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Representation and Visualization of Urban Fabric through Historical Documents

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Abstract

Documents serve an important role in understanding change in urban fabric. The available multidimensional (spatial, temporal and thematic) information in these documents narrate not only the various features of the elements of the urban fabric but also notifies their changes during time. CityGML standard is used to spatially and temporally represent the city objects. But it misses features to represent city lifecycle and its linked documents. The first part has been addressed recently. In this article, we propose an extension to CityGML standard to integrate city objects and relevant associated documents. Proposing a solution based on standards permits data interoperability. We also briefly describe how these documents are visualized in our current 3D urban environment prototype built over CityGML.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Computer Graphics]: Standards—I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—I.3.8 [Computer Graphics]: Applications—

1. Introduction

Buildings, bridges, tunnels, transport, vegetation etc. constitute the urban fabric. They appear and disappear from time to time, often replacing the older structures. There is an associated story for this change. For instance, new industrial projects require urban expansion resulting in the construction of new buildings and roads. New means of transport systems are created to provide access to the place of raw materials and other such industrial projects. Cities are therefore under constant evolution that is complex and difficult to understand and to explain locally or globally over time.

This evolution is often studied by taking into account the change in urban fabric and the change in urban planning. On one hand, these studies help to comprehend the history of a city, but on the other hand, these studies also provide guidance to the urban planners for their future projects based on the experience obtained from past successful as well as failed or non-realized projects. Some projects face socio-political pressures. Conflicts are resolved after a number of negotiations. Details of projects and the associated discussions or negotiations are obtained from diverse sources like municipal council meeting reports, newspaper articles, urban plans, aerial photographs, administrative correspondence, etc.

A way to explore the contents of these documents is to spatially and temporally locate them in a mapping environment in order to analyse urban change. Additionally, since these documents also serve as evidence to characterize the associated change from time to time, link between a change in urban fabric and the documents must also be established. Hence, the use of an evolving city

mockup that gives access to historical documents must also help to store and share the material used to analyse transformation of cities and landscapes [BCH10].

Projects with such purpose share a growing need for standards. CityGML [GKCKH12] is a standard provided by Open Geospatial Consortium [OGC] that is being used for representing structure and thematic information related to city objects. A versioning system to represent temporal city data has been proposed recently [CSG*16] to support versions of city objects and may be provided in the next version of CityGML 3.0. An ADE (Application Domain Extension) is already available for testing and using these new possibilities. But this standard misses features to represent document-related information and their links to any city object.

The main contribution of our article is to propose an extension to the CityGML in the form of an ADE that can be shared with other research communities. In this article, we describe this extension and its role in an interdisciplinary research project. A 3D mock-up of the city allows researchers to explore and visualize the roads, bridges, buildings etc. of the city in a virtual world as in the physical world. We therefore briefly present details of 3D visualization tool built over CityGML to view not only various city objects but also the associated documents at various levels of detail. Visualization of documents along with the linked 3D structures allows to filter out a lot of irrelevant documents during analysis.

Section 2 illustrates our use case (the study of cities located near Lyon in France) and discusses the urban fabric in cultural heritage. In section 3, various related works in this area are presented. ADE

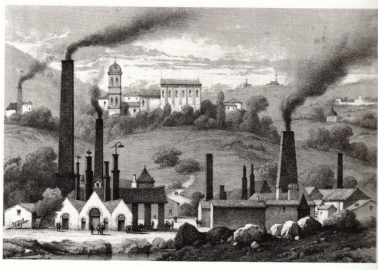


Figure 1: Drawing representing the factory of Terrenoire, 1851 - Municipal Archives of Saint-Etienne.

to represent documents is given in section 4. Section 5 presents an example and shows how the proposed extension can be used. Section 6 describes the prototype and finally in section 7, we present our future course of actions and conclude the article.

2. Urban Fabric in Cultural Heritage

2.1. Use Case: studying change of formerly industrial cities in France (19th and 20th century)

The aim of our work is to study the incremental urban changes of two formerly industrial cities of the Lyon-Saint-Etienne region in France (19th and 20th century). Though Givors and Terrenoire were (and still are) small cities, they were important sites of the first industrial revolution. The factory of Terrenoire was the first manufacturer of rails in France during the second half of the 19th century (Fig. 1). The site, situated in the town center stirred the rapid booming of the city of Terrenoire. It has seen several industrial restructurings until the late 1990's, when it was partially reconverted into a commercial zone and a residential area. The town of Givors also has to share such a similar urban legacy: one of its large industrial lands situated in town center, that produced raw materials for steel and glass industries since 1840 (Fig. 2). The process of de-industrialization is associated with the progressive change of an urban fabric for a long time guided by the needs of manufacturers. Both cities are nowadays parts of peri-urban areas of Lyon and Saint-Etienne. The objective is to observe the construction of these cities and their urban restructuring, in order to understand the existence of various industrial city models and their contribution towards the transformation of the sites. Several questions need to be answered. For example, what still remains of past conceptions of urban development in the actual city? How to comprehend an evolving urban fabric that is superimposing strong continuity and gradual change?

