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Automated Production of Interactive 3D Temporal Geovisualizations so as to Enhance Flood Risk Awareness

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Abstract

The FLOOD AR project originates from an explicitly expressed need for digital 3D temporal georeferenced models that can be largely diffused among riverside residents through computers and mobile devices, in order to support the raising of public awareness concerning flood risk along the Rhône river. This project is led by a multidisciplinary consortium of researchers from several fields who are working together to develop usable tools and models as well as recommendations regarding visual content, interfaces and context of use for those 3D models. As far as computer science is concerned, given the practical difficulties of resorting to 3D georeferenced technologies for practitioners and the current limitations of commonly used GIS data formats and tools, automatic tools allowing any interested parties to produce 3D temporal models in order to support flood risk awareness' enhancement were developed in the first phase of the project. The storage of those 3D models in an interoperable format (CityGML) ensures that those 3D temporal models are available for other purposes in relation to flood mitigation (regarding flood risk mitigation planning and public consultations or visual analysis for instance). Automating the production of 3D temporal models guarantees that those models can be produced for any territory along the Rhône river. A tool to visualize those 3D temporal models interactively will also be made available as an open source tool as part of the project.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Computer Graphics]: Curve, surface, solid, and object representations—I.3.6 [Computer Graphics]: Interaction technique—I.3.8 [Computer Graphics]: Applications—

1. Introduction

Raising citizens awareness about flood risks is an important goal as far as flood mitigation policy is concerned. By making people understand what can be done to protect themselves both preventively and during a crisis, it aims at reducing damages due to floods. In the case of the Rhône river, in France at least, scientific studies and polls have shown that, although the vast majority of citizens is willing to receive information about risks, only very few people are aware of flood risk and of measures that can be taken to reduce their vulnerability. Public authorities are thus actively looking for renewed ways and means for explaining and communicating about flood risk and, more specifically, in the case of the Rhône river, they are looking for georeferenced 3D temporal models that represent the flooding of a territory over time and that can be explored in interactive ways on computers and on mobile devices.

This paper presents the first developments and results of the FLOOD AR project, which is oriented toward the development of accessible and usable tools fitting those requirements. The proposed tools allow for the automated production of 3D temporal georeferenced models of flood to be produced and then interactively

visualized through spatial and temporal navigation. This paper first describes how the project was developed in response to specific demands from practitioners that required research in several areas of expertise (2). It then explains the research challenges that needed to be met (3), followed by the description of the digital tools and methods that have been successfully developed so far (4), before giving insights on how to move forward in order to produce tools adapted to flood mitigation policy (5).

2. Context and users requirements

2.1. Context and general objectives of the project

The need for tools to support the raising of citizens' awareness about flood risks is strong and citizens living in areas submitted to natural hazards are expressing the wish to be informed by public authorities [GB10] [DHMM04]. Indeed, polls that were conducted specifically among the inhabitants of risk areas in the Rhône river basin in 2009 and 2013 showed that 31 percent of all inhabitants were expressing a will to receive more information from public authorities, making this demand the first item on the list of ways to

ease life for residents of areas submitted to flood risk. Nevertheless, existing documents about risks are rarely consulted. The same polls thus revealed that only 1/5 of the inhabitants knew they were in risk areas and that less than 10 percent of them had ever consulted the information and regulation about risk provided by public authorities on their websites. This lack of knowledge of already available information has been noticed and taken into account by practitioners and they consider it to be linked to a failure in the spread of general information about risk (so that people would know that there is a risk on a given territory), to difficulties in finding official documents and maps on official websites and to shortcomings of those official documents, in particular 2D maps included in flood mitigation plans. Practitioners and researchers working on the project have established that those maps, in order to support the raising of citizens' awareness, lack interactivity, easy-to-decipher backgrounds as well as spatio-temporal representations of how a flood occurs over time.

