This paper presents a first critical framing of 3D digital reconstructions of lost buildings, hence focusing on reconstructions using 3D models. This critical framing is constituted by reflections on definitions, concepts, methodologies and digital technologies. Much experimentation in the digital reconstruction of lost buildings has produced valuable results during the last twenty years, but the variety of methods, software types, and purposes should be reorganized into clear operational protocols to allow sharing of information and collaboration across disciplines. We have therefore investigated the diverse approaches towards digital reconstructions of lost buildings and found that digital reconstructions are not typically aimed at simple visualizations: they are often further developed in virtual environments, information systems and tools for simulations and analysis. In this sense they are not products but instruments for further research and/or heritage conservation. Counter the large number of theoretical positions, methods and tools specific to different disciplines, such as architecture and archaeology, we can find the almost total absence of a comprehensive critical assessment. This paper, which is part of a larger project, intends to open and articulate a debate on how to define, analyze and critically systematize the methodologies for the digital reconstruction of lost buildings.

**Keywords:** Digital reconstruction, lost buildings, 3d modelling, information systems, virtual environments.
projects have also been consulted. This preliminary study has made evident the variety of characteristics of this research field. Lost buildings and their forgotten stories have always attracted the cultural interests and curiosity of scholars and lay people worldwide. An early example in which 3D modeling software is applied for lost buildings can be found in the Old Minster in Winchester, UK [1]. A long list of similar research initiatives have applied 3D modeling and virtual reconstructions to a wide variety of no longer existing buildings and cities from the medieval church of Cluny III, to Dudley Castle and the ancient Rome [2]. A digital reconstruction process of lost buildings is constituted by several aspects and steps; hence the main question is related to how to critically systematize this variety of heterogeneous information. As far as we know, this work represents the first such critical framing that tries to consider 3D digital reconstructions of lost buildings in a more comprehensive way. Most of the previous publications are focused on the description of individual research projects, however there are some exceptions. One of the most relevant is the first chapter of the publication by Novitski (Novitski, 1998), which is entirely dedicated to lost buildings. This section of the book presents descriptions of several case studies pertaining to various geographic locations, historical periods and building typologies, including classic Greek theaters, the Columbian village of Ceren, the palace of Kublai Khan and the Larkin Building designed by Frank Lloyd Wright. Each project was developed by scholars and experts with different backgrounds: students, archaeologists, architects, architectural historians; every description includes also information about the main aims, sources and names of the main software packages used. Nonetheless, the main aim of Novitski's work is to describe a selection of lost architectural treasures brought back to light thanks to modern digital technologies, especially 3D modelling, rendering and animations. Hence, there is not the explicit objective of systematizing digital reconstructions of lost buildings. Other publications are focused on specific typologies of buildings and historical periods, such as lost palaces [3]. This research deals with virtual reconstructions of historical, courtly architecture from medieval and early modern periods. Other studies (Anderson et al., 2009) focus on specific technologies (in this case game technologies applied to serious games) in a chosen field, cultural heritage. However, the piece of writing describes serious games in cultural heritage, whereas we aim to focus on technologies applied to lost building in general. We propose here to organize the digital reconstruction process by replying to three main questions: what, why and how (Figure 1). These three questions define the main aspects of digital reconstructions of lost buildings and at the same time can be used to build up a first critical frame for research. Next sections will elaborate each of these three questions, respectively (definition and analysis), whereas the concluding sections build up the targeted frame for the digital reconstruction of lost buildings (discussion and conclusion respectively).

Figure 1
The three main questions that address the digital reconstruction process of lost buildings.