The complexity of the approach of urban change has to be reminded. Urban change refers to long lasting spatial dynamics and is characterized by transformations of city objects that depend on strategic choices made by local authorities involved in urban planning. Cities are of lasting nature and thus characterized by the inertia of the urban fabric and social structures. For instance, a canal first planned to join the river Rhône to the river Loire for industrial transport and passing through Givors was partly built in the end of the 18th century, but waterways traffic rapidly lost out to rail. The



Figure 2: View of the center of Givors and its industrial sites in the 1930's - Municipal Archives of Givors.

canal became totally non-functional in the 1870, as the last industrial boat used it in 1877. Still the canal found new urban usages until the 1950's (irrigation for community gardens, water sports...). Multiple urban projects aimed to defend the continuation of the shipping on the river and the canal were regularly proposed by local authorities until the 1960's. Most of these proposed projects were never completed but all of them are signs of an industrial city model influencing the vision of the future of a city. Finally destroyed, the canal was replaced in the 1970's by a motorway. If practices and projects reveal the existence of symbolic places that contribute to the duration of a city model, at the same time, transformations that are not recognized by local authorities can be systematized. Hence, we need a special focus on the moments of rupture in urban planning. Following the above idea, we've chosen to study urban change not only by analyzing physical and functional transformations of the existing city but also by analyzing urban planning, in a long-term perspective. Both dimensions explain the progressive spread of renewed city planning.

To provide such knowledge, it is necessary to collect and manage a wide variety of historical records. The mostly used sources to inquire urban change, such as construction permits, are rarer for small towns than for larger cities. Moreover, such sources will not give information on practices and negotiated projects that were never completed. Studying industrial sites also supposes the use of information like private records obtained from manufacturers. But these records often do not exist. Hence, files of urban projects produced by the various jurisdictions responsible for urban regulations may be used, as indirect information. These files may contain technical plans, drawings, required regulatory documents and correspondence with manufacturers. City council's minutes also deal with all the aspects of local policy including the negotiation of urban projects with the different stakeholders involved. When existing and found, punctual registered land plots, press articles, wind-up reports or even private architecture plans provide further information of the negotiation of projects over time. In another realm, pictorial documents also provide information required to inquire the features of past cities and to comprehend the symbolic of urbanity at historical moments.

Subjects of urban documents give information on the constituents of a city model, without systematically referring to specific projects of construction or existing city objects. For instance, steelworkers on strike or political will to relocate heavy industry

in centers are important elements to contextualize local history of de-industrialization. A further example is the reference to industrial pollution and protection of nature: when did such issues become systematic arguments in the justification of planning choices? Hence, we need to inquire contents of documents, describing not only the layout of places but also urban issues put to debate by individual actors and local institutions. Clarifying actors of the urban fabric and the themes of their speeches are important to understand urban change.

Still remains the challenge of the reconstruction of the existing and planned city over time, in 2D and partly in 3D, if the information is available. Indeed, this reconstruction helps to formalize the results from the acquired knowledge of urban fabric. We need to link references of city objects in documents to the representation of the city, whether to linear (a road and other network elements), to surfacic (an industrial zone and other delimited area) or to geometric elements (a building and other individual city objects). All references of city objects need to be located on a mapping environment. This environment can be produced thanks to archival sources providing snapshots of the cities at specific moments in time. Such documents consisting of high quality black-and-white aerial photographs and cadastral plans are quite rare, one every fifty years or more. The mapping environment is then enriched with the use of previously mentioned other historical records.

The life cycle of planned or existing city objects are indeed deduced from documents. Many records only provide a summary information: an object existed or not at the time the document was produced, a project was debated at the time the document was produced. Hence, we need different records to know the temporal trajectory of a project or an existing object. The fig. 3 illustrates how documents help to inform the life cycle of planned city objects, with the example of two related construction projects, the one of a new railway line (V) that was actually built and a new railway station that was finally never built (V'). First discussed in 1868, the aim of the new line of "Givors La Voulte" is to double the connection between Lyon to the south-east of France.

The route of the railway line in the center of the town was largely debated: multiples administrative documents testify the importance of the negotiation that conducted to three possible versions of route (V0, V1, V2; V3 was the one actually built). A technical plan drawn in 1873 by the engineer of the railway company of Paris to Lyon and Mediterranean (doc. a) introduces a project of a new railway station named "station of Servettes" (V'0), situated on the planned new railway line. Several other documents such as an extract of a city council's minute (doc b) helps to understand when and why the project of the station itself was reactivated. This debate occurred in 1911; from 1873 to 1911, the railway line of "Givors-La Voulte" was finally built (V3) and caused a rupture within the existing urban tissue. The reactivation of the project of railway station reveals how local mobility is redefined at the time because of the presence of the infrastructure. Thus, urban projects can reappear decades after the first trace of their existence, which has a great significance for urban fabric and the gradual evolution of the urban planning. To understand their historical context, the access and reading of historical documents related to projects through a mapping envi-