This is why risk managers are actively looking for visuals that can effectively help citizens to understand how a flood spreads on their territory and that can be easily consulted and diffused among a large audience. They are willing to resort to 3D models since those types of visuals have proven their efficiency regarding the explanation of how a flood can affect a given territory during public consultations both with elected representatives and citizens ([JL10] [Jac11] [Jac14]). Accessibility of those visuals as well as widely accessible tools easing their production is considered as a key element in order to allow as many practitioners as possible to make use of those visuals in various contexts and events directed toward riverside residents. Resorting to an interoperable format to store those 3D models is also essential so as to allow these models to be reused for further tasks, including analysis of flood risk among experts, public consultation about measures to be taken, vulnerability analysis and training in crisis management. Indeed, previous research projects led together with practitioners along the Rhône river have proven the efficiency of 3D georeferenced models in performing those tasks. This encourages us to develop specific open source tools that can be largely spread among interested parties, and to use CityGML as our storing format [KGP05] [Kol09].

2.2. Users requirements

Following this diagnosis, a users requirements study has been conducted together with practitioners in order to define their needs in terms of tools and visuals to communicate information about risk to citizens. This analysis is based on both results from scientific studies on the subject of raising flood risk awareness [?] [GMLN12] [Aqu13] [CEP13] [Jac14] and exchanges with practitioners. The technical criteria derived from this analysis can be summarized as follows :

1. **Georeferenced technical data about flood risk, in particular results from hydraulic modelling, have to be visualized on a 3D model of the concerned territory**, 3D geovisualizations of this kind of data having proven their efficiency as far as comprehension of flood risk by elected representatives and citizens is concerned;
2. **Flooding of a territory should be represented over space and time, through a dynamic temporal model**, so that citizens can spot the spatial origin of overflows and become aware of floods' velocity and duration;
3. **3D spatio-temporal models need to be visualized interactively** and be usable on mobile devices, such as tablets and smartphones, as well as through on-site augmented reality, if possible.

Despite the growing number of technologies and tools available to produce 3D georeferenced models, producing 3D temporal models that can be visualized interactively is not such an easy task and several practical difficulties arise so that practitioners often lack the technical wherewithal to actually resort to those kind of models. Technical difficulties that need to be overcome are as follows :

- **Production of a coherent 3D model in CityGML using heterogeneous datasets**: data needed to represent the existing territory, its hydraulic configuration and results from hydraulic models are numerous and heterogeneous in resolution and stored in various proprietary formats, so that the production of a unique 3D model in an interoperable format like CityGML requires technical skills as well as the development of adequate tools, since GIS tools used by practitioners, in our case, cannot perform the necessary transformations;
- **Storage of temporal information in a 3D georeferenced database**, which can be theoretically done through CityGML, since there is a specific temporal extension [CSG*17], but the technical resources necessary to produce those databases are either not accessible or too complex for many actors in the field of geographical information sciences;
- **Methodologies on how to design 3D interactive temporal interface and 3D visuals**, which are scarce at best as far as their contribution to comprehension of flood risks in collective settings, so that additional research is needed in order to determine their efficiency as visual support in events aiming at raising citizens' awareness about flood risk.

3. Research challenges and project overview

From a scientific point of view, research thus need to be conducted both on 3D temporal georeferenced models and their efficiency. Indeed, there is little scientific literature that can help design devices allowing for the use of 3D interactive and temporal georeferenced models that can be effectively used in collective and collaborative settings with non-experts.

3.1. Research challenges

First, the use of 3D geographical information systems (GIS) tools and visuals for the comprehension of technical data about floods by citizens is poorly documented. As far as GIS and three-dimensional GIS are concerned, scientific literature in the field of flood risk management is indeed mostly dedicated to the use of georeferenced data and tools to produce data about risk in relation to hydraulic modelling, to produce analysis of flood risk and/or to build cartographies of flood risk and their impact on a given territory [CCS14] [AAC15] [CEO*15] [DK16]. Three-dimensional geovisualizations tools are also mobilized in crisis management contexts as tools to visually analyze a given phenomenon [NM15] or to deliver in situ indications to endangered populations (for instance

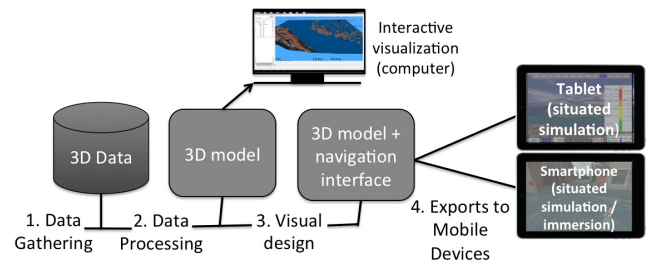
evacuation itineraries) during a crisis [LH15]. More broadly, three-dimensional geovisualizations have been used to produce visualizations of risk as part of decision support systems, oriented toward experts [SABWIBB15], but not toward citizens.

