Architectural Information Modelling in Construction History

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The past few years show a significant increase in the usage of three-dimensional modelling and semantic description techniques for architectural research purposes. Where this increase has already shaped today's design and construction industry, research in architectural and construction history can still improve its work methods and results through these techniques. Therefore, we propose a new conceptual approach for Architectural Information Modelling (AIM), which aims at describing historical information in construction and architecture directly related to design information and design practice. This paper will give an introduction into existing 3D modelling techniques and semantic description techniques, continuing with how these techniques are applied in the AIM approach.

This investigation of 3D modelling and semantic technology shows promising results. However, in order to integrate these techniques into an AIM framework, more work is needed. Future work in this research project will therefore explore in further detail the semantic description scheme proposed below and the implementation of a proof-of-concept.

INTRODUCTION

Typically large amounts of information are gathered and processed within research projects on construction history. The collected information is added to the researcher's specific project knowledge and applied to a particular question or problem. When the researcher is satisfied with the results, he or she will communicate this knowledge to various audiences. A particular interpretation is then made upon the information by these audiences. Given the large amounts of information often brought together, it is therefore important to consider the best communication methods, not only towards human users, but also towards information systems that process and reuse the information. The description and communication techniques deployed should be selected carefully, in order to ensure the most effective and error-free communication results.

Throughout history, description and communication techniques in construction history research typically build on physical media, such as books, textual sources, images, building plans, etc. Recent research in this field is, however, increasingly turning to digital technologies. One of the most representative examples of this development is the usage of three-dimensional, digital drawings of historical constructions. In a single three-dimensional model a whole structure can be built virtually and used for further documentation. By using digital techniques, significant portions of a research outcome become readable by information systems. This, in turn, provides opportunities for research via automated methods and procedures.

Compared to description and communication techniques deployed within other scientific fields, however, there are still significant improvements to be made. For example, today's architecture, engineering and construction industry shows improved automation capabilities mostly because of the usage of *semantic* description combined with three-dimensional modelling techniques (Eastman et al. 2008). Once a building is (re)constructed to a three-dimensional, semantically described building model, it is possible to process the information embedded in the model and automatically calculate construction costs, the energy performance level, an overall construction schedule, etc. (Verstraeten et al. 2008). Given our interest in the research of construction and architectural history, the overriding question in this article is to consider the ways in which the combination of semantic and three-dimensional modelling technologies can improve the quality and efficiency in the communication process within the research on historical information.

INFORMATION IN THREE-DIMENSIONAL MODELLING

Our research thus far has focused on the applicability of three-dimensional modelling applications for research on construction history. It has thereby covered the traditional geometrical Computer-Aided Design (CAD) applications and the newly developed Building Information Modelling (BIM) applications (Eastman et al. 2008).

Computer-aided design for construction history

Research on the applicability of traditional geometrical CAD applications to document construction history was undertaken for an 18th century banquet hall of the architect Louis Roelandt (Degels 1967). Constructed in the city of Ghent around 1825, the banquet hall was finally demolished in 1969 (Van Tyghem 1972). Research began by gathering available documentation from libraries and archives in Ghent (Belgium). After protracted study, a three-dimensional model was created using AutoCAD 2007. The aim of the reconstruction was to attach as much information as possible to the model, in order to make it more easily accessible for further research. Fig. 1 shows both an example of the kind of documentation encountered for this structure and the resultant virtual reconstruction.

Fig. 1: A drawing by Auguste Castermans (Castermans 1830), representing an elevation view of the banquet hall by Louis Roelandt (left), and the resulting virtual 3D reconstruction of the same banquet hall (right).

A major drawback in using the CAD application for construction history is that the application only enables the drawing of primitive objects, such as lines, boxes, cylinders, spheres, etc. Together, these primitives build up a geometric representation that can be useful in combination with textual or other graphical information. However, research into the construction history of this building would benefit from a more direct access to this information, namely through the 3D model itself. Modelling applications should therefore enable the direct attachment of particular information to these primitives, for instance permitting the annotation of an architectural element as a 'statue' or a 'decorative wall panel', and 'this statue is carved by sculptor X' or 'this panel was painted by Y' and so on. As we were unable to produce such annotation within the CAD application, the results of this first test-case was a geometric drawing without metadata or other information included, and a separate overview of all other available information in a textual format.