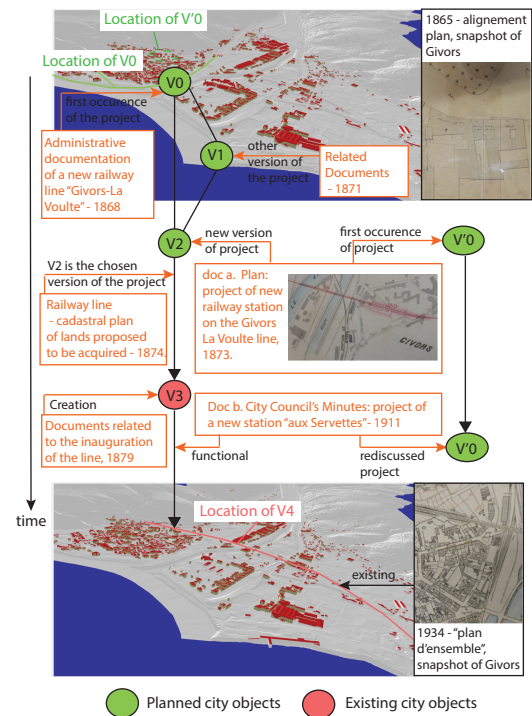


Figure 3: Life cycle of a construction project of a new railway line (V0 to V3) and of a construction project of a new railway station (V'0).

ronment appears to renew ways to investigate, produce and store analyses [BCH10].

As a first conclusion, the use case permits to precise what are the different types of metadata required to investigate urban change: to begin, we need to trace archival records, according to their nature and their original producer, who are indirect or direct actors of urban production. Secondly, we need to trace key topics in the negotiation of the future of the sites and to which urban objects these issues are associated with. Finally, we also need to trace urban transformations and urban projects, while managing spatial, temporal and semantic attributes of city objects in relation to their references in documents. Such reference system may validate city object attributes and the quality of their temporal representation in a mapping environment. The temporal 3D mock-up is the medium to call documents and interrogate their content according to different explanatory dimensions of urban change. The mock-up also reflects what is known of a past state of a city. The addition of new documents will clarify this representation.

2.2. Standards

CityGML is an international standard that is being increasingly used for representing various city objects and their three dimensional features at different levels of detail. For example, it can be

used to represent three dimensional features of city objects like buildings, bridge, tunnel, vegetation, city furniture, land relief etc. It also supports representing these features from lesser granular levels like the regional level to fine granular levels like the interiors of a building. The use of CityGML promotes data interoperability, allowing the researchers to share and exchange their work using their existing software and tools.

But CityGML is also an evolving standard. Various information communities have been using it for representing their own business-specific information. As discussed above, our work also needs additional features in CityGML in order to represent the documents and their association with different city objects spatially and temporally. CityGML provides different means to extend the standard to suit the business needs of many business communities. There are primarily two ways by which the standard can be extended, one by the use of generic objects and the other by Application Domain Extension (ADE). Generic city objects are used to dynamically extend the existing software built over CityGML. Hence this extension is limited to the users of those software applications. ADE can not only extend CityGML but the underlying schema and the associated data can also be shared with other communities. Thus, an ADE can be used to add new attributes to existing CityGML features or add new CityGML features.

An ADE based on [CSG*16] to represent temporality of the city objects has been developed. With this extension proposing a versioning system, the users are able to represent and visualize the change of city objects in course of time such as the various stages of development of a building, right from its construction to demolition. Versioning allows to represent changes like additions, removals or updates of features of city objects. The extension also provides features to manage workspaces of researchers. The workspaces can be used to study alternative city developments, to understand different scenarios of urban change and to propose new hypotheses.

But the CityGML has no support to represent various documents in a mapping environment. Yet, as explained above, these documents play a significant role in understanding urban change. Hence, we need to propose an ADE to represent these documents referring to any city object. This extension must also be capable of representing documents that serve as the information source to the past or projected transitions of the city objects. The proposed extension serves not only to represent various documents but also use this representation to test and query various hypotheses often required by the urban planners. It is not only a new way to query document database but it also brings a new way of understanding changes of the city. It may be important to explain the role of a document for understanding why a city or a city object is changing and not just how it has changed.

Works like the Dublin Core metadata initiative provide us a guidance to decide the relevant attributes concerning the documents.

3. Related Works

3.1. Evolution of urban fabric: data models

Studies of the evolution of cities are dominated by historical Geographic Information System (GIS) approaches. The insertion of

time in geo-spatial databases aims to enrich spatial analysis by an access to the historicity of transformation processes. We can distinguish two main directions in historical GIS. The first one is associated to a territory-oriented approach [BNP99]: the comparison of two snapshots of a territory is used to represent urban change at different periods. A previous state of all city objects of a territory is compared to a new one to detect change. But most of historical GIS are nowadays based on the updating of information related to individual city objects when a change is observed, that is to say notified by an historical document.

Following this approach, [Sim12] studied the evolution of historical objects in urban landscape considering the evolution of their functional and constitutional elements. This work is based on an official thesaurus to define the functions of a historical object (urban value and usage value). It further defines the constitutive elements of a historical object. Thus a change in historical object corresponds to a change in the functional value or in a constitutive element or even both. They used different types of documents like material sources, textual or pictorial sources to study their evolution.

