3D models as visual interfaces in the documentation of the architectural heritage: an experiment on the defensive system of Cracow

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Abstract:
Our research focuses on the issues raised by the development of visualisation and modelling techniques on the Internet for documenting and representing edifices of the architectural heritage. Architectural heritage is a research area in which the word “visualisation” is often given a misleading interpretation, this of a synonym of “virtual reconstruction”. We present another interpretation of the word by thinking of visualisations as a graphical disposals used as visual interfaces for architectural documentation. We consider 3D models of edifices sites as interpretations of our knowledge that can be efficient in retrieving information (i.e., documentation) about architectural evolutions.
We propose to discuss the key aspects of our development: theoretical model of the architectural concepts we are documenting, representation mechanism in VRML (Virtual Reality Modelling Language), database interfacing issues, use of 3D models in the querying and in the retrieving of information.
Our contribution details those various aspects and the experiment we have carried out on the evolution of the defensive system of the city of Cracow.

1. Statement of need in the application domain

Morphology plays obviously a major role when trying to investigate, document and represent the successive evolutions of an architectural artefact during its period of life. Isolating the morphological items that define the artefact’s form is naturally crucial to its understanding, but it also opens opportunities to use the artefact’s representation as an intermediary between the user and elements of information not only on the artefact as a whole but also on each morphological item considered relevant in the architectural analysis.
It is clear, however, that geometric modelling has up to now mainly given birth to still-life images of artefacts in which the semantics used do not appear. In the field of the architectural heritage, researchers and practitioners call for the emergence of modelling methods in which the geometry produced results from the instancing of a model of architectural knowledge, and therefore in which interaction with the model’s semantics is enabled.

In a previous contribution to VIIP [Dudek, 2001], we have introduced some aspects connected with the specificity of patrimonial studies. Section 1.1 briefly summarises aspects that are important to the introduction of our research. Section 1.2 will detail the goals of our latest developments which introduce several stepforwards:
- The definition of alternative scales for architectural concepts in order to better support the documentation’s variety , and the building up of 3D models in which appropriate levels of detail or if symbolism are available.
-The implementation of visual interfaces that not only allow the user to query from a 3D model but also to retrieve from his query a 3D model calculated online and featuring the only concepts corresponding to his search.
-The implementation of “justifiers” that are used in order to visualise through color coding an evaluation of the accuracy of each architectural object’s documentation (roughly ranging from observation to hypothesis)
-The support for variations through time of each architectural object with preserving its identity (variations of shape, position, etc..)
-A renewed computer architecture based on standard, open source formalisms.

In section 2, we will present the methodology we have adopted in order to tackle the problems raised in our previous contribution, and the current developments will be discussed in section 3.

1.1 The context of our application domain

Most often, historic buildings that we study have been widely transformed throughout the centuries when they have not been totally or partly destroyed. Investigating their evolutions therefore requires, by necessity, two complementary approaches
- A theoretical analysis of the architectural form in order to propose morphological simulations.
- A thorough documentation of each building in order to validate simulations when possible and

in all cases distinguish the likely from the hypothetical.

As a consequence, we believe 3D visualisations of these simulations should be considered not as representing the edifice but as representing our interpretation of what it can have been like at each phase investigated. In other words, visualisations should show what we know of the edifice more than the edifice itself.

An alphabet does not make a phrase

Like one needs to know vocabulary and grammar when trying to fill in the missing words in an uncompleted phrase, such an approach requires that one builds a visualisation basing on a predefined set of *architectural concepts*. Our position stems from a simple statement that can be summed up in these words : one does not fill in missing words basing on the alphabet, one should not fill in the missing architectural forms basing on geometrical primitives.

Another key point in our proposition is the necessity to document simulations and among them virtual reconstruction.

Understanding the meaning of the phrase implies understanding the meaning of the words it contains.

Here again, in a dictionary for instance, one does not look for information on a phrase but on each word it contains. It is therefore important to formalise an architectural model in which each meaningful individual concept can be documented independently form the others. Each concept can be documented theoretically (ex: what we know of THE arch) and locally (ex: what we know of THIS arch).