Building Information Modelling

Referring back to developments in architectural and construction design applications, it has been observed that the impossibility of adding information to a geometric drawing also generates essential limitations in design (Gallagher et al. 2004). Today's design-oriented application-builders aim to address this problem by supplying the designer with newly developed Building Information Modelling (BIM) applications. One of the most important differences with the geometric CAD modellers mentioned above is the presence of an information structure which is built up behind the geometric representation. This means that by drawing a BIM model one is actually drawing in a *semantic*-like way, using for instance 'wall', 'door' and 'window' elements instead of 'boxes', 'lines', etc. In addition there is extra information attached to these semantically rich elements (e.g. physical material parameters, geometrical parameters, cost information, etc.).

One of the major advantages of this BIM approach is the possibility to use this underlying building information for calculation, simulation and analysis in more dedicated software applications. Starting from the BIM model, these applications are accessible through a semantics-based interoperability language, namely the Industry Foundation Classes (IFC). This interoperability language was developed by the BuildingSmart Alliance (http://www.buildingsmartalliance.org/), formerly the International Alliance for Interoperability (IAI). By using this file format, it is possible to automatically generate derived information, such as a time planning or a cost calculation.

The aim of a second test-case was to investigate this BIM technique, as this could present more value for the documentation, archiving and dissemination process of construction history information. This test-case started from a project similar to the first one, namely the former Casino of Ghent, which was built in 1835 by architect

Louis Roelandt and demolished in 1945 (Fig. 2). Construction history research for this building started with similar input, predominantly drawings, textual sources, photographs and original sketches found in several libraries and archives in Ghent. A building information model was then built up representing this collected information. Three images of this building information model are shown in Fig. 3, and illustrated in Fig. 4 is some of the physical information that is semantically linked to the door objects in the BIM model.
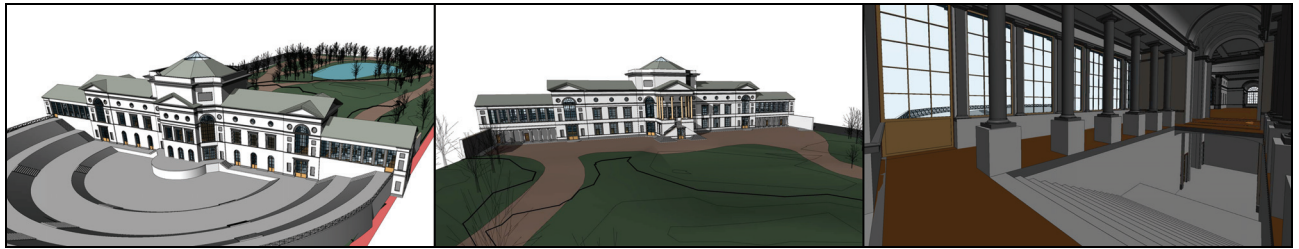

Figure 3: Three images of the BIM model built up
for the former Casino in Ghent.

Figure 4: Physical parameter information attached to a type of wood in the model,
containing information such as a Young modulus, a Poisson ratio, etc.

The information added to the model mainly deals with explicit and tangible features, such as concrete geometrical parameters, material characteristics (Fig. 4) and references to external research documentation (e.g. photographs, scanned documents, etc.). What is not included, however, is the more implicit and/or intangible kinds of information on the history of the building, such as similarities with related constructions, typological and topological information, annotations and comments of involved researchers, environmental constraints, regionally applied building regulations, etc. This kind of information exists for many historical research projects and is critical for achieving research objectives.

General findings

The two test-cases on 3D modelling demonstrate the significance of developments in the computer-aided design context for research on construction history. Especially semantics-based building information modelling applications are valuable for enabling the addition of diverse contextual information to traditional construction history documentation.

However, an essential part of the information remains missing in these modelling environments, i.e. implicit and/or intangible information. The present challenge is how to enable researchers to add this type of information to the 3D model, thus engendering a whole new range of applications. An important set of

applications can be situated in the preliminary design phase of an architectural project, but also in the methods and information flow in historical research for construction, cultural heritage and architecture. Further research into this problem has therefore concentrated on how to describe this kind of information semantically, while ensuring these semantic descriptions are linked to concrete objects in a 3D model.