Also related to the understanding of past evolution of cities, [LRS08] proposed OH_FET model to study urban fabric over long time spans. The researchers of the project considered three main aspects of a historical object: its social use (what), its location and surface area (where) as well as the duration and chronology (when). Like others, this historical GIS is based on the conceptual framework for spatio-temporal information defined by [PD95], and therefore on the recognition of the interdependence between temporal, spatial and thematic dimensions of objects. This means that a new version of object is updated when a notified event occurs, that conducts to a change of at least one attribute of an object of the city. Such historical GIS also need to model evolution of processes, hence to propose a diagram of every possible transitions from a state of an object to another through time [CSG*16].

Such an approach can be seen as an optimal solution to assure the management of the life cycles of city objects. But they also respond to a pragmatic approach of past states of a city for which systematic information of changes that occur is not available. Because remaining records will represent or describe only partial elements of a city and their distribution over time is erratic, historical GIS projects accept the discontinuity and/or the heterogeneity of the 3D mapping in space and time [AL15]: only data collected depending on the progress of the documentary research are represented.

Similar methods are also developed in the field of 4D-GIS (considering time-dimension) that describe projects "moving beyond the traditional 2D border" [DRBM13], mainly for archaeological purposes. 3D modeling of past cities often integrate direct creation of digital elevation models thanks to photogrammetry and laser scanning, and models issued from the interpretation of historical documents available, especially various graphic sources [PCD*13, CJH*15]. 4D GIS or so called archaeological information systems are increasingly being based on an approach, often inspired from the OH-FET model (historical objects have temporal, functional and spatial attributes). It was recently exemplified in Europe by the Nantes 1900 project [QHLK15], the virtual Leodium project [PCD*13] or the reconstitution of the medieval town of Cluny [RHPM*14]. In projects interested in change of cities and

informing larger scales of territories, the 3D may remain partly schematic because the objective is not to faithfully represent reality but to inform the reconfiguration of the urban fabric and to propose a representation of spatio-temporal dynamics of cities [LRS08].

Much of the above works focused on particular historical buildings, towns and cities. These approaches still need to be further generalized so that researchers can not only use them for other towns and buildings but also to share their 3D or 4D mockups in an interoperable manner. These works also point out a wide-ranging differences [SDLVF10, LRS08, Sim12] among the historians and urbanologists on defining the different possible transitions from a version of city object to another. [DRBM13] also stresses on the missing standards for the four-dimensional archaeological GIS.

3.2. The need to access documents in 4D GIS

All the projects described above also reveal a shared need not only to inform the dynamics of historical objects but also to integrate documents in city models. For a long time, both prospects remained separate in research projects. On the one hand, scientific projects intended to make available wide-ranging of digitized historical documents on map interfaces for cultural heritage and inventory. This was actually the first direction of an historical research using GIS [Gre03]. On the other hand, there are studies related to the constitution of spatio-temporal databases related to urban fabric of cities or individual architectural buildings, regardless of the integration of the origin of the data in the model.

Still, this integration was early identified as a necessary component of 4D GIS [Alk93, HPR00] for two major reasons. The first one is to provide access to the material linked to a given representation. In response to the need to trace the origin of collected data, some of the previously mentioned 4D GIS projects intend to propose infrastructures that give access to archived materials associated to objects of the past cities and that manage heterogeneous historical sources [YNI*08, PCD*13, QHLK15, TR15]. Thus, several data models have been proposed to describe and explore the documents related to the cultural and architectural heritage. [AL15] uses documents to study the evolution of historical elements of the city. In particular, they chronologically arranged their documents to understand the various periods when a particular historical element was documented or not documented. This helped them to infer the non-existence, hypothetical existence, verified existence, hypothetical removal and finally their verified non-existence.

A second challenge is to provide an access not only to spatial, temporal and geometrical information but also to other explicative dimension of the urban fabric provided by sources. Indeed, historical knowledge can't be reduced to the analysis of past physical aspects of cities. The shift in actual data models from description to understanding change (how and why) interrogates on the possibility to conduct an historical discourse about urban change. As detailed previously, understanding change of cities supposes to give access to sources containing elements of interpretation: who are the actors of urban fabric and related sources? What did they do and how? What did they want to achieve? Finally, both requirements question the possibility to preserve the richness of documents, especially for textual contents. If a recent controversy emphasized the insufficiency of interrogated using techniques and keyword search in

digitalized textual sources, 4D GIS are also an opportunity to interrogate differently such contents [Gre14]. For instance, researchers of the Nantes 1900 projects introduced medium that are historical descriptive pages and code lists of thematic subjects related to historical sources that were provided by historians working on the project [QHLK15]. Our proposal described below also intends to respond to the need to provide an access to collected documents regardless of their types and to manage the way we interrogate them, in relation to the temporal citymodel.

There is still no consensual standard to define the principal subject or purpose of a document. But some standards provide a solid basis to work in that direction. Dublin Core metadata initiative has been increasingly used by various research communities to manage their electronic records [Wei97] like scientific publications. To study urban fabric, the spatial, thematic and temporal aspects of the documents need to be considered. On one hand, there is the CityGML standard that is capable of representing various city objects and their evolution and on the other hand, we have a well-researched study on the document metadata. We explore in the upcoming sections a way to resolve the missing links between the above two, following the effort to propose generic approach to represent past cities and to extend the CityGML standard.