What is more time and human activity does not leave the architecture intact. In other words, we should be able to represent differences for instance between original parts and elements that were added later, were reconstructed or reused. What is more, When gathering data on edifices that are transformed or partly / totally destroyed, some elements are precisely documented, some of them have contradictory descriptions and for some of them, no single piece of documentation was found. How can we then represent in the same model parts that were documented together with totally hypothetical elements?

Realism in architectural modelling implies that a unique level of definition is chosen for the 3D model. As opposed to this, our knowledge about an edifice that we strive to document is neither complete nor consistent. In such a case attempts of realism force fiction. Therefore, if we want to use the 3D computer models to represent our knowledge we have to work out interpretative forms of visualisation.

In short, one can say that examining a realistic model can be compared to an unguided visit in an architectural monument. We can observe and admire all the elements. We see them but we do not know their origin, history, specificity, etc. Although such models may prove relevant with respect to communication goals, as shown in [Burton, 1997] for instance, we favour an opposite approach in which what is "beyond" the image is more important that the image itself, in line with for instance [Stenvert, 1991].

1.2. Research goals.

When confronted to the mass of documents related to patrimonial edifices or sites, researchers in our application domain naturally filter the information available in order to retrieve the only elements concerning the part of the edifice or site they are studying. In other words, it is common to analyse the documentation in order to isolate the pieces of information regarding the only shapes or arrangements of shapes we are concerned with. In other words again, the first step in architectural documentation is to connect groups of physical objects to pieces of information, may it be on the aspects concerning their structure (how they were built, with what material, what is their shape) or on aspects concerning their making (when were they built, who designed them, etc..).

In the field of the architectural heritage though, documentation is rarely precise enough to thoroughly document all aspects of a physical object. Elements of certainty that remain are then its documentation and the partial indications this documentation provides. The 3D shapes to which we will want to attach pieces of information may therefore be incompletely defined, and anyway will need to be visually marked with an indication on *what kind of information the proposed shape is based on*. Moreover, architectural documentation relates to a wide range concepts that can often hardly coexist with one another, calling for the necessity to re-introduce the notion of scale. It should at this point be noted that architectural scale has always been a central notion in the understanding of built edifices but is strangely widely absent in the field of 3D modelling, although [Alkhoven, 1993] or [Schilcher, 1998] mention it clearly[1].

Shortly said, we need to isolate architectural concepts that may serve as filters on the documentation, and to produce representations of these architectural concepts clearly revealing the nature of the inferences made when reconstructing them. Consequently, our objective is to lay the methodological foundations for an architectural information system inside which 3D models featuring physical objects the documentation relates to become natural visual interfaces to the documentation.

[1] The term 'Architectural scale' explicits a fundamental diffference with the concept of geometrical / geographical scale.

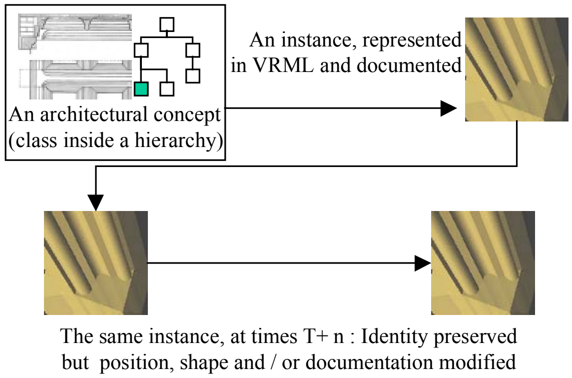
[Landes, 1998] have introduced geometrical objects used as visual interfaces for data retrieval on urban facilities, [Whiting, 1997] have introduced a cad-tool-dependant representation used as an interface inside spatially determined data; where information is attached to topological concepts.
We have been trying to introduce an architectural scale in which information is attached to *architectural* concepts. Our approach can be compared to this of GIS, but with two important constraints: representing the spatial concepts in 3D and taking into consideration the morphological evolution of the edifice during its history.

