A NEW LoD DEFINITION HIERARCHY FOR 3D CITY MODELS USED FOR NATURAL DISASTER RISK COMMUNICATION TOOL

Serkan Kemec, Sisi Zlatanova, Sebnem Duzgun

Dr. Serkan Kemec,
Yuzuncu Yil University,
Dept. of City and Regional Planning,
Zeve Kampusu, Van, Turkey,
skemec@yyu.edu.tr

Assoc. Prof. Dr. Sisi Zlatanova,
OTB, Section GIS Technology
Delft University of Technology,
Jaffalaan 9, 2628 BX, Delft, The Netherlands
s.zlatanova@tudelft.nl

Prof. Dr., H. Sebnem Duzgun,
Dept. of Mining Engineering and Deptment
of Geodetic and Geographic Information Technologies
Middle East Technical University
Ankara, Turkey
duzgun@metu.edu.tr

Abstract:

Taking precautions before a disaster to reduce the causalities and losses engendered by natural disasters is relatively cheaper, and more importantly, better than cure. The authors propose a conceptual framework with the consideration of all stakeholders related to the disaster management to have a better risk management, and to guide the design, implementation and integration of the 3D urban modeling tools into disaster risk visualization. In this study, a new indoor LoD hierarchy is proposed for building objects. The LoD definitions of CityGML are only for the external parts of the city structures and the indoor is modeled in one LoD only. Similar to the outdoor definitions of CityGML, the proposed indoor LoD definitions aim to achieve robust definitions. This framework allows visualization in all the possible 3D urban disaster situations.

1. INTRODUCTION

This paper presents a LoD definition hierarchy of the previously proposed 3D urban disaster risk visualization framework, which establishes a link between the disaster type (e.g. flood, earthquake etc.) and the components of 3D urban visualisation (Kemec et al., 2010). 3D semantic urban modeling is an important factor to be considered during the development of the framework. Although various aspects of 3D modeling can be accounted for in the proposed framework, the types of objects to be modelled, their representation and the resolution, or Levels of Detail (LoD), play the most critical roles in 3D urban modeling for natural disaster situations. In practice, the concept of LoD can be directly related to the resolution, hence the identification of objects in 3D modeling.

LoD originate from computer graphics and can be seen as different represnetation of one real-world object. LoD target the reduction of software and hardware difficulties to display a large collection of urban data (Foley et al., 1995). To meet the needs of real-time display, it is the best choice to generate as many LoD definitions as possible in advance and to store them in the database or to create the generalisation on demand (Meijers 2011). Nevertheless, due to the data redundancy and the storage limitations, generally only discrete LoD hierarchies are defined (Lin and Zhu, 2005). Improvements in users' spatial perception can be achieved by LoD models (Chang et al., 2007; Vanegas and Aliaga, 2009).

1.1 The Framework:

The framework, mentioned in the paper is the revised and improved version of the (Kemec et al. 2010) and enclose the proposed LoD hierarchy. The framework provides the benefit of enhancing the effectiveness of natural hazard visualization results and this improves the cognition of stakeholders about the visualized phenomena, which results in increased risk communication. The framework handles these parameters in a three-dimensional reference (figure 1) with three basic phases.

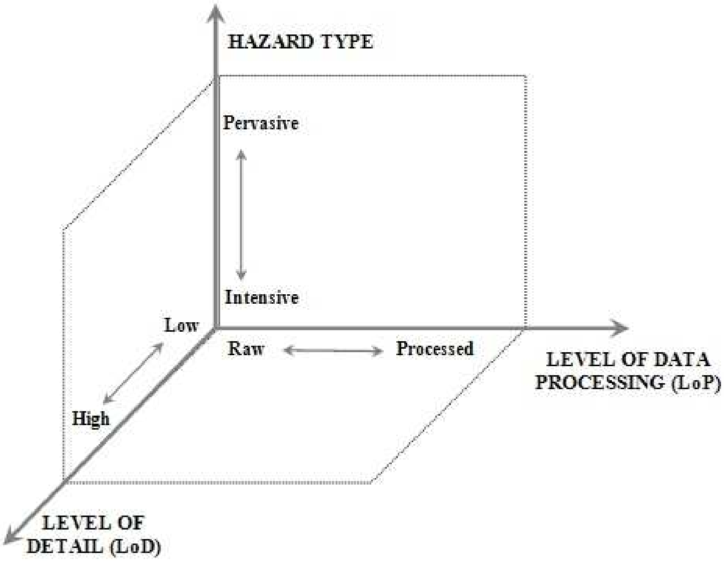

Figure 1. The reference frame of the proposed framework depicted with three axes of: Hazard Type, Level of Detail (LoD) and Level of Data Processing (LoP)