WHAT: LOST BUILDINGS
The expression "lost buildings" identifies buildings that have lost their original form and that pertain to one of the following three categories: partially lost, totally lost and transformed. The word "building" is here used in a wide multi-scalar way to include both single buildings and artefacts, designed by professionals and vernacular, and settlements from small villages to cities. However, we are aware of other definitions that include, for example, unbuilt projects (Glancey 2015), but these buildings deserve a future specific publication. It is important to define a classification, because for each category a different methodology may apply. We are proposing three general categories that represent what kind of lost buildings can be modelled, namely: totally lost, par-
tially lost and transformed (see Figure 2). The main conceptual, theoretical and methodological approaches towards the digital reconstruction of lost buildings lie within disciplines such as architecture and archaeology. The methodologies of reconstruction are conceptually related to the restoration theories and to the methods of architectural history. This requires any reconstruction to have a scientific basis, using literary or visual documentation, as well as physical evidence of the remains on site and other surviving parts. The typical example is the reconstruction of archaeological remains, starting from the building foundations and ruins, which can be identified and dated thanks to literary documents and artefacts found in the excavations. This example leads the discussion to four crucial questions that represent likewise lines of investigation:

1. How to represent conjectural parts (missing parts) from the ones that are certain (existing remains), how to indicate the level of uncertainty, and how to allow testing different reconstruction hypotheses;
2. How to provide information about the reassembly of parts conserved in different places, for instance when frescoes and sculptures integral with the architecture, but also objects of daily use, are stored in musea or private collections. This situation typically occurs in archaeological projects again (the Parthenon, or Pompeii houses), but other cases exist as well, for instance for the Chicago Stock Exchange;
3. How to document the evolution of the site over time: archaeology always uncovers a number of layers belonging to different phases of existence (while the classic graphic reconstructions show buildings frozen at a particular time in history);
4. How to link or refer the reconstruction to the documentation that forms the scientific basis and the socio-cultural context of the site. This is an essential question for academic research work as well as, in a different form, for cultural
tourism or secondary education.

All these points cover important lines of investigation about lost buildings, especially the more traditional ones in archaeology and architectural history, but represent only part of the studies that can be undertaken. For example, in presence of totally lost buildings, the first two questions should be formulated in a different way, because their remaining evidences are the sole archive records, which can be more or less complete. The lines of enquiry can be focused on other aspects, such as 3D digital reconstruction of no longer existing buildings within their urban context (Martens et al. 2010), or the study of complex geometries of dismantled pavilions, such as the one designed by Le Corbusier for the 1958 Expo Exhibition held in Brussels (Sdegno, 2012). Moreover, in disciplines such as architecture, studies on lost buildings are not limited to historical investigations. Digital reconstructions can also be more design oriented such as in Di Mascio (2010). In this research the massing model of the fortified center of a medieval village, destroyed by an earthquake, was digitally reconstructed using historical plan views, historical pictures and photos collected during onsite visits (Figure 3). The digital model has been used to identify tangible and intangible memories, such as shape and size of alleys and buildings, and the perceptual aspects on the alleys, that can inform the reconstruction of the fortified center (Di Mascio, 2010). We can summarize the main objectives of digital reconstructions of lost buildings under four categories:

1. Historical/archaeological research;
2. Visualization and information systems for cultural tourism;
3. Experiential virtual visit of totally lost sites;
4. Documentation and analysis for conservation and reconstruction.

From the above, we are able to extend our framework for digital reconstructions of lost buildings with an additional decisive step, namely the why of the digital reconstruction, which consists of a specific overall purpose and a preliminary definition of a number of particular products that are aimed at. We have outlined seven types of products, which then result in the diagram listed below in Figure 4. However, these products also represent further practical applications of the 3D digital reconstruction that use specific methodologies and software packages and as such they will be further described in the next section.