3.3. Experiments in 3D visualization

For studying urban fabric, visualization has been a key tool whether in the form of aerial views or cadastral plans. In a multidimensional context, 3D visualization has been explored in many works. Doc-Cube [MDA03] lets the user query and explore large document sets in a 3D visual environment. Urban documents, especially images and plans can be spatially and temporally located. The number of such documents available varies from place to place and time to time. A lot of user-generated photographs are available for highly touristic places whereas for some places, the available documents can be quite a few. Therefore visualization tools must consider the user-context and document priority to display relevant figures.

[ZTM14] explores displaying textual-based information in 3D urban environment. Four perspective factors (text size, text color, text transparency and text-resolution) were tested and evaluated. In our work, we want to extend this to visualize documents.

4. A proposal to represent and manage documents in a 4D approach

Based on CityGML and the ADE on managing temporality and versions [MG14, CSG*16], we propose another ADE to represent documents (fig. 6). In a proof of concept tentative, we will provide an ADE, but this work may also be proposed as a modification to the existing CityGML standard.

Thanks to data provided by the use case described above, this ADE is tested, using an urban scene editor called 3D-USE [Ala], a prototype that has been developed to test a generic approach of evolving urban landscapes. With 3D-USE, the user can upload CityGML files, manipulate and interactively visualize 3D structures of city objects. The ADE described below tests this exploration along with documents related to evolving city objects.

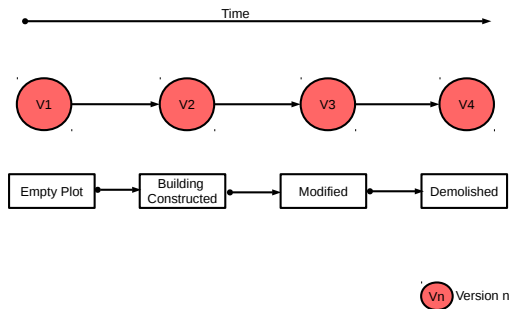


Figure 4: Real lifetime of a building: versions from its construction to demolition

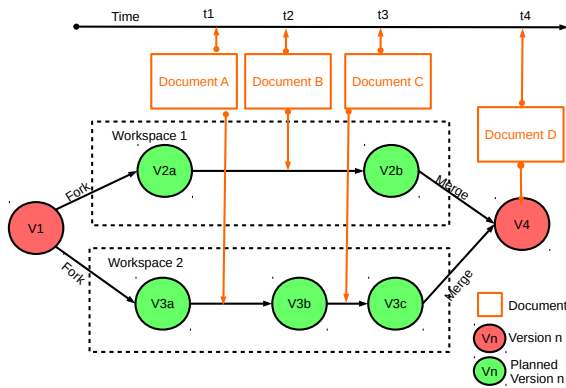


Figure 5: Workspaces to test various hypotheses justified by documents. Orange arrows show the time at which a document was published. They also show the link between a document and a version or a version transition

4.1. Relation between CityGML UML, the versioning system and documents

ADE classes [CSG*16] in (fig. 6) marked in blue like VersionableAbstractFeature, Version, VersionTransition and Transaction are used to represent various possible scenarios of urban change. In (fig. 4), a transition of buildings right from the state of an empty plot to its ultimate demolition has been shown. Each aspect has been assigned to a version. More additional versions can be added by a cultural heritage researcher if the building (especially the buildings of historical importance) has undergone several significant changes worth mentioning. But in such a case, every proposition need to be justified by a document. Thus a document can refer to any particular version of a city object like a building in construction as well as its changes.

In (fig. 5), we show this important link between the documents and the versions as well as the version transitions. Take for instance,

a researcher studying the impact of two parallel projects in two different scenarios named “Workspace 1” and “Workspace 2” proposes a series of transitions of the concerned city object (building), impacted by the two projects. A photograph (Document D) of a version of the building (V4) taken at a precise point in time (t4) is available; it shows the final state of the studied location. The transitions V2a-V2b and V3a-V3b, are justified respectively by Document B and Document A. The publication date (t1) of the Document A is somewhere in between the time when versions V3a and V3b were actually proposed. Nevertheless this document provides the information related to the change in some attributes. One can also consider another scenario where two independent researchers propose two different hypotheses of transitions of a particular city object based on different information sources.

Thus some documents give a snapshot of the city objects at a particular instant of time whereas some others concern the change of a single object or groups of objects. DocumentObject described below in detail is added in fig. 6 to represent a document referring to a particular version of the city object. In addition to this, a link has been added between the VersionTransition and the DocumentObject in order to track the document that justifies the information related to a change in value of an attribute or attributes of a City-Object.

4.2. Documents in CityGML

After explaining the link between documents and city objects as well as the link between version transitions and document, we now describe the three major object classes in our proposition (DocumentObject, Tag and Reference) of our proposed ADE for CityGML. DocumentObject is considered as an AbstractCityObject. Thus it inherits all the features associated to the GML (AbstractGML, AbstractFeature etc.) [SX08]. It also allows us to make use of the other features like the ExternalReference to provide links to various information systems having a copy of the concerned document. Considering a document as an abstract city object has the additional benefit of making the use of CityObjectGroup. A CityObjectGroup is a collection of city objects. Therefore a DocumentObject may consist of a single document (like a photographs) or a collection of different types of documents like maps, photographs etc.) One can also select desired city objects (buildings, documents etc.) to create a city object group for the purpose of sharing. We used attributes based on Dublin core metadata initiative and added some newer ones especially those related to categorizing the subject and the original producer of documents. These categories are important for facilitating the search by the end users.