Three axes of the proposed reference frame is related to the dimensions of time, space and attributes from the three-dimensional knowledge. In this respect, the Hazard Type (HT) axis represents the attribute dimension with its contextual effect to the framework, the Level of Detail (LoD) axis represents the space knowledge dimension because it defines the spatial representation of the modeling objects, and the last axis, Level of Data Processing (LoP), is analogous to time dimension. Actually, in the LoP axis the process load of the modeling methods is evaluated in terms of time and source costs. Then, the relation between the LoP axis and time still is not trivial. Moreover, the effect of the temporal resolutions of the used data sources is also managed in this axis.

3D urban model objects are pointed out in this three-dimensional reference frame consisting of three axes: LoD, LoP and HT. In an urban environment, with respect to a hazard type, a specific level of detail is required, which determines the level of processing for urban, urban zone or each building object by itself, depending on the scale of the assessment. This relation may be represented as a point, line, area or volume in the three-dimensional reference frame.

The LoD axis defines "in what form" the previously defined visualization objects will be visualized. The resolution obtained from a decision rule is used for finding the appropriate object representations. In this way, the HT and LoD axis are linked together. In this axis, the LoD definitions are adopted from the CityGML. In the axis, general LoD definitions are placed close to the origin and the detailed ones are placed outwards on the axis.

The proposed framework follows three basic phases to point each model object in the mentioned 3D reference frame. These phases are;

1) Definition of Visualization Components
2) Object Representations
3) Needs Assessment

The framework starts with the first phase, Definition of Visualization Components. These components are user and the related 3D modeling objects; Different users might be interested in different sets of risk elements, which depend on the components of the urban environment. For example, an insurance company may have interests concerning the buildings, while utility companies might be mostly concerned with the effect on utility networks. That is to say, the objects to be considered (and included) in a particular 3D model have to be selected with respect to the user. The second phase of the framework application is Object Representations. In this phase the appropriate object representations are analyzed and the levels of Indoor/Outdoor Resolution are defined by a decision rule. Indoor/Outdoor Resolution defines the abstraction levels of each modeling object where low spatial resolution would mean a low LoD, while high spatial resolution would mean a high LoD. Data Representation involves the data and procedures needed for a specific model. Here, the alternatives to 3D data representations such as boundary (surface) or volume approaches (e.g. voxel) should be evaluated. In this step, natural hazard-related definitions are also completed. Hazard Characteristic Medium is the hazard-related feature in visualization, which might be the vulnerability value of any building in an earthquake case or that of an object on sea surface in a tsunami case. When visualization objects and their LoD characteristics are defined, they are fed into the third and the final phase, which is called Needs Assessment. In this phase, data inventory and data / processes needs are clarified and the efforts and data needed to establish the model objects are put forward. In other words, in the first phase of the framework the points are defined; then in the second phase, these points are placed in the reference frame. Until the third phase, the framework defines the needed objects and their appropriate representations. In the third phase, the situation of the current data of practitioner is searched for with needed processes to achieve the desired representation results.

2. CITYGML

CityGML is one of the few 3D urban modeling concepts, which consider two aspects of 3D urban modeling in a generic sense (i.e. it is not application-oriented). These are syntactic and semantic aspects. CityGML is a 3D urban spatial data infrastructure. It is implemented as an application schema of the Geography Markup Language 3 (GML3) of the Open Geospatial Consortium (OGC). GML3 is based on OGC's ISO standards, which means that it is open and vendor-independent. Syntactic and semantic interoperability is necessary for each GIS component. By using an XML-based language, syntactic interoperability is achieved. Semantics is related with the geometrical and topological aspects of 3D city models and these are covered by class definitions of CityGML. All basic urban model components, that is, buildings, vegetation objects, water bodies, transportation facilities (like streets and railways) and city furniture, include this class taxonomy. The urban objects in CityGML are subdivided into certain thematic classes. One of the important classes is the building class, which provides the representation of thematic and spatial aspects of buildings. Another one is relief, which is simply the terrain. The others are transportation, which represents the objects of all modes of transportation, for example a road, a track, a railway, or a square, and land-use, which describes those areas of the Earth's surface dedicated to a specific land use. Several other objects such as city furniture, vegetation and water can also be useful for risk management. The city furniture objects are stable objects like lanterns, traffic lights, traffic signs, advertising columns, benches, delimitation stakes, or bus stops. The vegetation is used to represent solitary tree objects, plant cover as surface or plant canopy. The water object represents the thematic aspects and three-dimensional geometry of seas, rivers, canals, lakes, and basins. These object classes compose the object pool in the framework. A set of objects important for any particular disaster can be obtained from this pool. The only limitation is the lack of complete set of underground objects. Tunnels are now availble with the new realease of CityGML 2.0, as well as a mechanism to specify undeground parts of buildings and other features. Some research and developments has proposed solutions for geotechnical objects (Emgard and Zlatanova, 2008; Tegtmeier et al., 2008), which can later be included in the framework. These object classes compose the object pool in the framework. A set of objects important for any particular disaster can be obtained from this pool.