Our developments have throughout our research been focusing on two different problems:
-*Producing VR models in which* ***architectural*** *concepts are represented.* Giving a geometrical shape to the concept is then left for the system to handle.
What is more, mechanisms of alternative graphical representation of those concepts should be provided in order to take into consideration problems such as scale of visualisation (similar to distance to the object) or partial definition of the object.
-*Using visualisations as an access mode to information related to edifices*. This can be summed up by saying that we want the system to answer not only to this question:
What did John Smith write?
but also to this question :
What did John Smith write about the gothic phase of the town hall?
and moreover to this question :
What information, what documents, can I find on the buttress of the town hall's gothic phase?
allowing searches not only on what the document is (a book, a research paper, a map, etc.) but on what the document is about (edifices at different periods in time). It is then clear that visualisations should let us to attach to each concept represented in a scene elements of information that result from a critical analysis of the sources.
We have in the past year been introducing new constraints, as described in part 1.1 (notion of scale, visual interfaces in queries' results, justifiers, time variations) that renew the computer architecture and the data representation model, with notably two new problems:
-*Implementing the online making of VR models in response to user's queries on the database*, therefore allowing the user to produce its own set of 3D models with regards to a selection based on his search criteria.
-*Adding graphical disposals in the 3D models that let for the visualisation of qualitative aspects of the data model* such as level of certainty, type of documentation, etc..

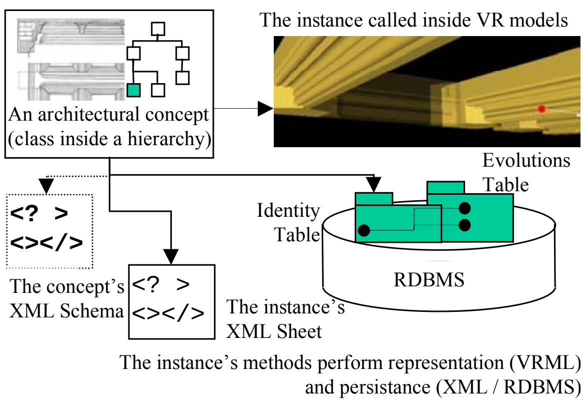
2. Method

As mentioned above, architectural heritage is an application domain in which both documentation and visualisation play essential roles. Moreover, ensuring their interdependence has clearly been acknowledged by numerous authors as a key issue if VR models are to be included in a research process (see for instance [Cuisenier, 1991], [Stenvert, 1991] or [Nakamura, 1999]):
- Visual results such as virtual reconstruction of edifices or sites can in no way be considered as elements of information in a research process if they are not put in relation with a documentation that authenticates, validates, explains each particular arrangement of architectural shapes the reconstruction proposes.
- Symmetrically, documentation about edifices or sites can very hardly be given a synthetic visual interface when this interface does not display what the documentation is about, meaning architectural shapes. What is more, in our application domain, documentation is particularly heterogeneous, ranging for instance form elements on the colouring of frescoes to the type of social activities occurring inside spaces of an edifice. There is therefore a clear need to use VR models not only as interfaces but also as filters or views on this documentation. As discussed later, such models will help the researcher to evaluate visually how precisely shapes are documented, in terms of dating for instance, and to withdraw from the system information that have been sorted out thematically.
Finally, it has to be stressed that in our research area a physical object such as "an opening" can have been re-used several times during history, and often inside different edifices. This introduces a level of complexity for which we lack adequate formalisms since such issues as dynamic data visualisation [RussoDosSantos, 2001] or time handling in GIS sytems [Bilgin, 1997], although already addressed, do not bring operational breakthroughs in our application domain. Both the shapes reconstructed and the documentation therefore relate to a moment in time, and the construction of an information system in which visual 3D interfaces connect the documentation to what it is about – architectural concepts – is even less straightforward.
Shortly said, our position is that 3D models of the architectural shapes our documentation is about, are a natural and efficient filter for data retrieval.
The figures below introduces the key aspects of our approach:

