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Digital Renovation: BIM for the Built Environment

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The scientific literature related to the adoption of the Building Information Modeling has incredibly grown up in recent years, although it is still lacking of formal and effective general workflows explicitly dedicated to the built domain. The meaning of the term HBIM itself, often misused to outline the digital process applied to existing constructions, is erroneously misconceived, as it is primarily a comparative methodology between digital surveys and their derivative 3D abstractions, not a generic acronym to be used when referring to the whole digitalization of the built environment. The aware acceptance of digital methodologies and procedures for existing buildings (not necessarily monuments or archaeological sites) as well as the BIM lifecycle approach adoption on new constructions, is a strategic decision that, however, needs to be properly evaluated when considering the optimal workflows to be preferred from time to time. Also, the intervention on consolidated buildings or facilities has to follow a path made of procedures and intertwined digital models, following patterns of increasing complexity. The two elements, process and models, are deeply intertwined even though the former is still not explicited for the latter, due to a standardization at an embryonic stage and, perhaps, seriously confused by someone with politics. From the software perspective, interoperable file formats and data structures considering information for restorations and renovations are in development all over the European countries. Thus, this paper delves into considerations, implications and effects of a possible mature and aware adoption of IT and digital technologies for restoration, renovation and documentation design intents. Introducing some reflections whose outcomes are represented by the application of novel dedicated strategies fitted on advanced equipment to better understand the existing realm (proximity TLS and UAVs surveys, use of sensors, etc.), the paper brings into the discussion some future scenarios on the uses of more and more interconnected semantic technologies, proposing a consolidated technique meant to survey, analyze and replicate existing buildings into semantic BIM models. Moreover, the data interpretation operated by machines could be the most promising scenario for the digital transition in the built environment: when most of the knowledge contents about buildings and monuments will be no longer intelligible only to the human perception, but they will be extended to the machine through a shared digital language, analysis, estimations, and different operational schemes will probably allow the choice of the right intervention through many alternatives, leading to an increased quality for restorations and renovations.

INTRODUCTION: BIM, HISTORIC BIM AND THE CONFUSED DIGITIZATION SCENARIO

The Building Information Modeling is a data management process actually adopted for decades in the AEC domain, especially all over the north American countries. Nevertheless, especially in Europe, its real potential has been focused only in recent years in terms of interoperability and data exchange, features whose interactive language made of digital models has started to be backed by today's computational hardware and software increasing performance.

However, the application of BIM processes and tools to existing buildings is still challenging, since the complexity of the built domain is often way difficult to manage when compared to new construction tasks, due to the frequent lack of data sources on techniques adopted and materials applied, as quoted by Volk, Stengel and Schultman (2013). Also, standard workflows and best practices dedicated to the built environment, in terms of codes, laws and regulations, are almost missing or unshared across different countries; this context leads to wide BIM experimentation currently in progress all over Europe, particularly on monumental sites or consolidated urban areas.

Novel technologies in architectural survey and digital representation, in fact, foster the transition towards the digitalization, even if some misunderstandings in terms and expressions still bring confusion to the actors involved in the process. The term HBIM, for example, is widely and unconsciously used when referring to any kind of intervention on an existing building, where perhaps 3D parametric models are involved as well. HBIM is becoming this way a synonym for "BIM technology applied to the existing buildings". On the contrary, the term comes from the scientific literature, where it is explicitly declared that the "Historic Building Information Modelling (HBIM) is a novel prototype library of parametric objects, based on historic architectural data, in addition to a mapping system for plotting the library objects onto laser scan survey data" as expressed by Maurice Murphy in 2009. HBIM is actually some sort of form-fitting between high definition surveys and man-made digital abstractions made of architectural components: existing buildings, regardless of their function, are easily and quickly detected using accurate tools and consolidated workflows such as TLS (terrestrial laser scanning, as suggested by Grussenmeyer and Hanke, 2010) or digital photogrammetry (whose feasibility was proved by Jean Angelo Beraldin, 2004, among others), so that the point clouds produced are then compared to software libraries made of objects that are placed on the top of the cloud until the resemblance of the model obtained is satisfactory.