CityGML provides the concept of a LoD for 3D urban visualizations, which is best developed for buildings. However, the approach of CityGML is appropriate for the introduction of LoD levels for various other objects. In CityGML, LoDs range from LoD0 to LoD4. LoD0 is the 2.5D level, over which an aerial image or a map may be draped (Kolbe et al., 2005), for a simple box model defines buildings in LoD1, while buildings in LoD4 are defined even with interior details of them. Naturally the resolution increases from LoD0 to LoD4 (Gröger et al., 2006). The concept of LoD is quite generic and suitable for small to large area applications. The concepts of LoD of CityGML are adopted as a starting point in the study.

3. PROPOSED BUILDING INDOOR LOD HIERARCHY

Currently, building LoD definitions of CityGML is robust and steady especially for the external parts of the city structures (figure 2). The same situation does not apply to the indoor representation definitions. In the LoD 4 of CityGML, indoor detail is defined as;

> *"LoD4 completes a LoD3 model by adding interior structures for 3d objects. For example, buildings are composed of rooms, interior doors, stairs, and furniture."*

This definition characterizes a building model that has all the architectural details in the most detailed representation level.

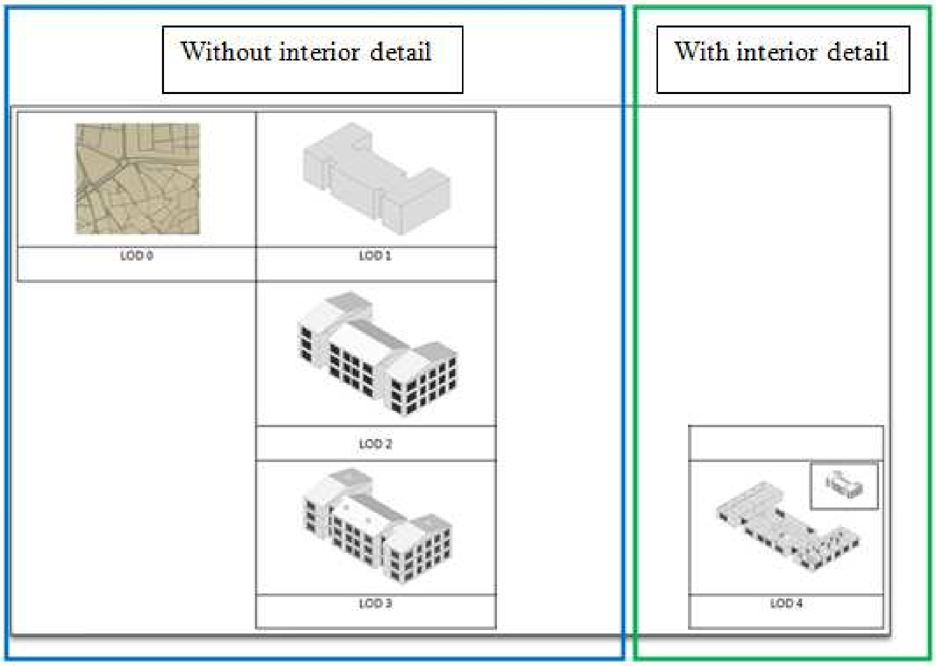

Figure 2. The current LoD hierarchy of CityGML

The main concern of the framework and the applications is finding the proper representation especially for building objects of the urban models for different disaster situations. In this context, more detailed approaches are needed to improve the efficiency and the communication capability of the generated 3D urban model in all phases of the disaster management. Pre-hazard phases, which are preparedness and mitigation, need to put forward the situation in more detail in the related scale. For example, the social conditions and accordingly, the resilience of all the residents in a high-rise apartment blocks are not the same, particularly in Turkey. Therefore instead of whole building representations, more detailed representations such as floor level or living unit level are more beneficial for the development of more coherent strategies in the preparedness phase. Some natural disaster management applications need indoor LoD definitions that are more general than CityGML LoD 4 in different phases of disaster management circle.