SEMANTICS FOR CONSTRUCTION HISTORY

From data modelling towards knowledge modelling

Before creating a concrete description framework for implicit and/or intangible historical information, research has to be done in the way this information is generally constructed and evaluated by researchers in construction history. A broader sociological and/or philosophical discussion would be appropriate, but extends however beyond the scope of this article.

Mostly building on traditional media, a researcher usually starts collecting *'data'* on the topic of his or her interest, while immediately interpreting it and transforming it into meaningful *'information'*, to finally use this information to build up his or her *'knowledge'* on this particular topic. Once a certain quantity and quality of information has accumulated, the researcher again tries to capture his or her knowledge into an abstract structure with meaningful information and in the end he or she will again be producing a collection of data. This data is traditionally contained in media like a book, a photograph, a schema, etc (Fig. 5).
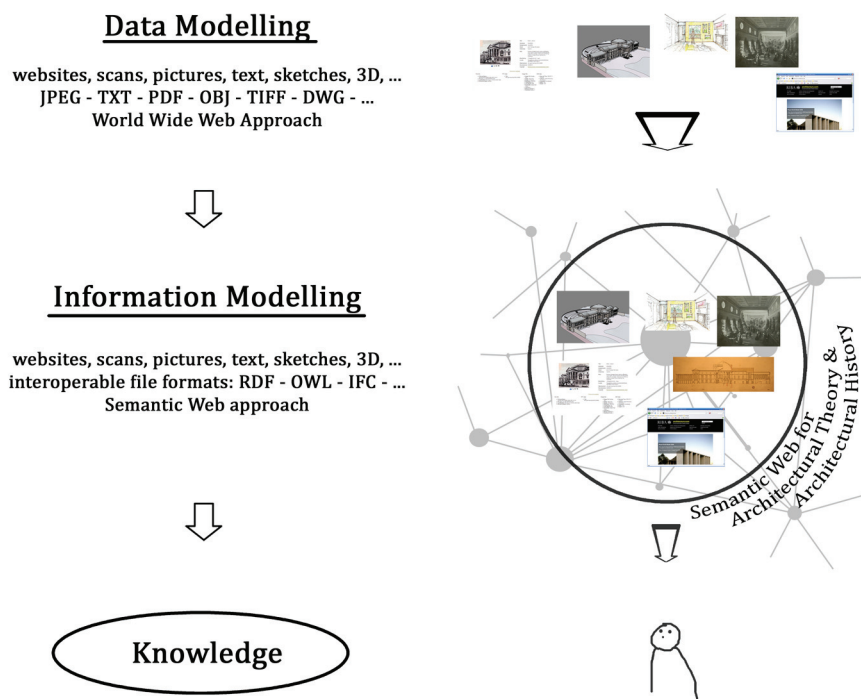

Figure 5: Overview of how data can be transformed into knowledge
through an abstract information modelling step.

Digital semantic description techniques make it possible to model the data as well as the attached meaning of a certain concept or object. Therefore, this part of research mainly focused on the first step, the transformation of data into meaningful information. The researcher generally starts reasoning about a certain ‚concept' within a research context, namely a place and time context (global background) and a personal knowledge context (local background). In a second step he or she tries to apply meaning to what is communicated to him or her through this (global) context, thereby using their (local) background knowledge. As a result of this second step, several meaningful (informational) statements can be formulated on the initial ‚concept'.

Taking this paper as an exemplary ‚concept', this means that it will be read in a certain context in place and time (global background) and it will be understood by the reader in relation to his or her knowledge (local background). Each time one of these two factors differs, the interpretation of the actual ‚concept' will be different as well, thus differing the actual constructed (informational) statements about this paper (e.g. „this paper discusses semantics", "this paper discusses three-dimensional semantics", etc.). This abstract information

modelling method can be applied to every ‚concept' in place and time, whether this is a conference paper, a certain building construction, a decorative architectural element or a cars design for instance.

Digital semantic description techniques

When comparing this overall approach on data, information and knowledge modelling with the overall developments in the domain of digital technology, a significant shift can be found from low-level data modelling techniques towards more semantic information modelling techniques. Whereas traditional information and communication technology mainly focuses on how to actually describe data, they now aim at describing the data *and* the semantic meaning that is given to this data. This shift can be recognised in semantic web technologies (Berners-Lee et al. 2001), the BIM approach discussed above, digital archiving methods (Van de Sompel 2008), etc.