The attributes of the DocumentObject are given below:

- title - title of the document.
- subject - the principal subject of the document.
- subjectType - the category/class of the principal subject of the document as defined by community.
- description - the detailed description of the document.
- creator - original individual creator/producer of the document.
- creatorType - the category/class original individual creator/producer of the document.
- publisher - the organization at the origin of the publication of the document.

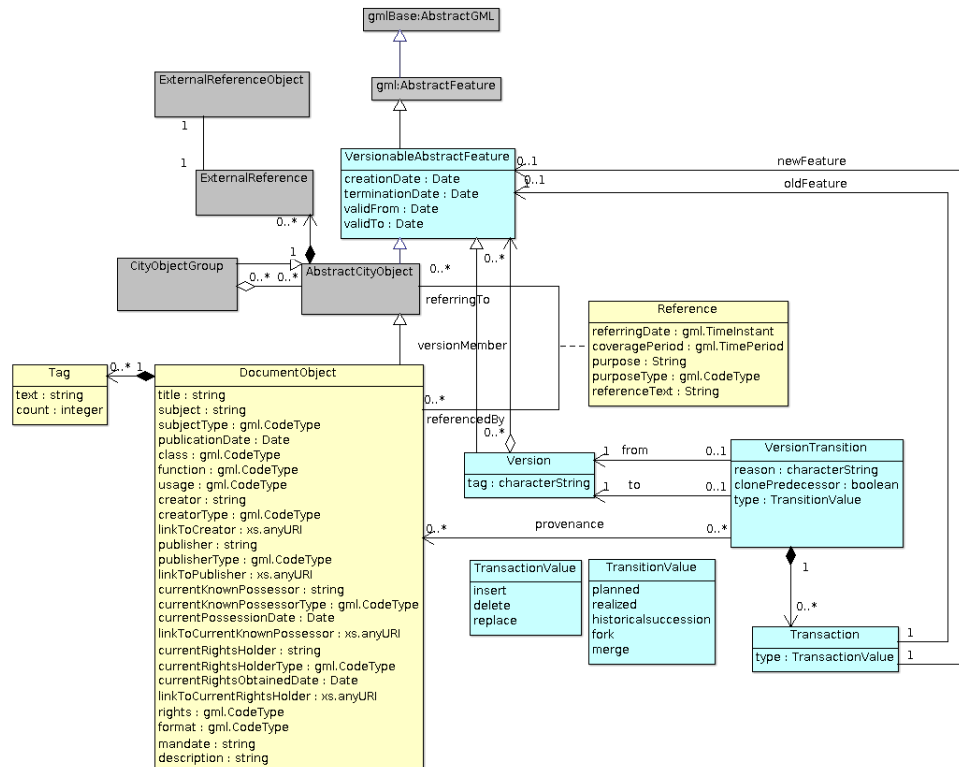


Figure 6: ADE to integrate documents in CityGML. Classes in grey come from the existing CityGML standard [GKCKH12], those in blue come from ADE on temporality [CSG* 16] and those in yellow are the new proposed classes

- **publicationDate** - the original date of the publication or creation of the document in the physical world.
- **class** - general classification of the document.
- **function** - the function of the document, like a document serves the purpose of a permission to construct a building.
- **usage** - the current usage of the document, like document is currently used as a historical record.
- **format** - data encoding format of the document, example: jpeg, png, pdf.
- **currentKnownPossessor** - the current known holder/possessor of a material version of the document.
- **currentPossessionDate** - the date on which a material version of the document was recovered/possessed by the current known possessor.
- **currentRightsHolder** - the current rights holder of the document.
- **rights** - rights of usage for the document as specified by the system.
- **mandate** - a mandate describing the document-keeping requirements.

In addition, we also have additional attributes to manage any external links (like a website or an external database) concerning the creator, producer, currentKnownPossessor and currentRightsHolder. Similarly like currentPossessionDate, we have attribute currentRightsObtainedDate to manage the dates related to the date when the currentRightsHolder obtained the rights to the docu-

ment. The three attributes class, function and usage are also present in other CityGML objects like building, tunnel, bridge etc. and serve similar purposes as described above. Similar to the approach taken in CityGML 2.0 [GKCKH12], we make use of the data type gml.codeType to create desired categories/classes (for e.g. in subjectType, creatorType etc.). This allows various communities to add, modify, delete and share allowed possible values according to their needs.

