ERAS – An Ontology-Based Tool for the Expeditious Reconstruction of Virtual Cultural Heritage Sites

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Resumo

Nos últimos anos, vários investigadores têm proposto métodos semiautomáticos para a geração expedita de modelos virtuais de edifícios e até cidades, em alguns casos direcionados à reconstrução do património cultural. No entanto, a maioria das abordagens propostas foca a geração de exteriores. Apesar da investigação realizada em torno da geração de interiores não ser inexistente, denota-se ainda uma falha de regras reais de suporte à geração dos referidos interiores. Para além disso, a especificação das regras de geração envolve extensas análises a documentos como livros, documentos históricos, plantas e outras representações gráficas, bem como o conhecimento de linguagens de gramática. Pretende-se seguir estas linhas de investigação a fim de obter uma ferramenta de modelação expedita que produza modelos de alta-fidelidade, empregando modelação procedimental. Este artigo tem como objetivo a apresentação da arquitetura geral de um sistema para a reconstrução virtual de sítios arqueológicos, incluindo exteriores e interiores de edifícios, aplicando um novo método de extração de informação a partir de dados geográficos e descrições textuais. Também se pretende apresentar a ontologia abstrata que regula a extração de dados e que define o esquema semântico de relação entre os diferentes elementos que integram uma cidade genérica, de forma a permitir a derivação por parte de outros estilos arquitetónicos.

Abstract

In the last years several researchers have proposed semi-automatic methods for the expeditious modelling of virtual buildings or even entire cities, in some cases applied to the cultural heritage reconstruction. However, most of the approaches focus the generation of the building exteriors. Despite the existing research work on interiors generation, there is still a lack of support from real rules. Besides, the specification of generation rules involves an extensive analysis of documents such as books, historical documents, floor plans and other graphical representations, and knowledge about grammar languages as well. We intend to follow these lines of research in order to get an expeditious modelling tool that will produce high fidelity models, employing procedural modelling techniques. This paper aims to present the global architecture of a system for the reconstruction of virtual heritage sites, applying a new method for extracting information from geographical data and textual descriptions. Moreover, it is intended to present an abstract ontology to rule the information extraction and defines a semantic relationship between the different elements that compounds a generic city in order to allow derivation by other architectonic styles.

Keywords

Grammars and Other Rewriting Systems, Computational Geometry and Object Modeling, Ontology, Rule-based generation model, Procedural Modelling, Three-Dimensional Graphics and Realism.

1. INTRODUCTION

Accurate 3D reconstruction and realistic visualization of both archaeological sites and ancient monuments allow experts to fine-tune their theories about the lost links in the history of civilization. Although the 3D reconstruction is a major challenge, precisely because of the lack of visual information, it constitutes a crucial task for experts who are interested in studying and interacting with long disappeared settlements and structures. Furthermore, the public in general will be provided with the tools to explore these archaeological sites within virtual environments, thus fostering cultural, social and scientific participation.

To achieve these reconstructions, the textual descriptions and geospatial data collected by archaeologists on site may be used to overcome the absence of visual information. Still, this data will not suffice, in which case procedural modelling turns out to be essential in order to avoid a great deal of time and labour consuming modelling processes.

Several researchers have proposed semi-automatic methods, using procedural modelling, to generate virtual models of buildings or even entire cities. Generally these approaches focus only on buildings exteriors or on buildings interiors generation. In this work the centre of attention, of the proposed methodology, goes to complete buildings, with interior and exterior, and to the heritage architectural rules by which they were built to generate complete 3D traversable models.

Far from being an easy process, the specification of these rules does involve an extensive analysis of the information contained in different sources (documents, ancient books, drawings, floor plans, etc.) and knowledge about grammar languages. Therefore, we want to contribute to the automation of some stages of this process, by developing methods to automatically extract and convert the information found on textual descriptions into an unified data model.

