States of knowledge: a basis for a spatio-temporal model of cultural heritage information.

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Abstract

Modelling cultural heritage information is a common requirement when considering heritage documentation. The digital documentation is now considered as the first step to heritage conservation. The replication of a geographical information model to cultural heritage information is not trivial. Most of proposed spatio-temporal information models do not encompass the diversity of some complex situations encountered in heritage documentation. This diversity remains both on the strong relation of heritage information with time and the necessity for researchers to record not only physical remains but also the planned projects that may never occurred or virtually reconstructed objects for which geometric information is incomplete. In this paper we propose a spatio-temporal information model that considers heritage objects that existed in the past, continue to exist, were planned or planned and never realized. This diversity is of a high importance for heritage research where the relationships between actual space and past states of planned project is their main concern. The developed model is based on the distinction between the existence, the physical realization and the geometrical definition of modelled objects. The proposed model defines the concept of state knowledge which is a cumulative representation of the documented information related to build heritage.

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1 Introduction

During the last decade, the techniques of documentation for cultural heritage have grown exponentially. The multiple recordings using such techniques provided a huge data quantity that has to be managed in order to retrieve easily and quickly required information for heritage researchers that are not IT experts [14]. Technologies such as laser scanning, photogrammetric reconstruction is now standard in most of restauration projects dealing with built remarkable heritage [20]. On the other hands, the heritage research opened to

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the field of geomatics and recognizes the digital documentation more than a simple tool but as a part of heritage conservation process. The digital documentation is not only a way to acquire geometric information in order to derive plans and maps or to propose some nice virtual visits of recorded objects. Digital documentation leads to a real conservation process and is capable to hold some heritage values as much as the real object [26, 19]. Usually, the restoration process of a recognized heritage building is based on the conservation of the values hold by the edifice [24]. Note that the values evaluation is also discriminant to define which building or site has to be preserved or not [15, 5]. The restoration or possible change of affectation has to be think to respect the initial values that was carried by the edifice. This does not impose to keep exactly the same uses but to respect the architecture and as much as possible the sense given to the place. Reporting some value to the digital representation of an edifice change the rules. The architect in charge of the restoration is consequently less constraint in term of possible reassign and building transformation since each edifice characteristic has not to be conserved in the physical world. However, since the digital representation cannot replace all the values of an edifice, it cannot serve as an excuse to destroy preserved heritage arguing that the digital representation will "replace" it. Unfortunately, for a lot of building the digital representation (for example, acquired by a survey) is the only remains of the edifice. As far as a digital representation stands for a place holding some building characteristics, the representation has to be strongly documented, performant, sustainable. Indeed, a poor digital model could conduce to a quick loss of the hold values. This explains why heritage documentation focuses on the development of spatiotemporal geographical information systems as building information modelling components. They both propose reliable systems in which the information description ensure a big part of the required information sustainability. Several developments, such as [21, 13], work with a formalization of time that encompass a significant part of the cultural heritage information necessity. However, such approaches are not initially tailored to answer at cultural heritage information requirement, specifically in term of querying different temporal building's snapshots. Dedicated approaches are more relevant in term of archaeological information system [16, 2, 3, 22]. Heritage building restoration is sometimes performed through modern planning tools based on building information modelling software. The building information modeling (BIM) allows to attach semantic information to constructive elements and manage their behaviors within the system following the semantic properties. This approach is extremely useful when different user's domain interact with the 3D model in order to track any changes that occurs during the planning phase and to ensure the consistency of any modification in the model [1, 9]. In the BIM environment, there is a strong disconnection between the current state of the building and its planned construction phases. Despite some visuals links between the two version, there is not a strong relationships between existing states and planned transformation. Moreover, the multiple representation of successive past states is hard, even frequently impossible. Finally, as argued in [18] heritage documentation gain at working with multiple geometry representation of modeled elements. In his approach, Poux proposes to transfer as most semantic information to the point clouds, which is the most representative of existing building state since it is acquired by this way. Building Information Modelling systems only support point clouds as a background layer in order to allow a parametric modelling of the environment. Such approach does not ensure a sufficient geometric level of details and generalize the survey granularity into flat or parametrized surfaces [7]. On the other hand, Archaeological Information Systems trends to model historical information with multiple dimensions as space, time and thematic [2]. Such systems sometimes take into account information uncertainty that results of a source interpretation. The interpretation frequently leads to different scenarios of what could be the evolution of an entity in time. Recording theses multiple tracks is not a trivial task and is formalized in [23]. All the described approaches still require some improvements to pretend at being the right system to fully encompass the digital heritage information. As explained before, this is of a major importance for cultural heritage since the digital documentation will be soon (and is already) the only remains of some heritages values in certain cases. If these systems miss their objectives of comprehensive knowledge representation, we face to a loss -as important as- a real built heritage destruction. In this paper, we do not pretend at proposing the right system but to open the reflection on a specific data model that focuses on the distinction between planned and realized objects. The knowledge of a heritage building is not only given by its physical components. Although the survey and the modelling of existing remains is primordial, it is not sufficient to pretend at fully encompass the building history. In addition to the sources that gives historical information of how was the element, there is frequently planned projects of rehabilitation, transformation,... which are not necessarily enforced. For some of the latter, they even influence the actual space or others subsequent projects. Recording the complete history of built heritage necessarily goes through the recording of all these "never constructed" projects.