It is easy to understand that this process aims at a general abstraction for geometries only, with the purpose to author lean models whose elements are meant to express an intrinsic architectural meaning related to their shapes and relationships (semantics), while the data collection from documentation or numerical sources embedding information into geometries comes only at a later time, to express all the BIM data management potential. HBIM is actually a technique, while BIM is more in general a process whose language is made of digital models, as reported by Eastman, Sacks, Teicholz and Liston (2008). Similarly, the term Scan-to-BIM is frequently misinterpreted, improperly used to identify the mostly handmade process of translation of data survey into 3D models; on the contrary it is important to understand how a BIM model is primarily a database in which the morphology is only one of the available data, even though extremely useful as a friendly user interface to browse easily extended metadata as defined by Mill, Alt and Liias (2013). This way, terms like BIM, HBIM (with its "flavors" Heritage BIM and Historic BIM) or Scan-to-BIM are becoming sort of homogeneous synonyms meant to generally identify interventions on constructions. Many scientific contributions discussing these themes, in fact, can be found on Scopus, ScienceDirect, and Google Scholar as mentioned by Lopez, Lerones, Llamas, Garcia Bermejo and Zalama (2018), who counted a total of 131 papers that were published between 2007 and 2018.

However, in this evolving context, the interest in information modeling techniques applied to the already built architectures is clearly increasing: the advantages in BIM-oriented restorations and renovations lead to a better understanding of constructions, a coherent collection of documents pertaining buildings and facilities, and better estimations on costs and resources.

Figure 1: The typical authoring workflow to get digital BIM elements out from terrestrial laser scanning. The real architectural component (a), the registered and segmented point cloud (b), the BIM abstraction authored translating the point cloud into semantic objects (c). The geometric element is now able to host linked information related to materials, building technologies, maintenance or technical specifications (Survey campaign, data processing and BIM model of a traditional Italian building by S. Garagnani, 2015).

THE DIGITAL TRANSFORMATION FOR THE BUILT ENVIRONMENT

Notoriously, language is the human faculty to express and communicate, in written or spoken form, articulated concepts through syntax and grammatical rules. The advent of digital frameworks, however, has introduced considerable changes in communications, arousing the fear of traditional idioms to disappear on one hand, while pushing the use of standardized common languages on the other. Technical English, as a typical example, has been elected as a reference for the global sharing of scientific information for software programming comments, favoring the genesis of IT neologisms in different languages.

The digitalization of the built environment is therefore a form of mutable, fluid and synergistic expression, which is articulated on several levels to combine the initial thought to the final result, the digital model to the real built architecture. However, it is necessary to understand correctly at what level of "spoken digitalization" to aspire, at least in its main contexts: as Jason Bloomberg (2018) wrote, digitization, digitalization and digital transformation are terms that express meanings very different in the language of the digital transition.

If the digitization is some kind of translation from traditional sources (paper documents, photographs, negatives and physical models) to computer-readable digital formats composed of bits (an optical scan of a paper sheet is an example), it has not to be confused, as often happens, with the digitalization, which is rather the process that can be implemented at an industrial level through which traditional interactions and exchanges are assisted by digital technologies (in the form of data models), leading to many benefits in terms of optimization and broadcasting. Digitalization is more comparable to a process of change that must be designed and that can start temporarily from digitization, both socially and productively.

On the contrary, the digital transformation is something that individual industries cannot approach by themselves, since it refers to a deep revolution in the business model of the whole AEC system level: it is able to influence the productive chain's behaviors over the long term.

(Figure 2)

These words are paramount in the application of the BIM paradigm to the built environment, since they represent different stages of the development of proper methodologies to face the many issues connected to the maturity level of professionals and scholars involved. If approaches such as HBIM or Scan-to-BIM are proper digitization for architecture, not necessarily monumental or placed in historical contexts, the digitalization is the step where all the data pertaining to the subject, its development, its inner historic essence and the evolutions that occurred over time can be shared among scholars, professionals and practitioners using the common language made of BIM models, which become the expression of a process, where all the BIM positive incomes in terms of reliability, optimization and organization can be extended to existing constructions, considering the digital transformation as a far perspective for the whole AEC industrial chain.

In other words, the digital transformation changes all the ways in which the building process is traditionally conceived by the involved figures, ferrying them from traditional operational practices towards original ones, implemented with advanced tools able to relate to each other through a language made of digital semantic relationships.

From a commercial perspective, the digital transformation will be a key asset initially in the public procurement of many countries, but it will be soon adopted also in the private sector.