In this paper it is presented the architecture proposed for ERAS, an expeditious modelling tool for the reconstruction of archaeological sites with traversable buildings. The architecture section will expose the main constituent processes: the information extraction process and the procedural modeller process. In the other hand, it will be presented a first approach of the semantic schema that will provide architectural knowledge to ERAS: the ontology. Based on it, this tool will be capable to extract informations from textual descriptions in order to mount a guiding data schema, endowed of architectonic awareness.

2. RELATED WORK

Most techniques for procedural modelling of buildings mainly concentrate their efforts on the generation of modern structures. In the past few years several methods have been presented (e.g. [Parish01, Greuter03, Wwsr03, Finkenzeller05, Martin05, Müller06b, Weber09]) which address different aspects for procedural modelling of urban environments. Most of them are discussed by Watson et al. in [Watson08] where several other aspects, advantages and practical applications of this promising area are also discussed. One of these applications is on the modelling of cultural heritage structures. A cited example is the modelling of ancient Roman Pompeii [Müller05] (Italy) and Mayan Xkipché [Müller06a] (Mexico). The XL3D modelling system [Coelho07] operates automatically based on a modelling specification and geospatial L-systems. The results obtained with the modeller have proved the potential to model virtual urban environments.

A common feature among these works is that the main effort is on the generation of the exterior of the structures. In most of the approaches the interior of the structures is not generated, thereby they are not traversable. In [Martin05], the author addresses this issue using graphs which represent the rooms of a house and the connections between them, to generate modern traversable houses. In [Hahn06], Hahn et al. also address interior generation, namely in real time, by randomly dividing rectangular floors, corresponding to building interiors, into rectangular rooms and hallways. Both these methods still prove to be unsuccessful if the goal coincides with the generation of structures which may represent real buildings. Rau Chaplin and co-workers [Rau-Chapplin96] applied shape grammars, usually used on exterior facades, to generate building divisions, which fit layout tiles from a library of room layouts. Each division is then fulfilled with furniture according to its functionality. Marson and Musse [Marson10] suggest a method for interiors generation based on squarified treemaps, which consists in a recursive subdivision of functional areas into rooms. The last step is the creation of the corridor to connect the rooms. Tutunel et al. [Tutunel10] developed a expansion-based floor plan generation technique. In this work the authors map the rooms into classes to define the adjacency between them. Next, the rooms are placed in the layout and expand until touching each other. Charman [Charman93] presents a technique that solves the generation of room layouts when the problem is stated as a planning issue. The author's planner works based on aligned-axis rectangles with variable position, orientation and dimension, which represent restrictions given by the user in order to express geometric constraints. Marrell and co-workers [Merrell10] also proposed a method to generate house interiors, using Bayesian networks, trained with real-world data. This networks provides floor plans stochastically, that are then transformed in 3D models including, doors, windows and roofs.

In [Rodrigues08a] the authors address this problem concerning modern houses, where a method for the automatic generation of traversable houses, using architectural legal rules and a L-system to generate the interior rooms, was presented. In [Rodrigues08b], the authors proposed a method for the automatic generation of heritage sites with particular focus on Roman civilization structures, where several rules were written based on the knowledge left by Vitruvius, mostly through the reading of the Portuguese adaptation from M. Justino Maciel "Tratado de Arquitectura" [Maciel06]. This method extends the one already applied on modern houses.

As stated by Watson et al. [Watson08] the automated production of rules is one of the most challenging aspects on procedural modelling. Muller et al. in [Müller07] presented one initial work towards this goal where they devised algorithms to automatically derive shape grammar rules from single facade images that can be used on a procedural modelling technique. The automated generation of rules from textual descriptions, contained on documents or books, implies the processing of the written text and the extraction of the information relevant for the production of the rules.

The Gate platform - General Architecture for Text Engineering- and the NLTK Project - Natural Language Toolkit are some of the solutions developed which can help researchers and programmers to develop applications that need some kind of natural language processing. While NLTK presents itself as a set of libraries and programmes developed in Python [Garrette09], the Gate platform has an open-source infra-structure to develop components for the natural language processing [Bontcheva02].