Moreover, in the specific field of flood mitigation, scientific studies of the uses of three-dimensional geovisualizations, as well as those interested in two-dimensional maps, are also concerned, in the vast majority of cases, by *individual uses*, that is to say how information can be perceived and understood visually by each map reader. Many scientific contributions in the field of risk communication are thus oriented toward semiology and graphic means to convey a given message about flood risk [Che06] [HKW09]. Those contributions are focused on individual map reading situations and do not consider a collaborative use of two-dimensional risk maps. The roles played by two-dimensional risk maps and other visual documents in operational contexts have been studied in the context of flood mitigation plan and risk communication in France, shedding light on the shortcomings of those representations taking into account how they are perceived by citizens [GMLN12] and how they are sometimes used by some actors to impose their decisions rather than to enhance consultation and participation of citizens [LB07] [Mar07]. On the whole, very few scientific works have been dedicated to explaining the roles representation can play in collective and collaborative settings.

In addition to those challenges in the design of 3D temporal models of flood for events and meetings dedicated to raising citizens awareness about flood risk, challenges in the field of computer science also need to be met. Indeed, both algorithms and tools need to be produced in order to create a temporal 3D georeferenced database in an interoperable format (CityGML) and to interact with this database through spatial and temporal navigation. Extensions have been proposed to manage temporal information in CityGML models [MG14] [CSG*17], and we use the last one in order to store our temporal data. We also need to visualize and interact with such temporal 3D models, as [CDMB*07] do with a tool based on Google Earth. Some papers present methods to visualize temporal data [SC00] [AMST11] but we chose to use a single timeline in order to be able to select a precise date and to render in the 3D scene the objects corresponding at this moment.

3.2. Project overview

Drawing from this diagnosis, a global framework has been established for the FLOOD AR project that describes the necessary steps to be taken toward the production of relevant tools to produce useful visual support for flood mitigation policy, as defined in the last paragraphs. A pluridisciplinary consortium has been established with researchers from various fields, each of them tackling one or several part(s) of the process. These steps can be detailed as follows : first, data from various sources need to be gathered or produced from raw data (topography, land use, aerial photography, built structures, multiple hydraulic data about flood describing its spreading over time as well as data about dams, dykes and plants along the river). Then all those data need to be assembled and processed in order to get a 3D temporal georeferenced model in CityGML, which required several developments from the computer scientists involved in the project 4. From then on, the auto-



Steps 1 to 4 are divided among the various researchers involved : GIS specialists are more or less involved in every steps, computer scientists are mainly involved in step 2 but also work on step 4 and information and communication scientists are mainly involved in steps 3 and 4 and are also in charge of the observation of experiments conducted in real life throughout the project in order to evaluate the efficiency of those tools in events that involve citizens.

Figure 1: Workflow describing the technical steps and their output

matically produced 3D temporal CityGML data can be interactively visualized on a computer through a specific tool allowing temporal exploration, which development was finalized as part of the project. Then the 3D model is represented through a set of styles for each datasets, derived from studies in cartography, geovisualization as well as information and communication sciences and an interface for navigation is also designed, including additional alphanumeric data given by practitioners as guidance for the public who will handle those 3D models. After that, the resulting interface and 3D models are exported to various mobile devices, more precisely on tablets and smartphones for on-site consultation as situated simulation devices. Figure 1 shows the technical steps of the process. Of those steps, step 2 is the one computer scientists have been mostly working on and what follows will concentrate on it.