TOWARDS A BIM PROCESS DEDICATED TO THE EXISTING BUILDINGS

It is somehow justifiable the pathway made of all the reasons that nowadays are pushing survey technologies in the rush to the digital transition; even if dedicated software do not still fully allow a complete automatic workflow in the features extraction and translation of digital surveys into BIM-ready all-inclusive data models, progresses are encouraging, as written by Xiong (2013) or considering the research work by Zhang and Zakhor (2014). The continuous data browsing and information embedding into models generated from digital surveys is paramount never than before, since the documentation authored in a BIM process is made first of all with the final goal of software interoperability and data sharing in mind as quoted by Quattrini, Malinverni, Clini, Nespeca and Orlietti (2015). This is very important in order to foster a digital transition as pointed out accordingly by many European best practices and regulations, which are introducing data fields in the IT language frameworks and proper Levels of Developments (LoD) dedicated to restorations and renovations. While the digitization carried out with increasingly feasible software is preluding to a digitalization made of more or less binding regulations, some standardization of the whole process is necessary.
Even if the LoD concept introduced the amount of information necessary for the different stages of the construction process among operators, when dealing with existing buildings is very hard to comply with predetermined thresholds. On the other hand, it would be difficult to lay standards out without a common level of knowledge embedded into digital models for different purposes. This is the reason why the digital transformation for interventions on existing buildings is a matter of arbitration, since every single case study is different and professional figures called to design renovations or restorations have to be prepared to evaluate the importance of data sources.

Figure 2: The most common authoring workflow to get digital BIM models from UAV digital photogrammetry. The real building (a), the registered point cloud processed from aerial pictures (b), the BIM abstraction authored translating the point cloud into a semantic object taking advantage of a BIM software environment (c), the final digital model meant to index embedded data about preservation of materials, as-built documents, structural simulation results and so forth (d) (Survey campaign, data processing and BIM model of a built sluice close to the Po river by S. Garagnani, 2016).

However, some common ground can be identified in digital modelling for the as-built scenario: while architectural components and their preservation are variable parameters, their semantics can be similar. This way, components' behaviors become a discerning feature in data layouts. Many case studies were approached following this process, leading to a framework that can be applied also to the archaeological field .
Building Information Modeling relies on a paramount feature, which is represented by "smart objects", architectural components self-aware of their identity and conscious of their interactions with each other. Smart objects are hard coded in BIM applications and they contain not only a morphological definition, usually ruled by numerical parameters, but interaction routines as well (e.g., doors and windows belong to walls, floor slabs are perpendicular to walls, trusses distribute their loads on pillars, and so forth). To translate existing buildings into digital models just like the ones used to design new constructions, families of smart objects representing real elements are needed. Again, components have to be acquired and prepared. As a consequence, three kinds of knowledge about them need characterization: knowledge about the object shapes, knowledge about their identities and knowledge about the relationships between elements. While the last two aspects are generally obtained by the investigation of semantics and undergoing analysis and trials, the first one can successfully take advantage of digitization techniques.
The application of this process to the built environment is although very different from traditional 3D modeling: a BIM model is hierarchically structured,