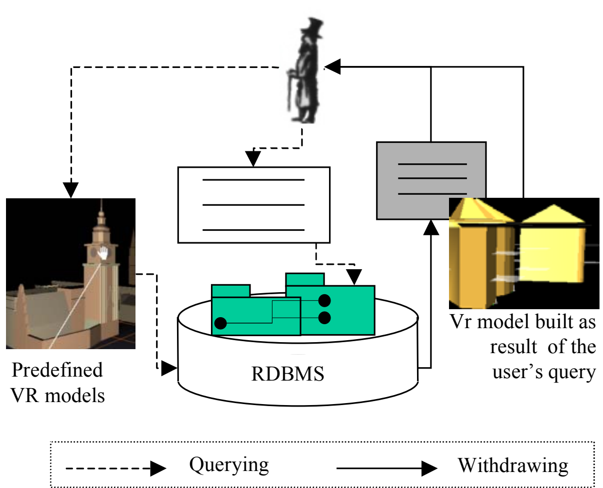
Step 1: Modelling of architectural concepts



Step 2: Persistance of the model's instances



Step 3 : Interfacing of the documentation through 3D models of the instances



The architectural concepts used for data retrieval are formalised as a hierarchy of classes, each class containing methods allowing representation of the instances in VRML (with embedded queries) and persistence mechanisms. Autonomy and perenniality of the VR models and of the data sheets being of crucial importance in our application domain, we have chosen to store both the visual results (VRML files) and the textual results (XML sheets) of the model's instanciation inside standard ASCII files that can be used independently form the system as a whole. In our approach, in line with [Huber, 2000], solutions for VRML models monitoring or Object persistence as those described in [Landes,1998] or [Conway,2000] are therefore not implemented here since they implicate a dependence of the results on the application that gave birth to it. In our development methodology, once instances are created, informed and stored, VR models can be produced that use the numerical information about an instance in relation with its evolution in time. Two types of models are produced:

- Predefined scenes showing the field of experimentation at key points of its historical evolution, scenes in which all elements in the database (with respect to the notion of scale[2]) are included.
- When the user queries the database a new VR model is calculated online that features a reconstruction of all the instances corresponding to his search criteria . In case two evolutions of a same instance match the query, the closest to the period investigated is selected.

As shown on the figures above, three steps are needed in order to implement this process:

1 Architectural concepts are identified and formalised as classes in a hierarchy with regards to the notion of scale (Urban blocks contain edifices that contain architectural entities- walls, arches, etc…)

2. Persistence of the instances of the model is performed at two levels: the RDBMS contains tables storing attributes of the root class of the architectural concepts hierarchy (flattened), and XML sheets store class-specific information.

3. The RDBMS stores information related to the model's instances (Identity, evolutions and justifiers for each instance of the model). It also stores information on the model itself (structure of classes and attributes), and finally elements of documentation. "Justifiers" of instances contain a qualitative evaluation of the documentation that justifies the creation of an instance. They include

[2] This means that we sort out objects detained in the database basing on what could be compared to levels of detail. For details on issues regarding scale in architecture, see for instance [Francis, 1999], [Donath, 1997].

information on the documentation type (for instance whether the documentation is contemporary of the instance or a researcher's hypothesis) as well as a link to in-deep information on the source. Justifiers therefore allow a graphical coding of the scenes in order to visualise clearly not only geometrical interpretations but "levels of certainty" about these interpretations.
The implementation of this methodology is discussed in the following section. We believe that 3D models can provide efficient visual interfaces provided that a few key issues are addressed when creating the scene.

- If we want to consider 3D models as successive photographs of our evolving knowledge on the edifice, we have to create those 3D models basing on the a theoretical model of the concepts we deal with, thereby allowing both generic re-interventions on the 3D models and a native connection of instances to sets of data.
- Creating 3D models should not result in the obligation for the modeler to give details he ignores either on morphological aspects or on qualitative aspects.
- Elements shown inside 3D models should be connected to a documentation allowing the researcher to not only see the scene but retrieve elements of justification on what [Kantner, 2000] calls the compromises on whet should or should not be portrayed in a 3D model.
- As far as possible show along with the geometry characterising the instances elements of qualitative analysis such as typology of the documentation, precision of the dating, etc...