The NooJ platform [Silberztein04] is a cooperative and free environment of linguistic development that includes a vast set of resources and modules in more than ten languages. With this platform it is possible to analyse the grammatical, syntactic or morphological structure of a text or group of texts, being able to process more than 100 file formats, including PDF and HTML.

In [Rodrigues10] the authors present a first attempt to generate buildings' models from textual descriptions written in Portuguese language. The prototype developed uses Port4Nooj [Ribeiro08], a Nooj version for Portuguese language, to extract the relevant information from the textual description and build a cityGML [Kolbe05] representation of a simple 3D church's model.

Liu and co-workers [Liu08] proposed an ontology-based method to guide the generation of Chinese cultural heritage buildings. In their system, the user can specify the rules of the building styles in a DTD format, and an urban map to be reconstructed. A style checker uses the rules and an ontology defining the semantics between the city elements to approve or disapprove the generated building models in a XML. The checking process aims to find a valid XML with a coherent city model to guide the virtual generation of the urban map submitted. Tutunel et al. [Tutunel11] developed a framework that also integrate ontology-based structures. This framework combines a set of procedural modelling techniques, which are used according to the phase of the generation. These techniques communicate with a semantic moderator to reach information about the buildings, using a semantic library with classes, attributes and constraints. This information is then combined by the moderator into a semantic model of the building, constituting an advisory base structure used to avoid conflicts, such as undesired buildings intersections or wrong associations like applying a bathroom window into a bedroom.

Differently from the referred works, ERAS is an expeditious tool that will automatically extract the informations from textual descriptions and geographical data in order to produce an ontology-based data schema, which will be used to generate a consistent virtual model regulated by editable rules of production. The next sections will expose an architecture proposal for our system, explaining the processes to extract information and to generate the virtual models. Moreover, it is intended to present a new ontological data schema that will be integrated in the ERAS system to provide archaeological organization knowledge.

3. ERAS ARCHITECTURE

To reduce the amount of human intervention, this work aims, besides other objectives, to develop an expeditious 3D modelling system. Accordingly, our modelling system will be guided by heritage knowledge about the construction rules of heritage structures, encoded in a formal grammar by expert knowledge in historical architecture procedures. This system will also encompass the modelling of façades and interiors in a way that both modelling processes integrate seamlessly and complement missing knowledge of the structure.

The specification of the rules used on the procedural modelling process is not an easy process since it involves an extensive analysis of the information contained in different sources (documents, ancient books, drawings, photographs, floor plans, etc.) and knowledge about grammar languages. We intend to contribute for the automated generation of rules from textual descriptions contained on documents or books.

Therefore, we propose the development of a tool, ERAS, for archaeologists to produce enhanced virtual reconstructions of archaeological sites. The architecture proposed for this tool (Figure 1) is composed by two main processes as follow:

1. Information Extraction Process;
2. Procedure Modelling Process.

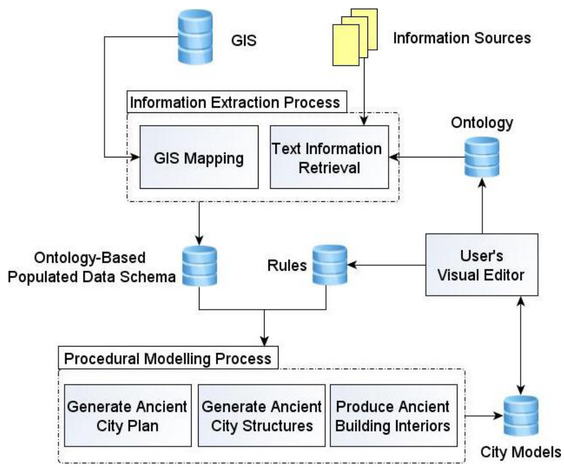

Figure 1. *Architecture of ERAS, composed by two processes: the information extraction process that acquires the relevant*

information relevant and determines the production guidelines and the procedural modelling process that constructs the 3D model of the ancient city based on architectonic editable rules.