Apart from disaster management, 3D urban models constitute spatial visualization or analysis environment for many other application areas like cadastre, planning, traffic, tourism etc. The large extent of the application area and the developing technology urge that more research is carried out about standardization for the interoperability issues. These are certain application areas that come to mind in the first place. Further application areas may also take advantage of an indoor LoD hierarch. As it was mentioned in the previous parts, spatial data infrastructures provide the rules of the required interoperability environment. Moreover, the CityGML of the OGC is a standard that focus on the 3D urban models. The proposed indoor LoD hierarchy is considered together with CityGML to improve the existent standards.

In the 3D urban modeling literature, the subject of the indoor LoD is usually handled under the general 3D urban information meta-model approaches. According to Billen et al. (2008), a unique building object can contain sub-units, which have different attributes in the thematic, administrative and cadastral senses. Consequently, there should be indoor LoD definitions as for the outer parts. Their indoor LoD definitions have three different generalization levels. In LoD1, generalized polyhedrons take place if these generalized polyhedrons have some openings at LoD 2, which link up the internal sub-spaces, and at the most detailed indoor LoD definition, LoD3 has an identical opening but there is no generalization at this time. At the end, these three indoor LoD definitions are connected to the LoD4 of CityGML.

Hagendorn et al 2009 propose an extenxion of CityGML with four indoor LoD focusing on route navigation. Their model consists of thematic, geomatric and routing model. The indoor LoD are definied in a similar matter as outdoor and are used for navigation. Elaborated discussion is provided on the use of the three parts for navigation and visualisation. The LoD presneted here have some of the concepts presented there.

Zhu and Hu (2009) drew a house property-oriented framework. They mentioned a weak side of CityGL in their study. According Zhu and Hu (2009), CityGML is a good abstract framework for 3D building geometry. On the other hand, CityGML's semantic definitions are limited to just structural components (room, window, door etc.), but not real property objects like storeys or living units. This semantic classification approach is the same approach as the one adopted in this paper, which forms the basis of the indoor LoD proposal. The hierarchical geometric LoD framework outlines indoor and outer detail definitions in a three-level framework with five different LoD definitions. This three-level geometric framework, which starts with 2,5D horizontal level for horizontal partitioning on land block scale in the LoD2 of their framework vertical partitioning, constitutes the main concern and this level is named as the vertical level. Finally, at the third level, which has the most detailed model object definitions, indoor LoD definitions are located. The name of this level is 3D interior level, which has three different indoor LoD definitions. LoD3, the first level of 3D interior levels, has storeys e.g. within a residential building. LoD4 is described with minimal spatial portions of real property unit (living unit). Finally, the definition of LoD5 of this framework corresponds to the LoD4 of CityGML, involving indoor details with entire details like roof, walls, doors and windows.

Yuan and Zizhang (2008) propose a framework by combining Building Information Modeling (BIM) and 3D GIS capabilities for indoor navigation. BIM is an information-rich model for building generation and management. It covers 3D geometry and semantic definitions like CityGML. 3D urban models are used to generate graphs that are used for indoor navigation.

Karas et al. (2006) also use 3D building models as the main input for 3D graph generation. 3D indoor navigation or network analysis applications could be a key element for the response phase of the disaster management circle. The outputs of such an analysis can reduce the time spent by search and rescue teams; besides, escape routes, which might be communicated to the community in the preparedness phase, can be a lifesaver for large numbers of people. The proposed indoor LoD hierarch can be adapted to these types of 3D graph generation algorithms. Rougher detail levels could be beneficial for upper-scale disaster management applications.

Billen (2000), Billen et al. (2008), and Zhu and Hu (2009) stated different definitions of urban abstract space apart from urban physical object definitions. In an urban-related visualization, the discrimination of the thematic subdivision on a separate building object could be more important than the physical components. The depiction of urban object composition given in Billen (2000) is a good example. According to this study, urban space is subdivided into two, urban abstract space and urban physical space. Current spatial data infrastructures mainly focus on urban physical space definitions, but under the concept of urban abstract space, thematic, cadastral and administrative subdivision definitions could be done.