The next of the paper is structured as follows. The section 2 presents a distinction between existence and presence of objects following the model proposed in [11, 10], and the basic ideas that guides the model construction, namely the cumulative states, the mereological relationships between elements, the event-based change and the distinction between geometry and location. The section 3 explains the proposed data model constructed following the previous enumerated statements. Then the section 4 draws some uses perspectivesand futures developments in the context of a destroyed recorded building. Finally, we conclude.

2 Model Fundamentals

2.1 States of knowledge : Distinguishing existence and presence

The spatiotemporal states (STS) model that has been proposed in Hallot [12, 11], aimed at defining the spatiotemporal states of a geographical object in considering all their possible evolution in time, from their identification to their complete destruction. Indeed, for most of spatial relationships such as the 9-I model or the RCC, the spatial relationships draw relations between objects that are supposed to be existing and visible for the analysis. If an object is deleted from the system it will not be possible to calculate its relation with others objects. However, this limitation has to be overcome when considering cultural heritage documentation since the current spatial situation is, most of the time, explained by some built elements that was existing and which are now destroyed. Such anachronistic relationships between an object that exist with another object that does not exist anymore in the real world has been proposed in [11].

Based on the spatio-temporal states of identity model initially developed to encompass all the diversity of geographical object evolution across space and time, we propose to make a distinction between the existence and the presence of a built heritage element. The taxonomy which serves as a basis for the model is driven by the difference between design and constructive steps. The proposed steps symbolize a cumulative state of knowledge where the accessible information for one object grows from one step to the next one.

- First, an object is designed towards a mental experience. At this stage, there is no definition of its location or its geometry. The designer only define an object identity that will be linked to others existing objects. Since the identity of an object is defined, we assume that the *object exists*. This definition is sufficient to establish relationships with others elements. For instance, if an extension is planned in a heritage building, there is a relationship between the planned project and the building. The object when only defined by its identity can also support relationships with physical environment and serve as a basis for every legislative procedure. In a lot of cases, objects remains at this stage since the project is abandoned or is not compatible with the constraints (legislative, financial, will of the owners...).

