quality results, but the simulation process is more time-consuming and the input phase is not always accessible: the physical description of each material, especially for what concerns its dielectric features, uses different parameters and approaches, and gives different results for each software. Furthermore, although the overall result might seem satisfactory, the numerical values input may not reflect the actual physical behaviour of the material. For this reason, these kind of engines require digital designers with high expertise.

VI. DEFINING STRATEGIES FOR A REPRODUCIBLE PROCESS

Having analysed the available technologies, we decided to opt for a hybrid rendering-engine: radiance + unbiased, combining the features of a perceptive similarity approach with those of the pseudo-physic simulation system.

A rendering-engine that evaluates segments of the electromagnetic behaviour as well as elements of the diffuse radiation effect, not only allows to take advantage of the local environment description (air density, relative humidity, temperature) typical of the unbiased system, but also to focus on direct and diffuse radiation - through the analysis of data concerning the lighting systems, directly extracted from the BIM model.

Moreover, the possibility to repeat the process as a key-point to guarantee a future re-work and a re-use of the lighting project, encouraged us to choose a very diffuse process in terms of available technologies, that would be available to many professionals in that initial phase and that could be then easily exported into similar and competitor technologies.

In the light of this, and testing the export-feasibility of the prototype, we defined an operative strategy that includes all the data deemed useful to the rendering phase. We then proceeded to elaborate an operative protocol to support the BIM model. First, we considered the data pertaining to the material textures obtained by a photographic survey, including high quality photos without filters - with direct lighting only - and videos shot using both Day and Night camera modes.

Each mode proved useful towards obtaining a specific characterization of the surfaces, which led us to combine them in order to have a sort of overlay of the single parameters. By applying semi-automatic procedures to each material and each pattern [4], we acquired information on various properties, and proceeded to organize them. Here follows a list of said properties:

- Main colour
- Porosity and/or pattern
- Roughness
- Brightness
- Reflection
- Glare
- Fresnel
- Dielectric behaviour.

We created a layer for each of these properties in order to attain a complete mapping of the textures: according to our approach, the real textures have been converted into “digital and multi-layered materials” and then organized in a material library ready for the BIM model.

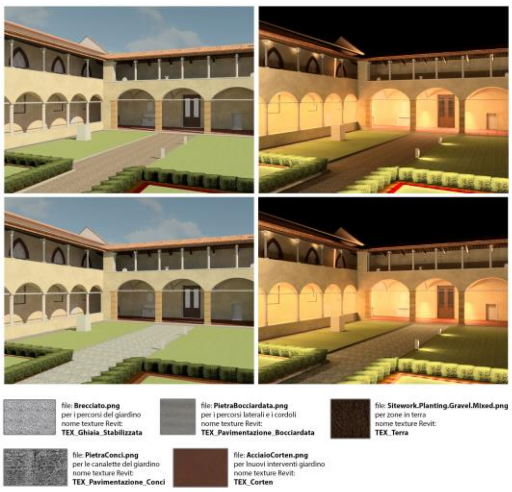

Fig. 5. Digital multi-layered material texturing.

VII. A VIRTUAL TESTING-ROOM

In order to model them as parametric components, we worked on analysing the geometry and collecting the data for both the existent and the new lighting fixtures, according to the lighting project. For each lighting fixture, we implemented the following data directly into the component:

- Luminous flux (lm)
- Source type (LED)
- Energy consumption
- Type of diffuser luminaire
- Materials and finishes
- Codes for the fixture and the internal parts
- Link to the product technical paper.

Most data have been integrated in the model by using IES curves, and directly inserted in each prototype of the lighting fixture as an exact result of their photometric data.

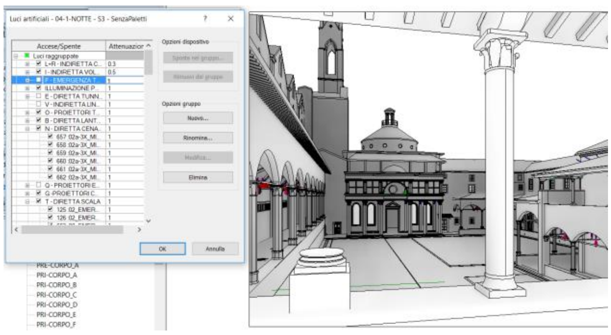

Fig. 06. Dimming setting.