In an urban space, these types of abstract definitions can be increased, but generally, thematic subdivisions originate from the cadastral subdivisions, which mean that different areas with varing theme are owned by different holders and an inherently administrative status automatically emerges. For this reason, the thematic subdivision of urban abstract space are considered for the basics of the proposed indoor LoD hierarchy. The proposed indoor LoD definitions are fully integrated with the LoD definitions of CityGML. Its notations are parallel with five level definitions of LoD. In LoD0, there is no 3D, thus the indoor definitions start with LoD1 with indoor which is denoted as LoD1,5 to LoD3,5. There is no LoD4,5 because LoD4 already covers the indoor details (figure 3).

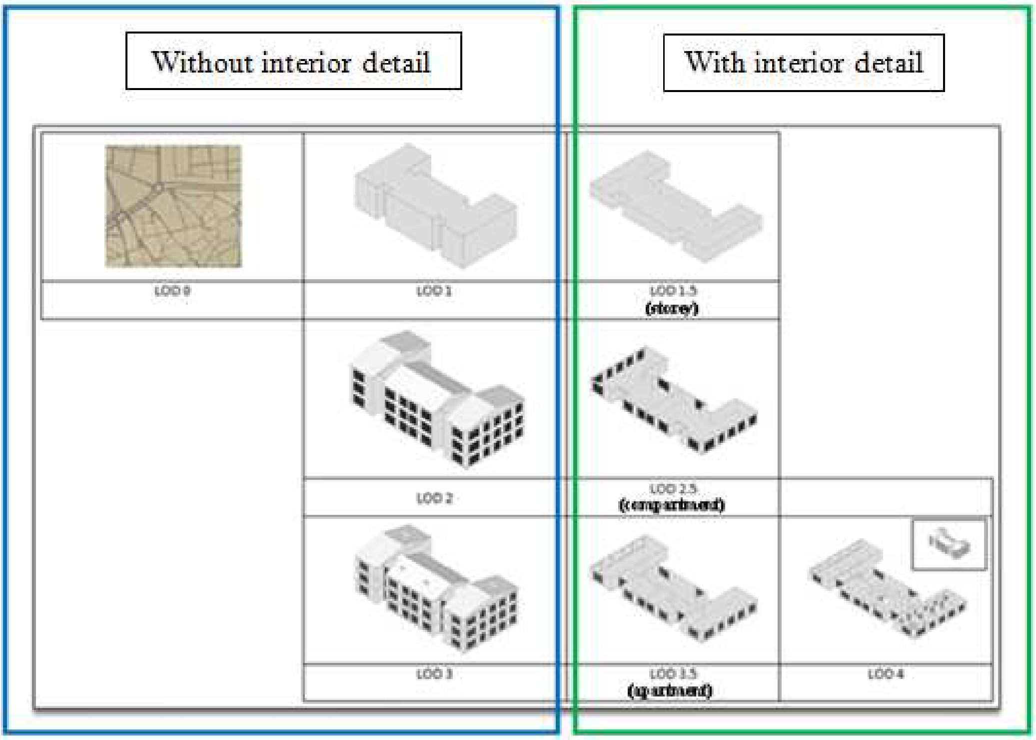

Figure 3. The proposed LoD hierarchy with indoor representations

In the proposed LoD hierarchy, each of the LoD1, LoD2 and LoD3 outer detail definitions is associated with the related indoor definition and notated with a half after the integer part, for instance, for LoD 1 with indoor. Semantic definitions are performed with real building objects, which are;

- LoD1 with indoor notated as LoD1,5, the corresponding building object is storey (figure 4)

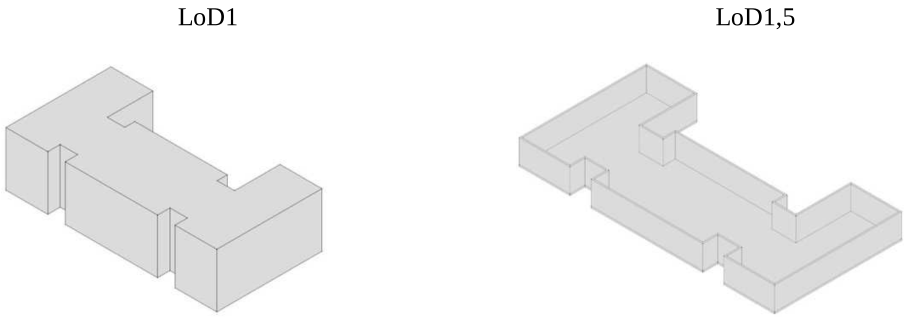

Figure 4. A sample representation of LoD1 building outdoor and the corresponding indoor representation