- The second step is the definition of the spatiality of the element. The definition of the shape of an element is known as the *designed object*. The design focuses on the definition of the geometry of every parts constituting the planned project. Based on this definition, it is possible to sketch new relationships especially with the existing environment to check the consistency of the project. Anew, a significant number of project are abandoned at that step. Indeed, attribution of a spatiality to the object allows, for example, to estimate the costs, the structure… The defined constraints are therefore analysed on a more restrictive basis.
- The third step is the *planned object*. This situation is quite close from the latter one except that the localization of the project in the environment is defined. The planned project is the most known phase from a user perspective. We acknowledge that during the design of a building or an extension, there is several round-trips between the design and the planned project phase. This step has to be seen as a state of knowledge that cumulate the information of object identity, geometry and spatiality.
- The fourth step symbolize the physical realization of the planned project. The object is considered as a *present object*. A this stage, the designed spatiality is materialized though the construction. A link is established from the object as conceptualized to the constructive elements. Depending on the care taken to the construction, the physical realization is quite close or not of the defined element. Each future transformation supposes to go through every previous steps since it represents a new built element. As far as the changes occurring in the physical world is documented and does not derivate from its formal representation, the link between the planned project and the physical realization remains. For most of built archaeology analysis, this link is not existing and has to be retrieve though a historical analysis.

The figure 1 express the different states of knowledge related to build heritage object considering the proposed taxonomy. Starting from a *void object* (?A), its definition lead to the attribution of an *identity* to the object (iA), the object "exists". When applied to heritage documentation, the relationship between the two states symbolize the discovering of new sources describing the existence of an object but without any information on its spatiality or location. At the end of the process, when every information related to the past existence are lost, the object is "forgot" and its identity disappears. The *designed object* represents the definition of an object geometry without replacing it in its context. There is no link with the geographic location of the object. Indeed, there is a lot of sources and planned project that are discovered in archive without information about the supposed set up of the project. Once a link between a designed project and a context can be establish the object is considered as a *planned object*. In the context of heritage documentation, this represents a lot of sources and the best state of knowledge that researchers can expect for every destroyed objects. The knowledge of the geometry and the location of the objects is known. The "physical realization" is the link between a *planned project* and its *presence* in the real world. Each archaeological remains or heritage building owns a "physical realization"

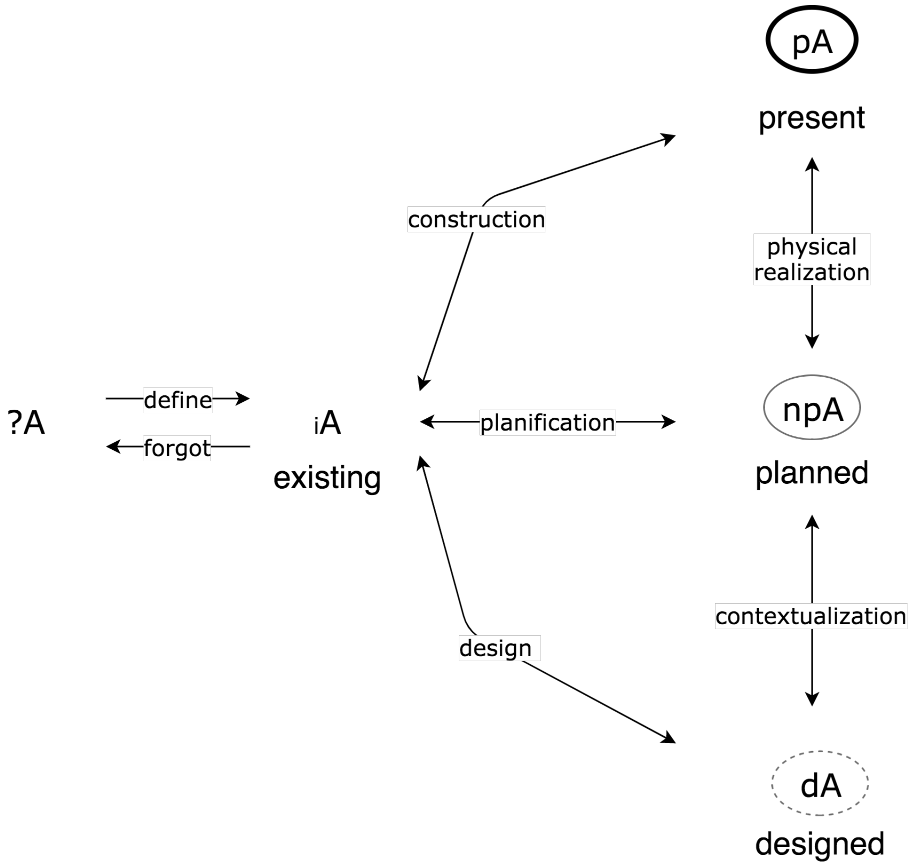

Figure 1 Representation of the state of knowledge related to a built heritage object across time. The relations shows the transformation that the object encounter to change of state.