**HOW: THE DIGITAL RECONSTRUCTION PROCESS**

As previously mentioned, the choice for a specific digital technology (‘why’) is influenced by many factors, from the conceptual and theoretical approaches, methods and tools within each discipline such as architecture or archaeology. For this reason, it is useful to highlight the main phases that characterize the digital reconstruction process and study of a lost building. We can then indicate to what extent this digital reconstruction process is realized for particular types of buildings (what) and particular purposes (why). The following three phases are consid-
ered (inspired by Pauwels and Di Mascio, 2014):

1. Data Collection and Analysis
2. 3D Digital Reconstruction
3. Multifaceted applications of the 3D model (documentation, analysis, and enrichment)
4. Dissemination

**Data Collection and Analysis**

Every digital reconstruction starts with a data collection phase in which the main objective is to gather information to support the modeling process. Besides traditional tools (on-site measurements and data collection, both intrusive and non-intrusive), 3D laser scanning technologies and photogrammetry techniques have become mainstream in the last fifteen years, and have greatly augmented the quantitative knowledge of important buildings and sites (see for example the Cyark archives [4]). Both techniques allow digital modeling to start with very accurate georeferenced data (e.g., archaeological evidence) of morphologically complex sites. Every scan acquires morphological and dimensional information, represented by point clouds. These documents are converted through specific software packages into 3D surfaces and meshes or used as reference points to model 3D objects (surfaces and solids). The passage from point cloud to mesh remains an important technical challenge that is considered by a large number of computer scientists. The scans of remains located in different locations, also very far from each other, transformed in 3D objects, allow in a later stage to digitally reassemble the fragments in a process that can be called digital anastylosis (Thuswaldner, 2009; Chiuini, 2011). Because of the large myriad of techniques, devices, software and tools, however, the granularity, level of detail and quality of point clouds are often different and not appropriate for the particular object that is considered (too much or too little detail). Furthermore, the fewer the building remains are, the bigger the necessity is to search and collect other documents. In the case of totally lost buildings, the only references may be represented by archive records. The digital reconstructions of the Synagogues in Vienna, entirely destroyed in 1938, are example cases of this situation (Martens et al., 2002). In this latter case, the available drawings are often redrawn in vector format, in software such as Autodesk AutoCAD, to be used as reference during the 3D modeling.

**3D Digital Reconstruction**

The main objective of the 3D digital reconstruction phase is to digitally recreate a 3D model of the considered object. The whole process is influenced by three main concerns: the collected data (and the way of collecting them) during the previous phase, the features of the object that should be modelled and further applications of the 3D digital reconstruction (connected with the purpose of the digital reconstruction, why). The digital reconstruction also has its own value because it allows elaborating hypotheses and evaluating them through 3D modelling; hence it typically represents a moment of investigation. Levels of detail and objects organization are strictly dependent on the final aims of the project. A digital model created for the purpose of investigating the constructive characteristics of a vernacular building (Di Mascio, 2013) or of an historical skyscraper (Chiuini, 2011) has a different geometrical complexity, level of detail and organization of elements compared to a model aimed at simulate crowds’ behaviour along the streets of an ancient city (Maïm et al., 2007). 3D modeling software, such as 3ds Max and Maya, are widespread solutions in digital reconstructions processes. In recent years, also BIM software is being applied to heritage projects. However, the use of a specific software package for the digital reconstruction process is strictly connected with the successive uses. The modeling process is a design problem: the design of an information system that can make us understand, in its multifaceted complexity, a lost building, site, or place.

**Further applications and analysis of the 3D model**

The result of the digital reconstruction process can often represent the starting point of further work that
can have several purposes. This work can to some extent be articulated in seven main branches that identify further applications and analyses of the 3D digital model: analytical representations, photorealistic visualizations, information management systems, documentation, simulations, augmented reality, virtual reality.

**Dissemination**
The dissemination represents the last phase, but not the least important; it can be the main aim of a research project or the final step, where part of the findings are packaged in ways that can be easily experienced and understood by users. The results of the applications and analysis of the 3D digital reconstruction constitute the main outcomes useful to spread the information to a wider audience for different purposes such as cultural tourism and education. All these products can be displayed in museums, online or included in products such as books or DVDs. To conclude, the digital reconstruction process typically goes through four practical key phases, namely a data collection and analysis phase, a digital reconstruction phase, a further application of the 3D digital reconstruction and a dissemination phase. Very diverse options exist in all these four phases, as is schematically displayed in Figure 4. In order to make appropriate choices in all four phases about the way in which the digital reconstruction process should take form, one should closely bear in mind the 'what' and 'why' of the digital reconstruction process.