Inserting lighting fixtures in a BIM model does not merely involve placing the components as “objects”, but requires further adjustments to align the lighting effect as it shows in the analytical data to what is actually perceived by people. In fact, the usage of the accurate technical data provided by manufacturers, does not always produce a correct and genuine result during the phase of view-rendering; to adjust that, every rendering engine makes available to the user some sort of optimization parameters, which can influence the rendered view in terms of precision and rendering conditions. As long as we consider getting a rendering view as similar to taking a picture, we have to keep in mind that all the image settings are very subtle and personal. In order to attain a positive result, we founded our strategy on the alignment of the lighting sources to the current exercise-conditions of the lamps. Despite working in a virtual environment, we decided to adopt the same logic used by lighting designers in physical projects: as a designer tests a lamp in a testing room in order to choose exactly what he needs in terms of performance, we built a virtual testing room with the same set up. Working in an easily manageable virtual testing-room made it accessible to adjust the settings in order to create a realistic lighting effect. Furthermore, by operating on such atypical contest we managed to obtain a set of valid and more general settings that can be used repeatedly in similar rendering conditions: they work now as guaranteed and ready-to-use fixture settings.

Fig. 07. Virtual testing room.

Our virtual testing room reflects the actual room used by lighting fixture manufacturers: we built the room in a BIM environment using the same set-up, checking for correspondence with real conditions. Once obtained a compatible result, we arranged the lighting fixture used in the project and then proceeded to apply the appropriate adjustments according to the lighting project objectives: the algorithms employed for the adjustments does not affect the manufacturer data, but rather keeps the simulation values in line with the planned scope.

Few other adjustments were required during the preview rendering phase: because we opted for practical choices and used short exposure-timing for our views, we had to reduce both the temperature colour and the lighting energy by 20%. However, this kind of adjustments were reduced in the following phases, and the discard of both the simulated and the real lighting were reduced to 7% using a longer exposure-timing for the final rendered views.

VIII. CONCLUSIONS

Our research has underlined the importance of analyzing our historical and archaeological heritage in a virtual environment, demonstrating just how important it is to replicate its exact and delicate conditions. We have obtained positive results that have the potential to reverse the current practice of intervening in this field without the support of effective planning and of leaving the worksite operators to deal with the unexpected.

Results so far have been very encouraging, although we have to remark that our research provides the framework for a new approach to managing our heritage, and it cannot still be considered as a comprehensive operative standard. We believe that our experience shows the concrete possibility of precautionary testing the correct strategies to intervene on archaeological and historical sites, and, perhaps even more importantly, it proves the advantages of including them in a typical work-procedure. This process does not require excessively advanced technology; indeed, it employs diffuse resources, simply providing innovative customized tools that can easily become part of our current and common technology as plug-ins.

At SPraUt, our main purpose was to test our approach flexibility, trying to extend its use to a wider number of professionals, adjusting the method to meet their needs. Remarkable results proved that our choice to build a new strategy that focuses on innovative methods and meta-software was successful in terms of time consumption and costs. We believe that this kind of approach has a minor impact when compared to producing virtual simulations and rendering through a process made of progressive revisions, which is currently the most diffuse practice among professionals.

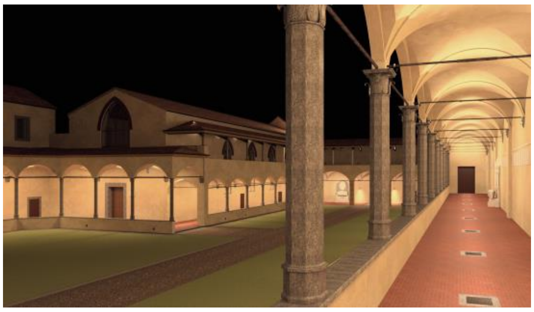

Fig. 08. Cloister rendered view, Santa Croce (FI).

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KEYWORDS

- 5D BIM/HBIM modelling
- Virtual prototyping
- Surface and material mapping
- Texturing
- Lighting simulation