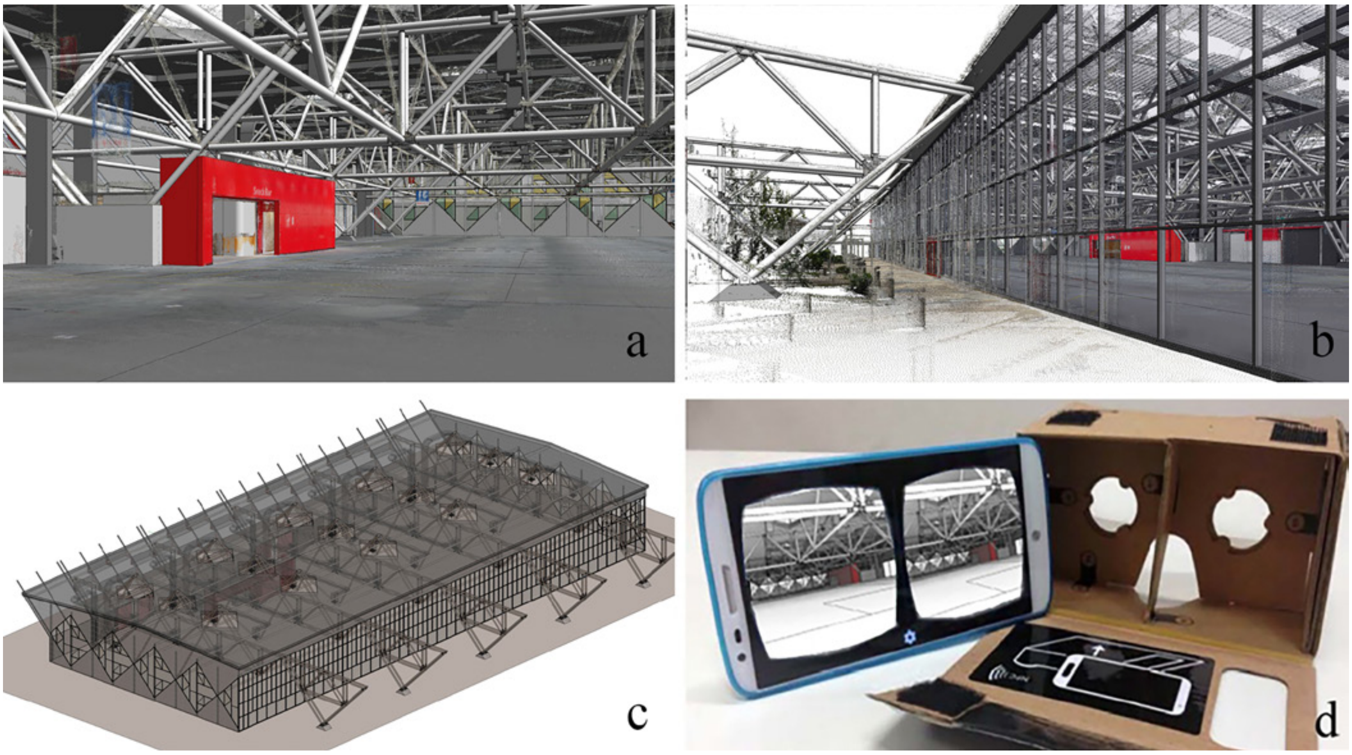

Figure 3: A cheap and feasible technology meant to experience digital models into a Virtual Reality environment. A simple VR app for smartphones is able to replicate into a dynamic stereoscopic view the BIM model (d), made of aggregated semantic components (c), authored from a superimposed TLS point cloud (a, b). The smartphone's sensors detect all the head movements, so the model view is changed accordingly (Survey campaign, data processing, app development and BIM model of Bologna Fiere's Pavillion no. 31 by S. Garagnani, 2017).

it can be used to filter information for various stakeholders (maybe interested in restoration or preservation), thence it can be made of parametric "smart" components, slightly lighter in computer's memory and much more editable than point clouds or polygonal models got from the surveys.
Following a methodology aimed to translate digitized data sets into segmented elements , many experiences carried out on some case studies during last years on historic buildings can be proposed as a reference in order to express a proper digitalization for the existing domain. The applied and severely tested pipeline basically consists of four stages during which architectural monuments are surveyed with high definition techniques, then properly segmented and finally replicated in their complexities using some software specifically developed.
The first stage of the process is the survey, in which architecture is captured in its morphology, where materials, colors and shapes are documented using digital techniques that often produce point clouds. Modern BIM applications are not designed for this task and, generally, they can import unreferenced pre-processed points as explicit "snaps". Edge detection on registered point clouds has to be often applied to identify components' boundaries and separate them from the heterogeneous, unsorted data set.
During this stage, points belonging to different elements can be simplified following an almost manual semantic attitude, even if topologies, relationships with other components, materials and assembling techniques inferred by human operators cannot be directly transferred in BIM modelers.
In the third stage of the process, registered and divided objects can be studied along with their relationships, their features and materials as these aspects represent important peculiarities of components. In a consolidated approach, segmented point clouds can be used as sort of geometric scaffolding useful to trace regular parametric elements on the point cloud: this process is mostly done by hand, then heavily subjective, time-wasting and almost inaccurate. To bypass these criticalities, the final stage of the process involved three tasks: the geometry modeling of the components in BIM software, the assignment to shapes of their category and material properties and the declaration of relationships between components, as requested by BIM semantics.

Latest developments of software applications by commercial houses will probably make this approach easier to be applied in the near future, however, the BIM process (long before the BIM software) already represents a paradigm shift for the architectural documentation and investigation.

CONCLUSION

If the digital transformation has a powerful development driver in the BIM process, the common language that would allow data sharing becomes extremely important dealing with the built scenario: it is also remarkable the idea, already expressed by Marvin Minsky in 2007, that information collected on the as-built constructions could be processed by machines themselves, following self-learning principles able to aggregate and analyze data according to precise mathematical rules. Simulations of possible scenarios starting from initial variables are just some of the uses that are fueling expectations and fears towards the most recent expressions of artificial intelligence. Terms like Virtual Reality (VR) or Augmented Reality (AR) are already part of many software houses commercial offers, to highlight the importance of real time digital simulations that are a direct consequence of space planning and architectural intents, as widely discussed by Park, Lee, Kwon, and Wang (2013).
But the most promising scenario for the digital transition in the built environment is perhaps the data interpretation as a prerogative meant to be a human exclusive no more: when most of the knowledge contents about buildings and monuments will be no longer intelligible only to the human perception, but they will be extended to the machine through a shared digital language, analysis, estimations, different intents and different operational schemes will probably allow the choice of the right intervention through many alternatives, leading to an increased quality for restorations and renovations.

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