A software technique that aims to capture and describe concepts and their informational relations is the Resource Description Framework (RDF) (Klyne; Carroll 2004). This description technique uses ‚triples' to store semantic information. Every triple contains an object, predicate and subject (Fig. 6). By applying this technique on an exemplary textual resource in construction history, multiple sets of triples can be generated. The different concepts in the textual source are expressed in the RDF format as separate entities, each of which is interlinked through relation identifiers (predicates). The resulting triple sets are stored in a 'triple store', which can be parsed and queried on demand (Klyne; Carroll 2004). A possible triple statement for a column, for example, is „aColumn" „isMadeOf" „concrete" and „aColumn" „isBearing" „aWall". A query can then be constructed to find particular information in the triple store, e.g. „what is the material of the column that is bearing this wall", or „what is the social significance of the style of this column", or „are there any other buildings that use a similar column type in their construction".
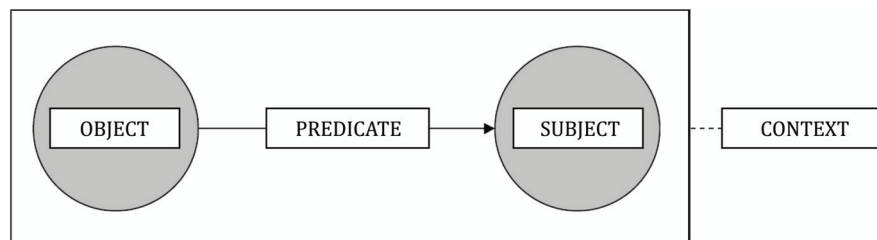

Figure 6: An RDF triple extended with contextual information.

These triples merely describe what *is/exists*, or what has *been*, thus generating an ontological description rather then a semantic description. The context mentioned before is thus missing in this RDF description technique, making the technique to some extent less appropriate for research on historical information. Several research projects on semantic web technology however have been targeting these drawbacks. One of these researches (Carroll; Stickler 2004) proposes the usage of named graphs in addition to the RDF triple structure. By proposing these named graphs, it aims to answer the need to add context to the triple statements („person_X" „isStatingThat" („aColumn" „isMadeOf" „Concrete")).

With this contextual dimension added to the functionality of the RDF triples (Fig. 6), these semantic description techniques promise to become a powerful mechanism in describing interpretations on specifically researched 'concepts'. By combining the techniques with the documentation capabilities of a solid three-dimensional modelling platform, an actively usable framework can be developed for in-depth research on construction history and architectural theories.

THE ARCHITECTURAL INFORMATION MODELLING FRAMEWORK

Central Framework

As a result of our research on three-dimensional modelling and semantic description techniques, we propose to develop a new, integrated framework for Architectural Information Modelling (AIM). Underpinning this AIM framework is an abstract, space-based, three-dimensional model. This model forms the core structure of the AIM model, to which further architectural or historical information can be appended during different stages of historical research as different kinds of features. In addition to concrete geometric information and material characteristics, these features describe typologies and spatial relations, implicit environmental or architectural constraints and historical references for instance, etc. Each information statement is linked to a corresponding element within the AIM model.

To explore the feasibility of this framework, we undertook a conceptual AIM test-case. An exemplary semantic description format was built for one of Andrea Palladio's Doric columns (Palladio 1570) (Fig. 7). Instead of developing the existing IFC Classes of the BIM approach further, we decided to adopt a more general