**PRODUCTS OF THE 3D DIGITAL RECONSTRUCTION**
Of course, in many cases, the 3D digital reconstructions of lost buildings are directly aimed at producing specific product outputs. These are further applications of the 3D digital reconstruction that form part of the reasons why a lost building is digitally reconstructed. Of course, as can also clearly be seen in the last section, these products are closely linked to the actual purpose of the 3D digital reconstruction. The end products should always be devised and produced in service of a particular purpose, whether this be data collection for conservation or restoration projects, 3D graphic representations for touristic visits, historic documentation or other. Diverse multifaceted uses can be identified for a 3D digital reconstruction. On this basis, we are proposing seven categories that represent further applications and analysis of the digitally reconstructed lost building. These are very diverse products. Choosing to aim for any number of these products should be done soon enough, in combination with defining the purpose of the digital reconstruction. Namely, these products all use some form of 3D or data, but they are very diverse in nature and typically require a specific way of modeling. In other words, in order to produce any of these products ('why'), one will need a different digital reconstruction process ('how'). Furthermore, some products ('why') may be more appropriate for lost, partially lost or transformed buildings ('what'). Furthermore, each of these applications can be combined with the others.

**Analytical Representations**
These analytical representations allow to analyze, document and communicate only a few aspects of the building. Thanks to these graphic drawings it is possible to split the characteristics of a building to better study and represent them individually or in sub-groups. Consequently, attention is paid to one or more aspects, isolated from the whole building and analyzed through one or more graphic works. In fact, an overall view of the building can limit the analysis of a particular characteristic. Axonometric exploded views to study the aforementioned constructive characteristics of buildings are example analytical drawings. In (Webb et al., 2011), digital representation techniques, inspired by forensic analysis, are used to investigate, specific lines of enquiry related to selected features of a building.

**Photorealistic Visualizations**
This is the traditional approach that aims at very accurate architectural and realistic visualization of the lost building, including the lost parts. The reconstruction
of Trajan’s Forum in Rome includes an archaeological investigation and a sophisticated modeling work (Packer 2001). A similar purpose has led the digital reconstruction of the Empire Exhibition held in Glasgow (Scotland) in 1938 and subsequently dismantled [5].

**Information Management Systems**

Recent work in the field of archaeology, cultural heritage and architectural history tends to move beyond digital 3D modeling into more specific technologies for knowledge organization. This includes data management, ontology engineering, multimedia systems, immersive environments, virtual and augmented reality and semantic information modeling (GIS and BIM). Thematic modeling integrated with GIS is becoming common practice in archaeology. Human interfaces, interaction and usability have become an essential component of reconstructions. The 3D model can also be enriched with information pertaining to any knowledge domain using semantic web technologies. The model can become an information portal, designed to allow updating and alternative interpretations.

**Documentation**

The model allows producing architectural graphics and other information for historical studies, conservation, restoration or adaptive use. Rendered images and animations of the digitally reconstructed portion of the cornice of the Chicago Stock Exchange Building documented the relationship of the terra cotta envelope and the steel frame that resulted from the 3D digital reconstruction phase (Figure 5). The modeling developed effectively as a heuristic process, which revealed how an entire row of terra cotta blocks had been damaged during construction because of lack of coordination between the terra cotta production and the steel design. When the digital terra cotta blocks were positioned on the model of the frame, it appeared that all blocks below the coping had been chiselled on the back at the same level, which was confirmed by visual inspection of the fragments. The portion removed from each piece lined up perfectly...
with a horizontal steel angle mounted at the top of the steel brackets. This work, perhaps hastily executed while setting the terra cotta on site, cracked the material causing water infiltration over time (Chiuini, 2011).

**Simulations**

Simulations can be interactive (e.g. for training purposes) or devised for specialist applications (bearing structures, lighting, acoustics, etc.) and can use different technologies such as virtual reality.