As far as outputs are concerned, images produced from those 3D temporal geovisualizations were used with riverside residents on mobile devices as "situated simulations". During the first experiment in June 2016, tablets were used from a vantage point up on a hill facing the studied area. From this point of view, residents could contemplate their district and see on the tablet a 3D geovisualization of their district with flooded areas, through images taken from the same point of view in the 3D model. Another way of interacting with the data was also tested, through smartphones inserted into virtual reality headsets. Residents could use those smartphones+headsets on one of the town's square. Standing there, they would then see the same square modelled in 3D with flooded areas through 360 degrees panoramic images.

4. Algorithms and developed tools

Our objective is to generate a temporal 3D model of any given territory along the Rhône river. This model has to be as easy as possible to decipher by riverside residents, so as to allow them to locate themselves while navigating in the 3D scene. They particularly need to recognize the surrounding environment to be able to locate precisely the flood they are offered to visualize throughout its duration (i.e. where overflows are coming from and where they expand

on their territory). However, there is no readily available 3D models of potentially flooded areas in France including topography, land use and landmarks. Since we can access multiple databases, we combine them to generate a temporal 3D model. We chose to use the CityGML standard for storing this output model since it proposes an interoperable way to store multiple layers of 3D models and an extension has been recently proposed in order to store temporal information linked to these [CSG*17]. Figure 2 illustrates the different processes developed to generate such CityGML models from the data at our disposal.

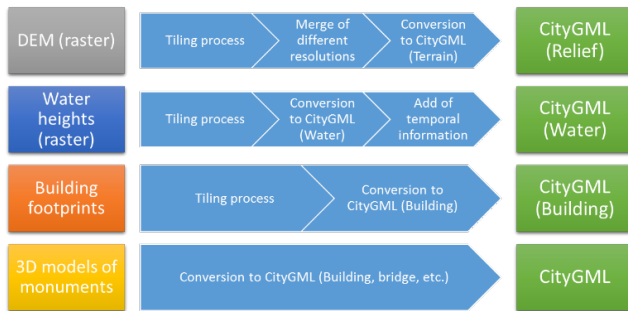


Figure 2: Generation of CityGML files from multiple datasets.

This process can be used on any area where those kind of datasets are available. In terms of 3D modelling of an existing territory (excluding thematic data, which are, in our case, hydraulic data), and as far as France is concerned, data produced by the French national mapping agency (IGN) allow for this process to be used for any territory (both metropolitan and overseas). This kind of datasets is mostly used to describe an area at the scale of a district or a city, that is to say that it provides a general overview of the morphology of the territory (global topography, built structures, road networks, water and vegetation areas, administrative limits). As a consequence, those data allow neither for a precise 3D modelling of a single building or even a small group of building, nor for the representation of public spaces and street furniture. Nevertheless, those datasets are relevant in order to visualize, analyze and present hydraulic data concerning floods caused by major rivers, since those floods concern quite large areas and generate flows that can expand on dozens of kilometers, so that a large view is required to perceive them and understand their trajectory. Consequently, those datasets can very well be used for urban visualization, as far as major floods are concerned, in order to present the spatial extents of floods and the paths of water flows. Figure 3 shows an example of 3D geovisualizations of flooding from the Rhône river in a urban context. Those images were used during a trial in order to prevent construction in this potentially flooded area. They were produced manually a few years ago using the same datasets as those we can now use for the automatic generation of a CityGML database.

4.1. Available data

The different datasets needed in order to produce our 3D models, composed of data about the territory and data about hydraulic facilities and floods, are presented in Figure 4.