and then classified as *present*. Even if the design of a present building is not known, it can be retrieve by a survey operation, this is a case of "contextualization". Some questions about the difference observed between the planification and the construction due to a default of construction or the absence of as-built survey remains but are out of the scope of this paper.

2.2 Cumulative temporal states

Changes occurs frequently in cultural heritage buildings. They are continuously restored or transformed to preserve or to assign them new functionalities. Considering the research on object identity [18, 19], we state that the identity of an object does not change if a part of it is transformed. The identity of a building does not change if some transformations in the building occurs. For example, the construction of a building extension or a restoration of the electrical network does not change the identity of the element (see figure 2). However, the state of the building change each time that a transformation occurs. The state of an element is defined as a triplet linking a time, a geometry and a set of semantic attributes such as the functions, the constructive elements, the owner, ... Each change in one of this values lead to the definition of a new state of the object which symbolize the transformation. The proposed time interval refers to the temporality of the triplet. Indeed, we do not define an *a priori* temporal validity of states since several interpretation of successive states can lead to different valid propositions. An approach of multiple interpretation can be found in [23]. In order to keep the identity over time, we gather the two concepts using a composition relationships. The heritage object is defined as the set of every states that compose its history. It is a container of all the known history for the object. In doing so, the identity of the object is not re-defined each time a change occurs to the object. The states are also characterized by a timestamp stating the interval of time during which the state is considered as valid. Note that several states can share a same time interval, this is like considering a multiple interpretation of object history. Such multiple interpretation approach have been discussed in [22, 23]. The

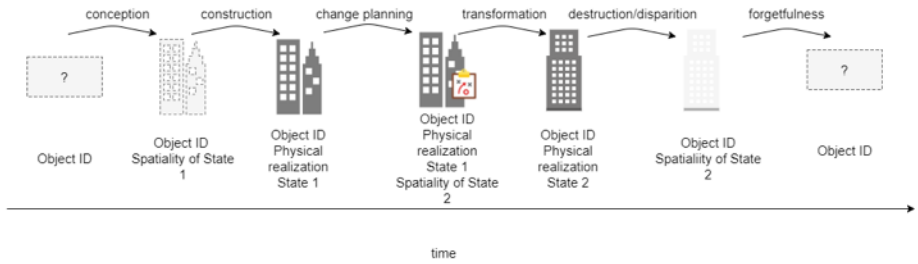

Figure 2 Successive states of an heritage building. Inspired from [10].

figure 2 shows some successive states of a building which is transformed in time. In regards of cultural heritage documentation, a complete knowledge of historical building states is not frequent. Indeed, it is not easy to retrieve a complete historical information in regards of an edifice if a heritage documentation procedure is not set up initially with the building design. Researchers frequently face to a lack of information and needs to establish some hypothesis on the succession between states. The concept of an heritage object which gather temporal states helps to connect all known information through the object identity. The concept is proposed at figure 3. Each object state has its own identifier key and the heritage object keep an identifier which remains stable over time. Going deeper in the analysis and following the paradox of the "Thesee's Boat" [8], we might face to an incoherence if the successive transformation impact so greatly the objects that the final shape, properties, functions does not correspond at all to the initial identity. To overcome this limitation, we propose to report some essential properties to the Heritage Object class. If a change occurs to theses n *fundamentals properties*, then we consider that the object has change of identity and that it is a new object. The n *fundamental properties* can also be calcultated in order to measure the rate of change of one object. Among a fixed threshold, the object objectif identity has to be changed. Note that the change of an object identity does not break the link with the previous objects that generated it.