Our approach, favouring interpretation over realism, favouring the reality of what we know over the seduction of what one can infer, is clearly not in the mainstream of VR applications in architecture. It still is defended notably in [Alkhoven,1993] and [Kantner, 2000].

3. Developments

Our contribution does not stress one technology but investigates a possible combination of formalisms : OO modelling, XML Schemas, Interactive VR modelling basing on open standards, VR scenes / e-databases interfacing. The choices we introduce hereafter can probably be better understood if we here mention some of the guidelines we follow:
- Autonomy of 3D models and textual results with regards to the application that gave birth to them.
- Interactive visualisation of 3D models on the Web.
- 3D models stored in a format that can be manipulated with a standard programming language.
- 3D models used as graphical interfaces connecting the user either to an RDBMS or to other 3Dmodels and any other textual data.
- Use of existing RDBMS structure for the documentation itself

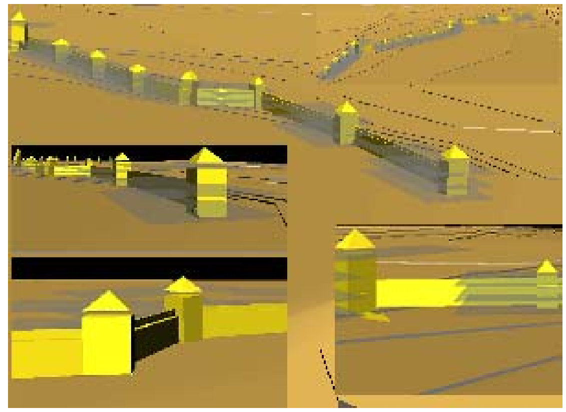


Figure 1 : Snaphots of a predefined 3D VRML model

3.1 A combination of technologies

The development we present has been carried out on a PC platform running Windows 2000, apache server and Perl 5. The RBBMS is MySQL running on a Linux .

The architectural model

Architectural concepts are formalised by a hierarchy of classes with the root class factorising documentation mechanisms as well as justifiers (represented in another hierarchy). Each concept isolated detains several blocks of attributes:
- Information relative to the concepts localisation in the space of the city.
- Morphological description (providing information for the calculation of a geometry for the object). The geometrical representation in VRML can match the concept's complexity or provide a symbolical shape.
- Information relative to the concepts' "time localisation" within the city's history.
- Inherited Justifiers objects giving a formalism for the visualisation of the documentation's accuracy on various aspects (shape, time, material, etc..) .

Each concept is also given a VRML representation method that writes out

Basic elements concerning the structure of our architectural model are given in [Dudek, 2001], and although such experiences of knowledge representation in our application domain are not very numerous, [Donath, 1997] or [Landes, 1998] can be quoted. Implementation was written through Perl 5 modules [Conway, 2000].

The persistence of instances

Each instance of an architectural concept ought to be unique. But as mentioned before, in our application

domain objects are often reused or partly destroyed. This problem has been raised in works like [Lukacz, 1999]. We have as a consequence provided each object with persistence mechanism that store independently the object identity (identity + concept documentation + position in the model's structure) and its various states of evolution (morphology, position, instance documentation, justifiers).
Instances are stored in an RDBMS context (mySQL) as well as in ASCII xml sheets. The top class attributes are flattened inside an identity table and inside an evolution table for its various states of evolution. Class-specific data is stored inside XML sheets. Basing on the analysis of XML formalisms proposed by [Castro, 2001], we implement XML schemas corresponding to each concept in the model that support the strong typing of attributes.

Representing the concepts : 3D models.