4.3. Relation between documents and urban components

A document may refer to any city object. Since a document in itself is a city object, it can also refer another document. References are important since they give information about the city objects of importance at different periods of time. The association class Reference has the following major attributes:

- **referringDate** - the date for which a particular (abstract) city object is referred to by the document, with respect to the original date of publication of the document,
- **coveragePeriod** - the period for which a particular (abstract) city object is referred to by the document, with respect to the original date of publication of the document,
- **purpose** - the purpose/reason for which a particular (abstract) city object is referred to by the document. Take for example, in a

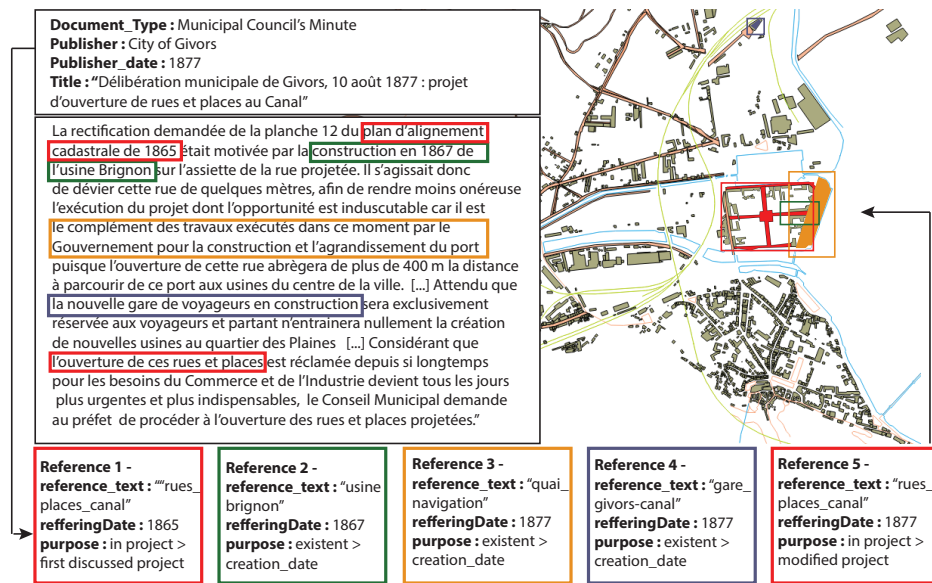


Figure 7: Example of model instantiation: an extract of municipal council meeting referring to various city objects

city council meeting report, a city object may be referred for the first time before giving approval for its construction.

- **purposeType** (the class/category of purpose/reason for which a particular (abstract) city object is referred to by the document). **purposeType** values are derived from the works of [SDLVF10] like creation, demolition, variation etc.
- **referenceText** - the name by which a particular (abstract) city object is referred to by the document.

A document may refer to a location, like the name of the city or a particular city sector. We propose to use the city object 'LandUse' in CityGML to create various locations of interest and then using them for references.

Additionally, we would also like to manage the key content of the documents. Sometimes, a document may not be completely accessible. Only the key phrases present in the document are known along with the number of their occurrences. The class **Tag** has therefore two attributes:

- **text** - the interesting keyword/keyphrase present in the document or concerning the document
- **count** - the number of times the interesting keyword/keyphrase is present in the document.

With the above extension, the spatial, temporal and thematic relation between documents and urban components can be represented.

5. Example: description of an historical document

Fig. 7 proposes a practical example of how we manage so-called references, especially in textual sources. Dated from 1877, the chosen extract of Givors council's minutes refers to the reactivation of

a construction project of a public place and two streets that was first discussed in 1865 (reference 1). As explained in the source, the reactivation of the project is due to two changes in the city: the ongoing construction of a new quay to extend the industrial harbor of Givors (reference 3) and the ongoing construction of a new railway station (reference 4). The modification of the project is due to another change which is construction in 1867 of a new factory (reference 5) on the first chosen route of one of the streets. Every reference is linked to shapes of planned or existing city objects and their states (in construction, planned...) are specified in documents. If the project of construction of place and streets was never realized, a focus on one document helps to understand the context of a negotiation of a project and how changes in the city lead local authorities to rethink their planning strategies.

The CityGML content corresponding to the reference of a building by a municipal council report meeting is given below. A small part of the XML is given here to illustrate our purposes. The building in Reference 2 is referred to by the name 'Usine Brignon' and for a past date of 1865. First we describe some of the attributes of the building, then those of the document and finally those linking the above two through a reference. Notice the use of XML Xlinks in reference to refer to the building and document.

```
<cityobjectmember>
  <building gml:id="bldg_102">
    <identifier>b102</identifier>
    <function>Factory</function>
    ...
  </building>
</cityobjectmember>
<cityobjectmember>
  <documentobject gml:id="doc_303">
```

```

<identifiant>doc_303</identifiant>
<creator>Municipality of Givors</creator>
<title>Deliberation municipale de Givors,
  10 aout 1877: projet d'ouverture
  de rues et places au Canal</title>
<publicationDate>10-08-1877</publicationDate>
...
</documentobject>
</cityobjectmember>
<reference gml:id="ref_001">
  <referringDate>1867</referringDate>
  <purposeType>Existing-Creation</purposeType>
  <referenceText>Usine Brignon</referenceText>
  <referringTo xlink:href="#bldg_102"></referringTo>
  <referredBy xlink:href="#doc_303"></referredBy>
</reference>

```

The main difficulty of the work remains in the quantity of data available. Lots of geo historical information are in 2D like in the example given here. Another limitation is the quality of documents themselves: as often reminded by humanities researchers, such exploration won't replace the need for reading and interpretation of the chosen sources [Gre14]. Even though not every historical source gain from being spatially localized, some intuitions about urban change can be formalized by their exploration in an evolving mapping environment. Of course the interaction between human sciences and computer sciences is at the core of this positioning.