**Augmented Reality**

Augmented reality applications allow overlapping the virtual model on a real site using a portable/wearable device. In (Madsen et al. 2015) an augmented reality installation, that includes two interactive devices (a tabled connected to a large TV screen and an hand-held tablet), has been developed to allow people to experience the visual appearance of the lost interiors of the chapel of Koldinghus Castle in Denmark. The chapel was destroyed and reconstructed several times and what people can see today is a ruin resulted of a basic restoration undertaken in the 1970s (Madsen et al. 2015).

**Virtual Reality**

Despite how it may seem, virtual tours have been around already for several years. In fact, it was possible to experience, for the first time, a virtual tour already in 1994, in the visitor center in the remains of Dudley castle in the West Midlands, England (Boland et al. 1996). This first virtual tour anticipates the recent, and for several aspects, more advanced real-time virtual and interactive tours using game engines technologies that have widely spread recently. Digital modelling in general is today also conceived as a way to embed information in a three-dimensional representation of the physical world. The use of game engines and VR device allow to navigate and explore the reconstructed buildings in a virtual environment; it can include interactive components and metadata. The integration of dynamic systems and physical simulations such as gravity allow a realistic experience. The reconstruction of Hadrian’s Villa [6] focuses not so much on architectural accuracy, but on the analysis of astronomical alignments with specific artifacts on site, using the NASA calendar for the year 125 CE. Also digital characters (avatars) provide realism to the experience by moving and talking. This type of model can be used at different levels: for the general public and for the historian. It is not just a visual representation of a space, but an instrument to analyze the architectural design intentions and historical hypothesis in an interdisciplinary environment.

**A CRITICAL FRAMING FOR 3D DIGITAL RECONSTRUCTIONS OF LOST BUILDINGS**

The overall diagram displayed in Figure 6 now provides an excellent resource to compose a visual framework in which many existing and forthcoming digital reconstruction of lost buildings can be categorized. The diagram is composed by three main parts that represents likewise questions and important phases of a digital reconstruction process of lost buildings: what, why and how. The first column is related to what. Hence, at the beginning it is necessary to identify the lost building that is to be modelled and its degree of loss. Reason and the identification of the building/site type are useful to provide both a more comprehensive overview of what is to be modelled and clues to search reference buildings that are essential for filling the unavoidable information gaps. The second column refers to the purpose of the 3D digital reconstruction, namely why we are undertaking this kind of study. At the same time, it is possible to define the products that we are aiming at; they represent a concrete reply to the purpose. However, this is still a planning phase that can be updated and modified afterwards according to the available documentation. The last part of the diagram is constituted by the four key phases from Data Collection to Dissemination passing through the actual 3D Digital Reconstruction and its further applications. The how phase is oriented in the practical creation of a final product that replies to a specific purpose and dis-
CONCLUSIONS AND FUTURE DEVELOPMENTS

This piece of writing presented a first critical framing of 3D digital reconstruction of lost buildings based on the result of an examination of example projects and personal experiences in the field. The big amount of research about 3D digital reconstruction of lost buildings, developed in a span of over 30 years, presented a wide variety of theoretical positions, methods and tools influenced by disciplinary areas such as architecture and archaeology. However, counter this amount and variety of research, we found the almost
total absence of a comprehensive critical assessment. This piece of writing proposes a critical framing that suggests a way of organizing these research initiatives by replying to three main questions that define every digital reconstruction process: what, why and how. We recognized that the category of lost buildings (what) is not restricted to heritage but consists of every building, including the pavilions of recent world fairs. For this reason the theoretical approaches, the aims (why), and the technologies and methodologies (how) can be varied and not confined to archaeology and architectural history, even if these disciplines represent an important number of investigation. Moreover, the piece of writing identifies a set of products of the 3D digital reconstructions that form part of the reasons why a lost building is digitally reconstructed. These products are the result of further applications and analysis of the 3D digital reconstruction; they show, organize, communicate, deepen and enrich the knowledge about a specific lost building for several purposes. This first critical framing constitutes the basis of further studies, such as a state-of-the-art review.

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