approach and deploy the semantic description techniques of RDF within our framework. This enables the framework to connect to a broader set of software applications within the semantic web field, within semantics-based digital archives, etc.
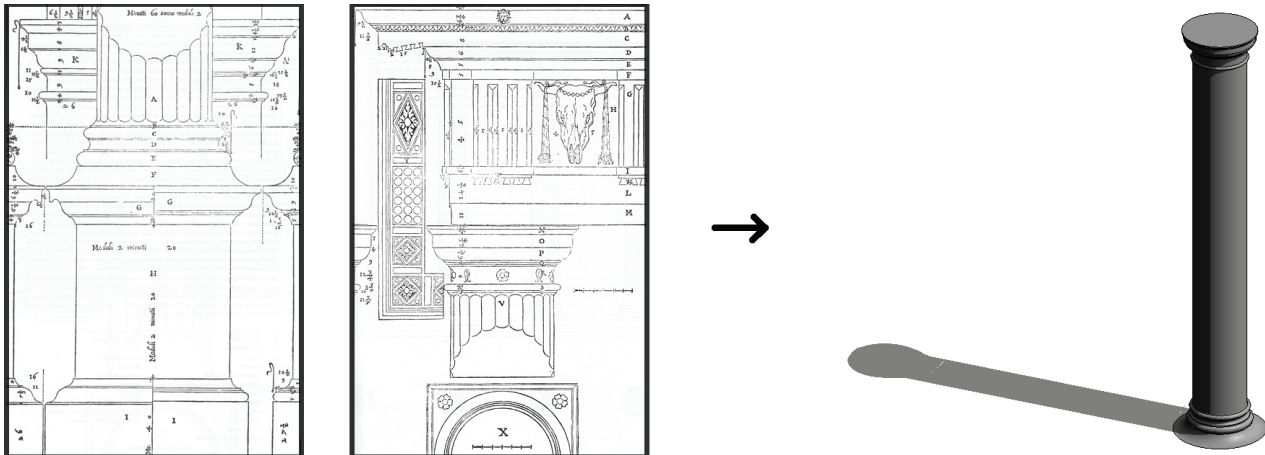

Figure 7: Drawings of Andrea Palladio's Doric column (Palladio 1570) were modelled in Revit Architecture 2009, thereby generating a parametric geometry to which semantic annotations can be attached.

An example of the way in which information is attached to the 3D model through RDF is shown below. Starting from the actual concept 'doricPalladianColumn', extra statements are attached. These state that the concept "hasColumnType" "doric" and that its geometry constitutes an architectural feature of the type "columnCapital", and so on. Almost any information type can be described through this RDF description technique. Similarly, information and characteristics concerning the deployed construction can be attached to the column model for performing constructional analysis and related calculations.

```
<rdf:Description rdf:about="http://www.aim.be/aimontology/architecture/doricPalladianColumn">
<aim:hasColumnType>
      <rdf:Description rdf:about="http://www.aim.be/aimontology/architecture/doric">
        <rdf:type>
            <rdf:Description rdf:about="http://www.aim.be/aimontology/architecture/columnType"/>
        </rdf:type>
      </rdf:Description>
</aim:hasColumnType>
<aim:hasGeometry>
      <rdf:Description rdf:nodeID="geometricEntity0001">
        <aim:hasPart>
          <rdf:Description rdf:nodeID="geometricEntity0002">
            <aim:hasPart>
                <rdf:Description rdf:nodeID="geometricEntity0005"/>
            </aim:hasPart>
            <rdf:type>
                <rdf:Description rdf:about="http://www.aim.be/aimontology/architecture/columnCapital"/>
            </rdf:type>
          </rdf:Description>
        </aim:hasPart>
      </rdf:Description>
</aim:hasGeometry>
```

With this semantic AIM model at its centre, the AIM framework is further developed in conjunction with three software components that together generate the overall advantages of the framework (Fig. 8). These components include an architectural memory, a virtual simulation and calculation component and a virtual reality visual simulation component.
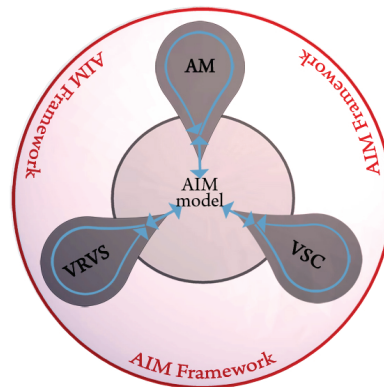
Figure 8: The AIM framework is built up from a central AIM model and three software components:
an architectural memory (AM), a virtual simulation and calculation (VSC) and
a virtual reality visual simulation (VRVS) component.

Architectural Memory

The first software component to which the central architectural information model is linked is an Architectural Memory. This should be understood as a global repository of general and specific knowledge concerning architecture and construction (Heylighen et al. 2007). The explicit linking of this knowledge through a clearly structured, semantic network effectuates the introduction of extra yet related information into the AIM research and design framework.