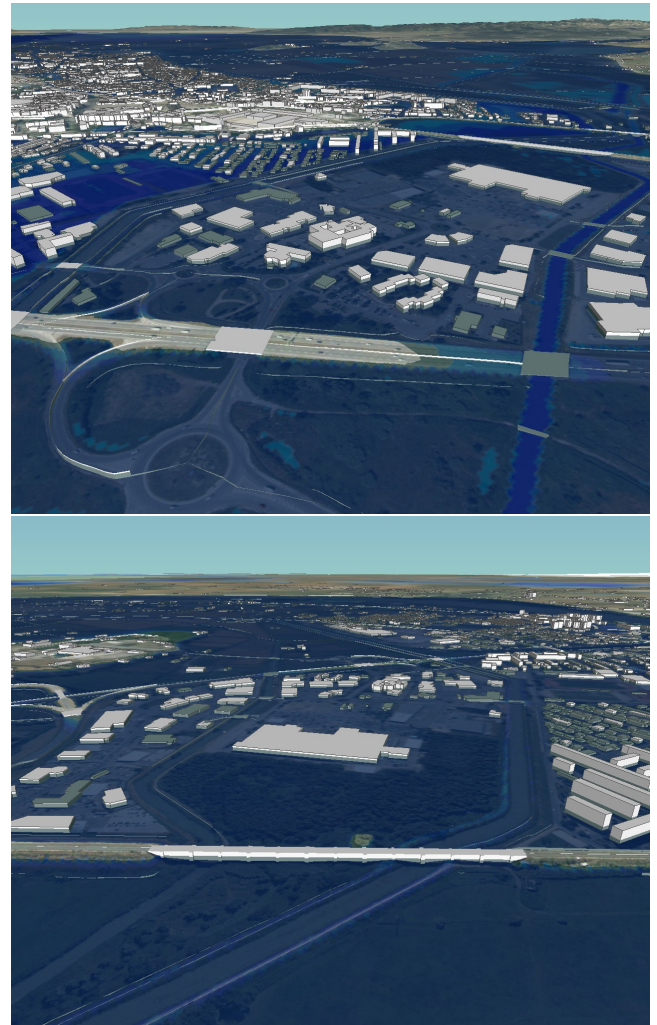


Figure 3: 3D geovisualizations of urban flooded areas. ©Image F. Jacquinod, Data IGN, CNR

The first four datasets in the table (Figure 4) are freely available from the French mapping agency (IGN) for practitioners working in public institutions, so that the entire river basin could be modeled in CityGML, once we have developed freely available tools to automate the process.

Nevertheless, data about floods and specific built infrastructures related to the hydraulic management of the area (dams and hydroelectric plant for instance), as well as chosen landmarks to ensure that residents can locate themselves easily when navigating in the 3D models, had to be produced by researchers working on the project. As far as data about floods are concerned, we use a tool that was developed in earlier projects that allows for the automated creation of flood data. This tool is a dedicated (and also freely available) QGIS module named CartalIN [VBL14], that needs to be used by an expert in hydraulics (at least as far as the production of input data is concerned). The work needed to produce the data on any territory along the river Rhône is thus facilitated. The only

Data Type	Spatial coverage	Format	Producer
DEM (25m/pixel)	whole area	Asciigrid	IGN
DEM (2m/pixel)	partial	Asciigrid	IGN
Orthorectified aerial photo (50cm/pixel)	whole area	ECW	IGN
Buildings	whole area	Shape 2D (+height as attribute)	IGN
Data about floods	whole area	GeoTIFF	Project members
3D models (landmarks)	chosen landmarks	.OBJ	Project members

Figure 4: Data composing our 3D models.

manual work that was necessary was the production of 3D models of landmarks (church, local gymnasium, city hall, etc.) and of hydraulic facilities. This was done by using free software (Sketch Up Make and Blender). The 3D objects were modeled and then textured with pictures that were taken on site. Figure 5 shows some of those 3D models. On the whole, the technical process of producing a 3D model of a chosen territory along the river Rhône is almost entirely automated, except for the creation of 3D landmarks, which need to be spotted and manually produced for each territory.

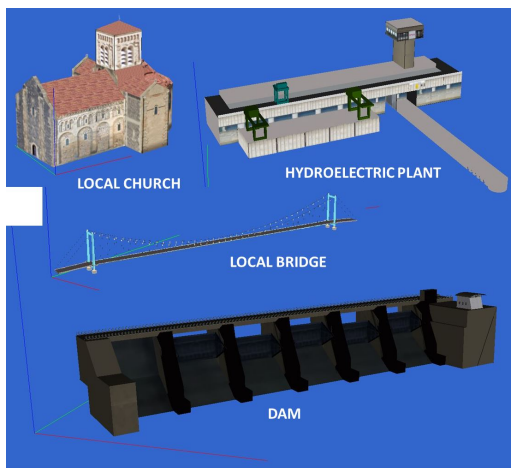


Figure 5: Examples of landmarks modeled as 3D objects.