Scenes are written in VRML 2.0 both for Cosmo and Cortona plug-ins. The use of VRML 2.0 for architectural scenes is investigated in various researches, see for instance [Oxman, 1999]. Although often considered too heavy, the language provides features that are particularly relevant in our context (see [Dudek 2001]) and notably its events routing mechanism that we use in order to provide the user with client-side interaction disposals that are nested inside the scene (node PROTO) and therefore not dependant on an application or an applet. (See for a discussion on this point [Lund, 2000]). Such disposals are used in our case either for object control (choice of the database to query on when selecting the object, autonomous rotation of the object on himself for shape investigation, …) or for scene control (lighting conditions, ground anamorphosis, …).

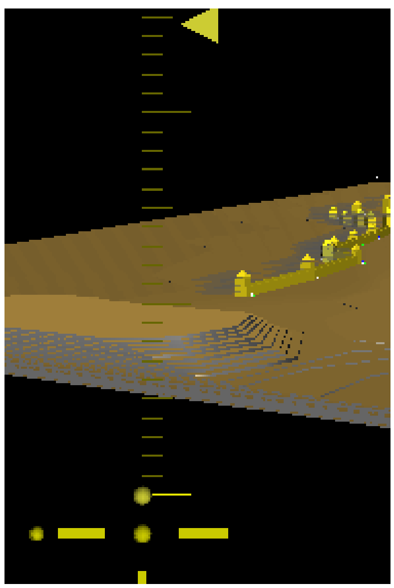


Figure 2 : VRML Interaction disposals, lighting slider and object control chooser

Interfacing 3D models and the database.

As mentioned before, 3D models are used as a query mode (predefined time-related scenes) by selecting an object inside the 3D model or as a visualisation of the query's result, by instancing the objects corresponding to the search and calling their VRML representation method. Since model and RDBMS platforms are chosen independant, the Perl CGI Interfacing modules we were using up to then were preferred Perl online written PHP modules that monitor the RDBMS links.

We believe at the current stage, the development we carry out has reached a point where it provides a representative example of what 3D visual interfaces could be in the scope of the architectural heritage, under the condition that modelling is thought of before representing. Still, this development remains at an early stage and opens to us numerous research questions both in terms of knowledge handling and in terms of technological solutions.

3.2 The experimentation: evolution of the medieval fortification system of the city of Cracow.

First fortified structures constructed around the town were built after 1258. Initial walls and tower-gates were made of wood and earth. Quite soon they were replaced by stone structures consequently improved, restored and renovated. Since XV century newly constructed elements were build of brick.
The role of the fortification was to defend citizens and their goods against enemies therefore consecutive improvements and extensions of that system were conducted during ages.
As a first innovation the simple tower system was introduced (approximately 28 simple towers added). Successive improvements included reinforcement of the tower-gates's defensive systems, digging of the moats, construction of the additional defensive walls and introduction of the escapes, modernisation of the existing simple towers and addition of the new ones (in 1473 there were 17 tower-gates and simple gates, in 1684 number of simple gates reached 47), erection of barbicans, bastions, etc.
Weapon development and consecutive evolution of the war systems inducted changes in the defensive systems. Starting from XVIII century towns were defended by a system of distant forts and not as it had place up to XVII century, in the proximity of the town itself. Successively defensive lines and a system of forts enclosed Kraków. Since that moment the fortification system around the medieval core of the city definitively lost its importance. This situation gave the end to restoration and renovation of the old fortification system. Towers and walls were left on the mercy of time, wind and rain.

At present the old town is surrounded by a ring-like park (length 4 km, thickness of the ring 40-120m) that took place of the city fortification system, demolished between 1810-1840.

4. Conclusion

Our contribution introduces a methodology for using 3D models as efficient visual interfaces to a documentation about historical buildings. The key aspects of this methodology are:

- Identification and organisation of a theoretical corpus of architectural concepts
- Modelling of interpretative VRML scenes basing on this corpus, with nested client-side interaction disposals.
- Online creation of 3D models as answers to users queries on the database
- Support for evolutions in time of the model's instances
- Support for the concept of architectural scale allowing to define alternative levels of detail.

Our work clearly positions visualisation in our application domain as an *interpretation*, with an ambition not for realism but for the better documentation readability and access, in line with contributions such as [Stenvert, 1991], [Alkhoven, 1993] or [Kantner, 2000] .

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