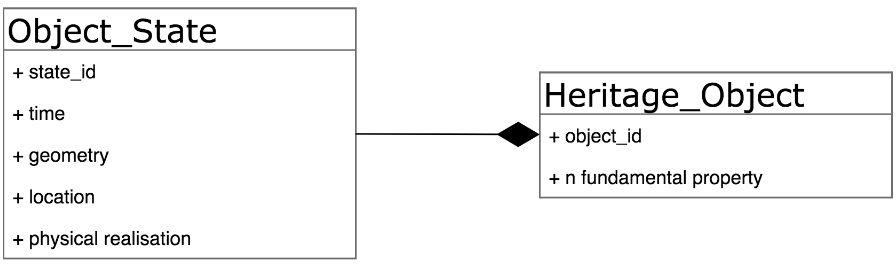

Figure 3 Model for cumulative state of knowledge to compose a heritage object. Each object states gathers together to compose the Heritage Object.

2.3 Mereology for built heritage

The heritage documentation focuses on the description of the whole edifice or on a specific part of it. The historical sources or the surveys that document the built heritage frequently refer to a portion of space related to a specific transformation, restoration etc. These information might have no sense if reporter to the whole building [25]. For example, the description of a specific constructive element as a brick in the wall of a specific room of a three story building does not need to be related to the complete edifice but to the specific wall into the specific room. The relation linking such parts to the whole is described through a mereological relationship linking parts to whole. The part-whole relationships has been extensively described in [25]. They propose a taxonomy of 7 classes for the part-whole depending on the type of objects they are applying and the sense given to the relationship. In our case, since the parts are distinguishable from each other, the parts have a formal existence by themselves, we associate our relationship to the component-integral relation as described by Winston et al. The mereological relationships is also necessary to retrieve the parents of a referenced object. The historical analysis of a heritage object can take place in a context and new links can be established depending on the successive mereological relationships. For example, considering a brick which is a part of a wall which is a part of a room can infer the new information that the brick is a part of the room. The historical reference related to the brick can be transferred (if it makes sense) to the room. This representation of heritage information make sense when considering a user perspective in the heritage documentation. Usually the documentation is not realized by a single domain perspective. The documentation gathers observation from archaeologist, art historians, architects, built archeologist, historians... They all have preformed an analysis which is based on a dedicated building division. Despite the simple approach of the part-of relation, it allows multiple domain division and a structuration of the information on a hierarchical approach. The proposed mereological relationship is represented in 4. The semantic division of a building is a complete research field where information norms such as CityGML [4] or IFC [4] can be transposed to build heritage. Documentation ontologies as CIDOC [6] might also be useful since they can help at referencing sources related to building elements in a heritage or archaeological perspective.

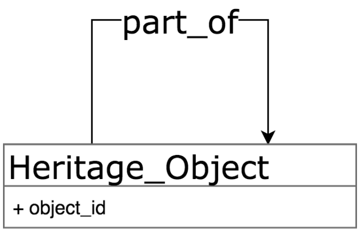

Figure 4 Mereological relationships established among heritage object. The part of relation allows to structure the heritage documentation information.

2.4 Event-based change

All the presented approach resides in the documentation of the changes that occurs in the built heritage. In heritage documentation, sources give information either on a static state of a heritage object or on an event that cause the change from one state to another. Documentation sources usually inform on the planned changes, such as planned works, transformations... As far as each changes in the attributes of the object's state leads to the creation of a new one, most of sources will so create a new state. To record this change description, a versioned approach is not suitable. We propose an event-based change description where the events are organized as objects that can be linked to a document or a historical source. The figure 5 represents the event-based approach as proposed in the model. An event links two states together. The first state is considered as the initial state and the second one as the modified state. In doing so it is possible to retrieve the history of a succession of modified states by querying the relation recursively a sufficient number of time. Uncertainty related to object temporality definition is not encompassed straightforward in the model. Some extension based on archaeological proposition will be considered in a near future.