4.2. Data processing and visualization

4.2.1. Data processing

The first step consists in tiling all these data. They may represent large superficies so we propose to tile these according to a regular grid with cells of 500m length. This will allow the user to explore only the area he is interested in, without having to load unneeded 3D models that would degrade the visualization performances. The tiling process is also a key element for the use and spreading of those models since it allows for the production of a 3D model at the scale of the entire river basin, on the French side at least (about 90 000 km²).

The IGN provides free access to a raster DEM on the whole French territory, with a resolution of 25m by pixel. This is sufficient to model surrounding territory, so as to provide a background landscape, but not precise enough to propose credible visualizations of flood simulations. This is why a second DEM is used, with a precision a 2m by pixel but limited to flood-risk areas. IGN also produces ortho rectified aerial photographs (orthophotos) on the territory, with a precision of 50cm by pixel. We use the two DEM in order to generate a triangulated 3D model representing the topography and orthophotos to texture it. Since we have raster DEM from different resolutions, we have to manage the transition between them: we want the most precise DEM when it is available, but without discontinuities between the two DEM. Since the two DEM are regular grids of 3D points but with different interval values, we generate triangulated versions by connecting neighboring dots. We combine these two triangulated DEM by taking the more precise one when it is available, and we manage the transition in order to keep a continue DEM on the entire area, as illustrated in Figure 6. We then save this triangulated DEM in a CityGML file as a Relief feature.

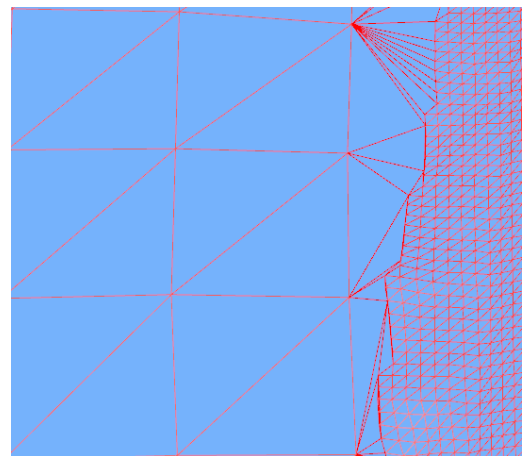


Figure 6: Transition between two DEM with different resolutions.

A raster water heights data is an equivalent dataset: it is a regular grid of georeferenced point with an elevation value corresponding to a given time frame. We triangulate the Asciigrid file and save it in a CityGML file as a Water feature. We do need to process multiple versions of such data since we have different flood data for different periods during the flooding of the area. Each of them

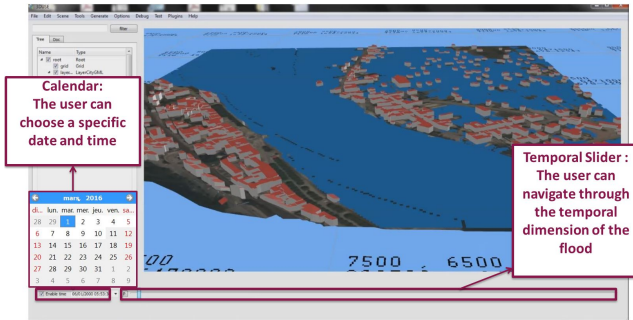


Figure 7: Navigation interface to explore temporal data.

is composed by a single file representing the water height at a given time. The time and date corresponding to each file is encompassed in the name of each AsciiGrid file, during the production of flood data in QGIS 4.1, so that it can be easily exploited. We then use the temporal extension to generate temporal CityGML files storing how the water height changes over time.