The information extraction process will derive a structured data set from several information sources (e.g.: geospatial data, textual descriptions). Such information extraction process will be based on an Ontology created to this domain that will allow eliminating ambiguities and, alternatively, adding semantic information to our model. Thereby, this process results in a fulfilled data schema in which are set the city elements, including the buildings, and for each building is defined its divisional rooms.

The procedural modelling process is now ready to use the data schema to produce the virtual model. However, this process is regulated by a set of defined rules according to an architectonic style. The rules also have the crucial mission of avoiding inconsistency in generation, for instance, preventing the generation of buildings upon streets or putting windows on facades that are between adjacent houses. The rules, as the ontology, are editable thus a visual interface will let the user visualize and modify the rules to customize the generation constraints or guidelines, according to user's expectations or expert's point-of-view.

Taking rules in consideration, the procedural modelling process will be done in three stages. In the first one, it is generated a plan of the city in which is determined, at a very low level of detail, the placement of the basic components (e.g. streets, buildings, gardens, etc.). Then, the components are converted to tri-dimensional shapes with an increased detail (e.g. building mass models and street marks). At this point, the model does not contain the interior of the buildings, only an approximation to the exterior of the buildings. Hence, the final step is to generate the interiors where the exterior can act as a constraint, for all buildings in the model. The floor plans are generated with a defined adjacency for the divisions based on ontology and rules. Then, these divisions will be expanded until they fit the external contour. Finally, the buildings interiors are transformed into tri-dimensional representations with transitions between the rooms, such as windows and doors, were properly applied.

3.1 Information Extraction Process

We will define, in the section 4, an ancient urban ontology that best describes the semantic information of an archaeological environment. The ontology must deal with cultural and age difference, thus producing a general information model but that can encode different cultures and ages styles. This ontology constitutes a shared vocabulary that will allow modelling the type of objects and their properties and relations, including geospatial information. This vocabulary will be used by the information extraction module to encode structured data from the textual descriptions. In several documents one can find textual description of ancient structures and sometimes definitions of architectural styles. This textual information can be used to collect a set of guidelines which is a data schema containing the definitions of the existing elements in the city. This data schema will guide the procedural modelling process. In a recent work [Rodrigues10] we presented a first approach for the expeditious building modelling from textual description. The prototype developed was used to automatically produce simple 3D models of monumental buildings based on a textual description written in Portuguese language. We intend to improve this methodology in order to generate more detailed 3D models of several types of structures, guided by the ontology defined and to extract information from generic descriptions, for instance, to define a specific building, with a position and a number of floors and room divisions. Other feature supported by this system is the capability of improve data models fidelity by obtaining the real positions of the elements present in the descriptions, whenever possible. This kind of information is provided by GIS (Geographic Information System) databases that retrieve a set of coordinates defining a street network or a building's base polygon. This information has to be converted by this process to an unified format used to map the virtual model, which was previously made by Coelho and co-workers[Coelho07].

The information extraction process will be responsible for translating the unstructured data presented on plain text to a more formal, ontology based, data that will be used for procedural modelling. This module will use the GATE ("General Architecture for Text Engineering"), which is bundled with a free Information Extraction system that will be configured to work for this domain and ontology. Moreover, the resulting data may contain geographical coordinates associated to the elements in the produced data schema, in order to provide location awareness.

The data schema produced by this module will feed the procedural modelling process while the rules will regulate it to ensure a reliable consistent model generation in order to avoid awkward situations such as buildings upon streets or even to amplify data to deal with the lacks of information.