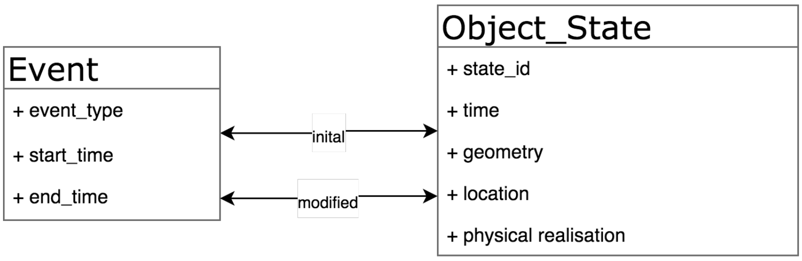

Figure 5 Event-based change modelling. Each changes are described with an individual event linking the initial and the modified state of the object.

2.5 Geometry is not location

As explained in the previous section, the evolution of cultural heritage object has to consider separately the geometry of an object compare to its location. When planning a project or analysing a sources, the shape of an object is defined or retrieved. In most cases, the link between the shape of the object and its location in the environment is not straightforward. Considering the transformation occurring to building's parts, each states holds a different geometry although the location of the whole building can remain stable. When considering historical sources, the retrieved information can inform on a geometry (the shape of the transformation) without giving explicit information on the location. Depending on the uncertainty of discovered information, the location can be considered as unknown if the location precision is significanlty higher than expected. For example, if the sources refers to a transformation that occurs in Europe, the location vagueness does not give information on the transformation location within a specific building.

3 STS-Model applied to Cultural Heritage

In this section, we combine the four proposed statement into a single useful model to manage all the diversity of built heritage information. The proposed model is dedicated to serve as a basis for a heritage documentation system. The development takes place in a specific framework that aims at proposing a virtual notebook for researchers from multiple discipline to gather all historical information in a same information system. This information system is designed to spatially reference every object's location (when available) on a 3D representation. The location in the 3D model has to be seen as an indexation scheme. Note that the

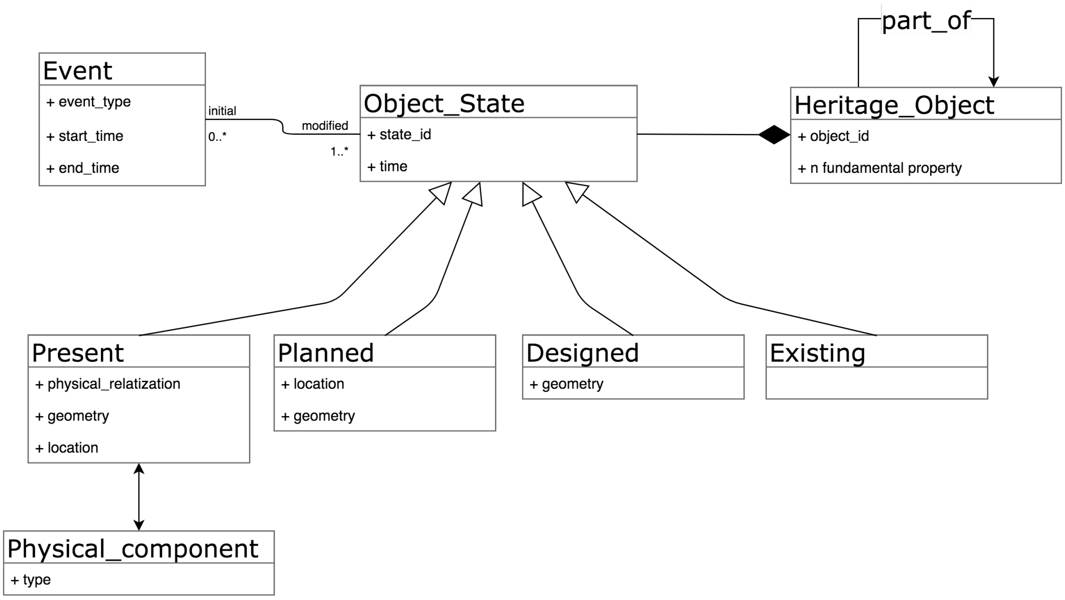

Figure 6 Conceptual model for cultural heritage object information management considering different states of knowledge related to states objects.

information which does not have a location is also referenced in the system through the object states.