At this point, we have the necessary data to propose a basic visualization of how a flood occurs on a given territory. After that, we have to add built structures as well as landmarks like noticeable buildings and hydraulic facilities. We use the building dataset provided by the IGN which contains 2D buildings footprints with a height value as attribute and we use it as 2,5D data to create CityGML LoD1 building models [KGP05]. These buildings are extruded according to the DEM previously created in order to correctly position their footprint in 3D. The last set of data at our disposal is a set of landmarks manually modelled in 3D (bridges, churches, etc.), which are used as visual references for users. They are also stored in CityGML files thanks to a conversion from OBJ file format we have developed. Those 3D objects can be modeled manually in freely accessible 3D software. Since we need those objects to be in the .OBJ format to create a CityGML file, the conversion to an OBJ file is done with Blender, a free software that allows us to keep the objects' coordinates, which corresponds to each object's actual location (expressed in the used coordinate reference system).

For each cell of the tiling grid, all these data can be combined into a single CityGML file that will be composed of different layers of data according to the standard definition, and with temporal information for the flood related data.

4.2.2. Data visualization through temporal navigation

In order to visualize these data, and especially the temporal evolution of the water height, we use the software 3D-Use [3DU] that has been developed in our team. It is able to manage the temporal extension of CityGML in order to propose a visualization of the 3D model over time, thanks to the timeline illustrated in the bottom of Figure 7. It allows the user to navigate through time and to make the software render only the 3D scene corresponding to the selected date.

In our dataset, we have files describing the water height of the river every 8 hours after the flood beginning (plus a few data on

shorter intervals so as to shed light on particularly key moments during the flood). Using those multiple files, we assigned for the n th file a temporal period from $n-1$ up to n by 8 (or less) hours after the beginning date of the flood. In the temporal extension of CityGML, we then store its two temporal bounds corresponding to the dates it appears and vanishes. The timeline of the developed software is able to read these two information and to propose a continue browsing of successive models whose dates have been correctly entered.

The timeline can be set by the user to correspond to a precise date, which has the effect of filtering object in the 3D scene in order to render the water height whose period of existence includes this date. The user can also trigger an automatic playback of the timeline in order to visualize the flood evolution according to temporal interval he chose. For instance, he can navigate through all the data by selecting a temporal interval of 8 hours as well as he may trigger a faster visualization by choosing an interval of 16 hours.

5. Conclusion and perspectives

The FLOOD AR project is still in progress and we will only have final results by the end of the year. So far, the tools developed in order to automatize the production of 3D models of potentially flooded areas including 3D temporal data about floods have proven their efficiency. Although some manual work is needed to model some landmarks, the process has been successfully tested on a pilot zone of 80 km², for which ten landmarks were manually produced. The ability to automatically produce such models for practitioners already opened up many possibilities in terms of raising citizens' awareness about flood risks. Our first public experiment took place in June 2016 and showed that 3D models showing the spatio-temporal progress of a flood provides an adequate support to explain important aspects of flood risks to riverside residents. Some improvements still need to be done. For instance, we will probably need to be able to merge orthophotos from various producers and heterogeneous spatial resolution on some other territories, so that a specific tool could also be developed. Inserting vegetation in the 3D models would also be interesting, although orthophotos already give a sense of the presence of vegetation on the modeled areas, as it was observed during our first public experiment. This issue was already tackled in another research project so that some processes to convert vector layers in ESRI shape format and LIDAR data into CityGML vegetation features already exist. This could thus be used to complete our tools. Others improvements could be considered, such as a specific representations for road networks and the use of more precise data about built structures when available.

More broadly, the interdisciplinary work that is conducted for this project sheds light on the entanglement of the research challenges that need to be met in order to develop useful and relevant tools for supporting a given task. For instance, the development of the above described processes was discussed with GIS researchers and practitioners throughout the project, since the tools need to overcome both technical and practical constraints related to how they will be used *in real life*. This is also true when it comes to visual design of the applications, which is still tested and evaluated by information and communication researchers, GIS specialists and all the practitioners involved, whether local or working for govern-

mental agencies, based on scientific work, previous experiments and public experiments realized during the project. This interdisciplinary setting provides an exciting and challenging research environment that researchers involved in the project are willing to make last.

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