Figure 9 shows how the architectural memory works in combination with a central AIM model. When an interpretation of a certain concept is built up, whether this is documented in a 3D AIM model, a photograph or a textual source, a semantic description can be given. The semantic descriptions can then be queried to find, for example, similar features in other areas of an AIM model or in other linked semantic sources, e.g. images. For the column capital in Figs. 7 and 9, references can be found to objects that are located in the same area, or to objects that have similar geometric parameters or construction characteristics, or carried other meaningful information to the object/concept around which the query was constructed.
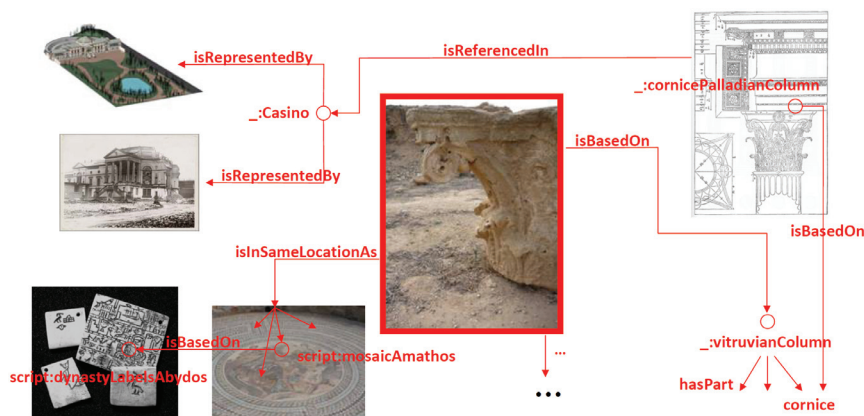

Figure 9: The virtual linking of a central AIM model to information in the architectural memory makes it possible to find references relevant to a given the topic through a semantic query (Prud'hommeaux; Seaborne 2008).

By querying in this architectural memory, a researcher working on construction and architectural history is able to search for documentary references relevant to a given research question. He or she can then investigate in further detail the documentation found and, when appropriate, generate new information on the original concept. This information can be added to the central RDF of the concept under study, thereby adding knowledge to his or her 'local' architectural memory as well as to a 'global' architectural memory.

Virtual Simulation and Calculation

The second software component to which the central AIM model is connected, deals with virtual simulation and calculation. Through the component, a simulation can be created, based on the AIM model, for example to assess the accuracy in correspondence between one of Palladio's found Doric columns and the geometric descriptions he made in his books. Another example of information that could be simulated is the calculation of the load-bearing capacities of the column, or the energy-efficiency of this column within a context of surrounding architecture and constructions.

This is done as follows. The required information from the semantic AIM model is imported into the relevant application within the software component. The required simulations and/or calculations are performed, and the results are (re-)entered into the central AIM model as part of its documentation.

VR Visual Simulation

The interface through which the user can interact with the AIM framework is of capital importance. Various interactive tools are needed to facilitate the work processes and methods of researchers and architectural designer. These tools have to allow, for example, calculations and simulations to be performed simultaneously, while the user adjusts the AIM model according to information from the architectural memory. This will require further development of both virtual reality and computer vision techniques and their integration into the AIM framework. Progress reports in this area of research will be forthcoming.

CONCLUSION

Building on the latest three-dimensional modelling techniques in the AEC industry and the potential of semantic description technology in general, a new conceptual framework for architectural information modelling (AIM) is proposed. Central to this framework is a three-dimensional AIM model. Meaningful information is appended to their associated 3D elements using the RDF resource description framework.

The central AIM model is linked to three software components that together generate the key advantages of this framework: an architectural memory; a component for virtual simulation & calculation; and a virtual reality visual simulation component. Through the architectural memory it is possible to construct queries on representative historical references and a range of other related information, e.g. typologies or geometrical parameters. Simulations and calculations can be performed in the second software component, based on given semantic properties, e.g. load-bearing capacities or thermal characteristics. Finally, a virtual reality visual simulation component aims to visualise the information processed with direct reference to the 3D model.

Future work on this research project will explore the proposed semantic description scheme in further detail with the aim of producing a first version implementation of the actual AIM framework.

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