The model presented in figure 6 shows the cumulative object states that compose an heritage object. The object state specializes in states of knowledge as proposed previously. Each state is linked to an event which is the container of the semantic information related to the modification that occurs to heritage objects. The states of knowledge are the *present state*, for an object that has a geometry, a location and which is related to some physical components (as concrete, a brick, a plaster...). The *planned state* is a state where the object has a known location and geometry but no link with a physical component. This is for example the case of a building for which we did a survey (i.e. with a known geometry and location) but that is now destroyed. The *planned state* keeps only the geometry and location in the system as a memory. Note that when an heritage object has a location, it implicitly define some object geometry. Even if the geometry definition is not accurate, it is at minimum defined by a point which can be considered as a first basic geometry. The *designed state* class gathers objects for which the spatial definition is known without location and link to a physical component. This is the typical example of a planned building part transformation where the exact location is unknown depspite the plan conservation. Finally, the *existing* state group objects for which only identity is known. For instance, cultural heritage researchers know that a transformation took place in an edifice but do not know the nature, the geometrical description or the location of the transformation.

The model links together two vision of the successive knowledge states related to an edifice. First, a constructive vision where the knowledge is constructed step-by-step according a classic scheme of existence, designed, planned and present object. The second vision is the reference of historical sources where the retrieved information related to heritage are rarely exhaustive. By definition, researchers face to incomplete knowledge and have to draw hypothesis to extrapolate what could happened between to temporal successive states of knowledge. By its construction the models is suitable for the latter vision. Each source is analysed in order to be classified in regards of the state of knowledge taxonomy. In this case, the knowledge related to an edifice is not necessary constructed in the ordered succession of states. The states of knowledge encompass the diversity of the historical sources that are usually referenced on a cultural heritage element.

4 Perspective and futures developments

This research takes place in the project VP-Num initiated at the University of Liège. This projects aims at studying the heritage values that building numeric representation can hold especially if it is destroyed or not accessible for a long period of time. The project focusses on two remarkable edifice of the city of Liège, Belgium. The first one is the "Collégiale Sainte Croix", a gothic church initially constructed during the XXth century and transformed several times during the XIVth and the XVIIIth century [17]. The successive transformation focused on building parts and finally completely changed its appearance ranging from Roman to Gothic style. This building is not accessible for the public for safety reasons. It will now enter in a deep renovation phases which will last for at least ten years. The second edifice studied in the project is the Hotel Rigo building. This building from the beginning of the XXIth century was a symbol of the rich aristocracy of the city of Liège. Due to urban planning necessities following the construction of a new railway station, this building has been completely destroyed. Actually, there is no remains that shows the former presence of a building at that place. In this framework, the proposed model will provide to researchers a framework where the two building can continue to be studied. For both of the two buildings we made a complete survey in order to create a digital 3D model in the form of a point cloud and they have been documented to propose virtual visits. Some intermediary results are presented in figure 7 and figure 8.

Figure 7 Panorama of the interior of the Hotel Rigo, Liège. These images helps at colouring the acquired point clouds from laser scanner devices.

The semantic information which is associated to the two building will be organized following the proposed model. For the first case, most of the building is in a present state of knowledge since the building is still in place. The relationships between the 3D documentation (the point cloud) and the building is valid. The Hotel Rigo does not share a relation with a physical element any more since it has been destroyed. The complete edifice is in a planned state, i.e. there is an information on the geometry, the location, the identity of the element.