6. User Interaction: Prototype for visual representation of documents according navigation point of view

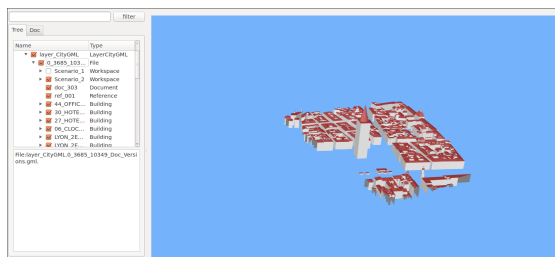


Figure 8: 3D-USE tool to interact and visualize with CityGML objects

To visualize the city objects, we use the abovementioned urban scene editor called 3D-USE. After uploading CityGML files, 3D structures of city objects like buildings, bridges etc. can be visualized. The goal is to let the user interact with city objects and see different views of the city from different camera angles. Apart from the menu bar, the user interacts with 3D-USE in four different ways. When a user uploads one or more CityGML files, various city objects are displayed in a textual tree view format. On choosing a particular city object, its attributes are shown in another view. A major portion of the tool is to provide a three dimensional view of the city objects. Finally, a limited search option helps the user to filter out desired city objects with desired query terms and the corresponding city objects matching the query are selected on the tree view as well as on the 3D view. Fig 8 shows the view of the tool after a CityGML file (extended with the example given above)

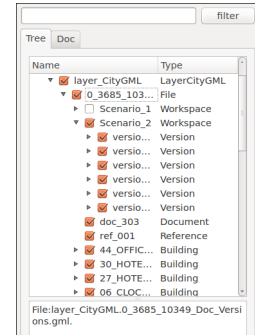


Figure 9: Tree view in 3D-USE displaying workspaces (and versions), documents, buildings etc.

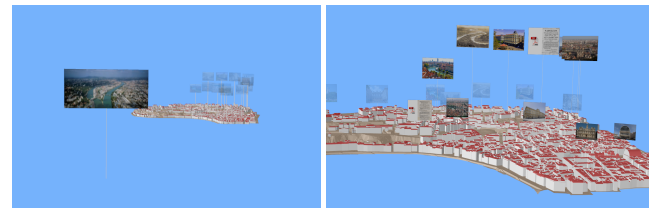


Figure 10: Documents visualized with different transparency values in 3D-USE. (a) Panoramic View and (b) Zoomed-in View

is uploaded. The tree view (fig 9) shows the various city objects including the documents, workspaces, buildings etc. The user can interact with the tool by choosing the desired items. For example, here, the user chooses the workspace “Scenario_2” and a detailed list of the various versions are shown. Likewise, the user can select/unselect a document or a reference.

In our prototype, the user can also enter the details of a number of documents. At the time of entry to 3D-USE, the user specifies various characteristics of the document like its title and location. Primarily, documents like images of various encoding formats (like jpeg, png) and textual formats (like pdf) have been taken into consideration. These documents are displayed at various spatial levels based on the camera position. Two visual factors are considered for displaying images: size and transparency. Several factors decide whether or not to display an image. Due to the lack of space, these methods will not be described in this paper. One of the factors can be the distance. In this case, when the camera is far from the various city objects, panoramic view images are shown and other images are shown with lesser transparency (fig. 10 (a)). When the camera gets closer to a city object, any image or textual document associated to the object are shown in bigger size and images of other nearby objects are shown with lesser transparency (fig. 10 (b)). User can also search the documents based on their various attributes like the title. The selected image(s) are then highlighted. Our current effort is to further enhance this search and filter option so as to consider the associated time, subject type etc. as well as to consider the user context.

7. Conclusion

The role of documents in understanding the change in urban fabric cannot be underestimated. They play a very important role in constructing a view of the city model at a specific instant of time as well as to notify the reasons for specific changes in urban fabric. Yet they come from heterogeneous sources and are of different types or formats like texts, iconographies, maps. Our proposed model is able to represent such documents as well as the relevant metadata important for understanding the urban fabric in the context of cultural heritage in a manner that can be easily exchanged between experts as a CityGML file. It therefore provides a new method to share and exchange documents related to urban changes but can also be used for a database storage.

We continue to explore user interaction through visualization process of these documents in a 3D mapping environment. The previously integrated temporal features of CityGML need to be further tested along with the documents. There is a growing need to focus on proposing a generic model for representing the data quality information in the study of past cities. Therefore another important direction that we are focusing on is the quality of documents. The quality of information contained in the documents must be linked to the city objects. For example, a document may refer to a location whose perimeter has not been well defined or sometimes cannot be inferred. We need to integrate quality aspects to our tool in order to manage what we call fuzzy city objects. Another requirement is the need to automatically correct the model when new information from more valid sources are obtained, sometimes requiring us to change the attribute values of city objects.

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