3.2 Procedure Modelling Process

The second module is related to our recent work on expeditious modelling of urban [Coelho07] and archaeological [Rodrigues08b] environments. In the former it was defined a methodology for expeditious modelling of 3D virtual environments based on "Geospatial L-systems", a derivation of parametric L-systems [Prusinkiewicz90]. This methodology was mostly applied for the generation of urban environments (Figure 2). In the latter a framework for expeditious modelling of ancient structures was defined, based on a set of rules derived from constructions rules from the period of time in consideration and from expert knowledge. The buildings generated include the interiors and are traversable. This framework was applied to generate roman structures using Vitruvius' architectural rules (Figure 3). We intend to improve and merge these two works to develop an unified framework for the expeditious modelling of ancient cities with all their entities, where the buildings interiors are also generated depending on the active level of detail.

Figure 2. *Urban environment procedurally generated [Coelho07]*

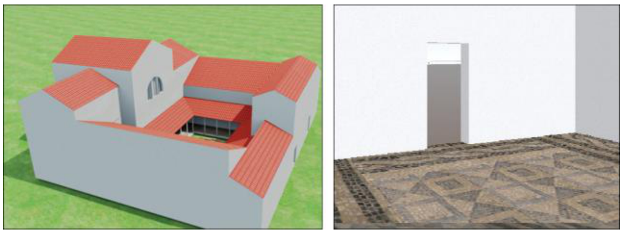

Figure 3. *Rule-based generation of ancient roman houses; left: exterior appearance [Rodrigues11]; right: interior facade [Rodrigues08b].*

The archaeological data collected on site will be stored in a geospatial database according to the defined ontology. This data will be amplified in order to generate the 3D virtual environment by using geospatial L-systems. This technology, already tested with good results in urban environments [Coelho07], uses a set of rules that encodes geospatial knowledge about the site such as the location, external polygon, type and height of each structure/building. The result of this first stage is a basic mapping of the entire archaeological site with a low level of detail, i.e., buildings, streets, gardens and other city elements will be, initially, represented by a two dimensional shape, creating a sort of a floor plan of the whole city. In a second stage, the two-dimensional shapes will be replaced by tri-dimensional shapes in order to improve detail and produce empty buildings mass models. At this point the city model should have the basic street definition and the buildings already assumed a 3D shape with a proposal for the outer facades. The last stage of the generation is reserved to the building interiors generation. The floor plans are generated for each produced building in the model and for each floor in all building. At this point, the floor plans have a two-dimensional representation and define the rooms of a given floor and the respective adjacencies. Next, the rooms are expanded until fit the exterior limits, fulfilling the inner space and respecting the defined adjacency. Then, it is marked the transition points that connect the division to each other and define the transitional passages between floors. Lastly, the tri-dimensional model of the interiors are generated, including the transitional points (windows, doors and staircases), regarding all the defined constraints. The whole process follows the guidelines previously extracted which are based on textual descriptions and ontology.

4. ERAS'S ONTOLOGY APROACH

The ontology is the semantic structure that describes the relationships between the different elements on a system, as can be noticed in [Liu08]. This semantic definition represents by itself a guideline for the generation process by setting up a predefined structure in which every element should fit on. In order to define an ontology for ERAS system, the first approach was to develop a semantic structure that defines the set of abstract elements present on a abstract city. This ontology is based in the following principles:

- A city is composed by blocks and distribution networks, such as streets and water networks;
- The other components of the city are generated upon a block;
- Buildings can have gardens (private gardens) but gardens may also hold buildings (public gardens);
- A building is an abstract structure of a city that is constituted by one or more building parts;
- A building part is a vertical composition of a building and the horizontal compositions, floors, are seen as specializations of building parts;
- A building part is also a container of building divisions, such as main corridors and rooms, possibly containing other building parts;
- Building divisions have transitions or points of connection with the exterior of the building or passages for other divisions, such as windows or doors.

In Figure 4, it is shown the ontology used on ERAS according with the mentioned premises.