Note that some parts of the edifice has been conserved. The saved parts are in a present states even if they location has changed. The Collégiale Sainte-Croix has fundamentally changed of shape during the past centuries. There is a lot of sources relating the existence of a primitive church, but only a few information on its geometry. Following the proposed taxonomy, the primitive church is in a existence state of knowledge. The only remaining information is its identity, since even its location is not known in the site. In the following

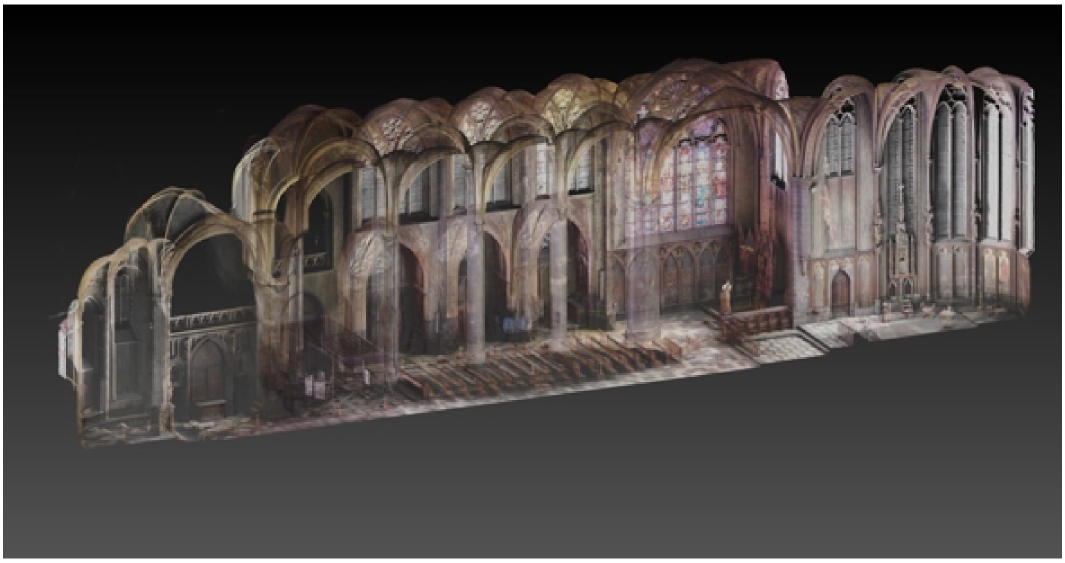

Figure 8 Subset of the 3D point clould of the Collégiale Sainte Croix, Liège Belgium. This survey has been realised in collaboration with the SPW-DGO4-AWAP and Jean-Noël Anslijn.

we plan to implement the proposed model and link the geometric information to a 3D model visualization tools. By the way, the researchers could also access to the information through the 3D interface.

5 Conclusion

The cultural heritage information is characterized by a strong relation with time and a frequent lack of information. These two fundamentals characteristics cause some difficulties to manage heritage information with standards geographical information or building information modelling systems. In order to encompass all the possible diversity in term of knowledge, tailored spatio-temporal data models has to be proposed. In this research, we throw the basis for a heritage information model that take into account the successive states of knowledge that the research can provide to an edifice. Instead of considering that historical sources are incomplete information, we proposed a taxonomy imitated from the cumulative states of knowledge that occurs when a building projects is realized. The taxonomy proposes a vision where the identity, the location, the geometry and the physical realization are the keys to classify the knowledge states. Moreover, the states are proposed to be a cumulative set that compose a more generic spatiotemporal object which is the heritage object. This allows to keep structured all the information in relation to an heritage building and not having to select or dispose of hypothesis when recording the information. The model will serve as a fundamental brick for a broader project related to the values hold by the digital representation of build heritage. During the last couple of years a lot of heritage building and site has been destroyed due to wars or ideological purposes. For some of them, a survey have been realized or a digital reconstruction can be done using photography. The digital representation of these objects is the only remains of their geometric description. As far as the conservation process cannot be performed on the physical object, we need to report the process to the digital representation since it is the last container of most heritage values. The heritage information models have to be modeled in that way.

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