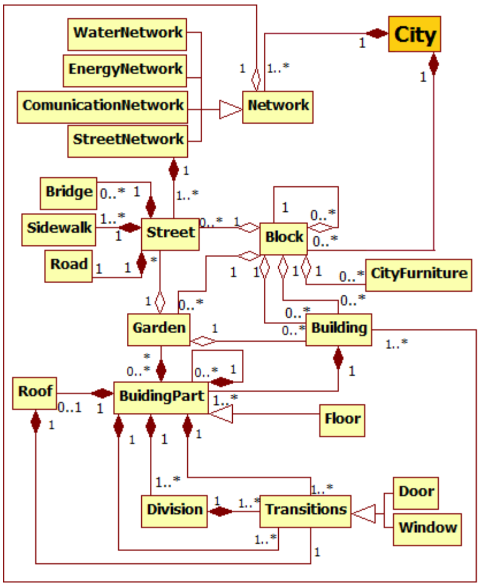

Figure 4. *ERAS's abstract ontology, defining the relations between city elements.*

Our ontology was planned to allow extensions to other architectonic styles. The city elements of a particular style can inherit characteristics from the main elements present in the abstract ontology. For instance, a roman style is constituted by its own building types that inherit from the building of our ontology (Figure 5). The mechanism will allow a reutilization of the elements and the expansibility of the ontology to other architectonic contexts.

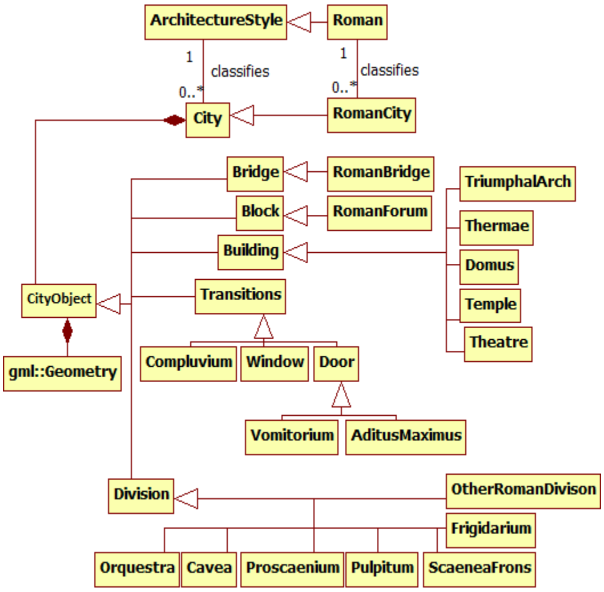

Figure 5. *The inheritance of the roman style elements from the abstract ontology*

5. CONCLUSION AND FUTURE WORK

In this paper we presented the system architecture of a tool that will enable archaeologists to produce a virtual reconstruction of an archaeological site in a short time period. The defined architecture exposes two main action processes: the extraction information process and the procedural modelling process. The first one proposes an innovative way of collecting and processing automatically the informations present in textual descriptions and GIS, based on our ontology. The output produced it is a structured data schema, with amplified data, that will be used by the procedural modeller, the second operating process. This generator applies the data schema given by the first process, and generates the 3D model of a city in a few steps. It is regulated by the rules that avoid inconsistencies in generation (e.g. generating building upon streets or intersecting each other) which can be edited by the user. Furthermore, it was presented the ontological data structure that guides the extraction of informations to form a coherent data schema. The designed ontology is abstract enough to be reused and expanded to a concrete architectonic style.

All the main technologies and methodologies needed to achieve the main goal of the project have been successfully tested in previous projects. Thus, we are confident that the hard work of integrating them in one single system capable of producing virtual reconstructions of archaeological sites will be successful.

In future work, we intend to develop each operating process described in ERAS architecture section based on our previous work. Our objective is to build a functional tool endowed of semantic capabilities to extract automatically informations that will feed the procedural modeller in order to produce enhanced virtual representations. The ontology will be also refined and structured to be enabled for use by the extraction information process. It is also our intention to develop a graphical user interface to provide an interactive way to the user of editing the ontological data structure and the rules that will control and constraint the generation process. Finally, it is expected a successful development and integration of all the referred components to provide an innovative tool to aid archaeologists refining their theories, based on faithful and consistent virtual representations.

6. ACKNOWLEDGEMENTS

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