- LoD2 with indoor notated as LoD2,5, the corresponding building object is compartment (figure 5)

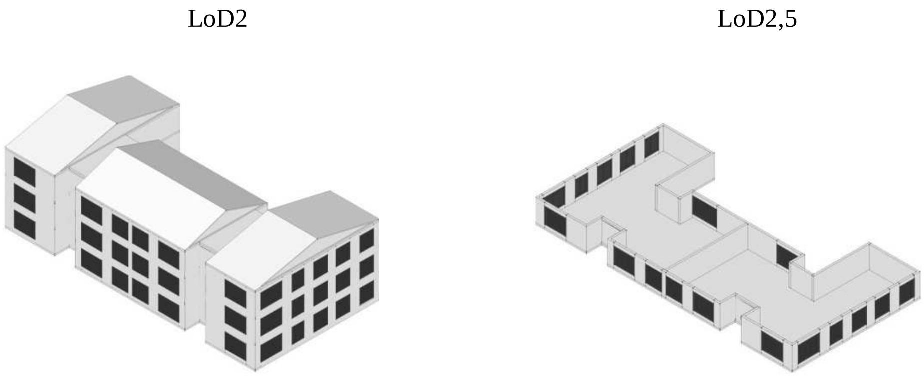

Figure 5. A sample representation of LoD2 building outdoor and the corresponding indoor representation

- LoD3 with indoor notated as LoD3,5, the corresponding building object is apartment (figure 6)

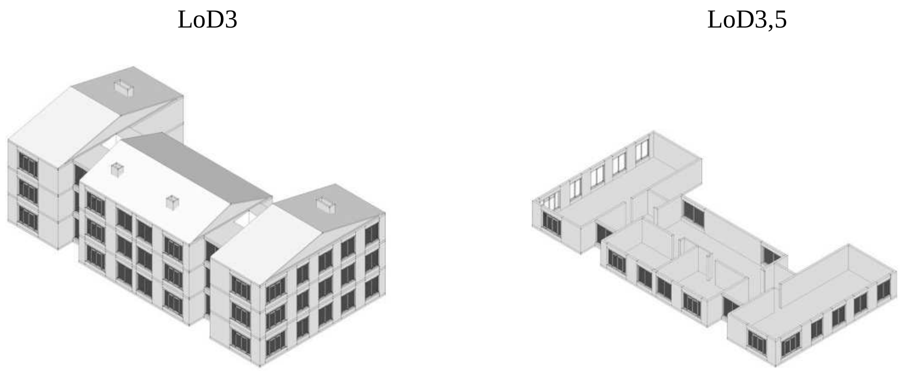

Figure 6. A sample representation of LoD3 building outdoor and corresponding indoor representation

- The demonstration of LoD4 on the same sample building representation could be similar to figure 7.

LoD4 Outer LoD4 Indoor

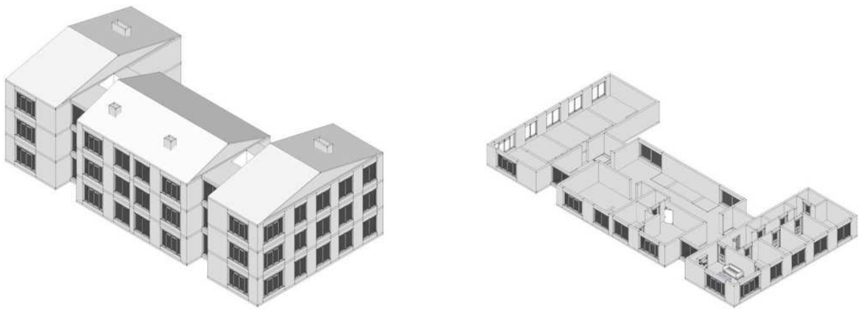

Figure 7. The same building with LoD4

As dicussed in Kemec et al., 2010, five hazard assessment parameters (with indoor penetration) are used to achieve outputs (indoor/outdoor resolution, hazard characteristic medium, data representation), the first being the so-called hazard prevalence index of different hazard types. Decision rule is summarized as follows:

$$I_p = [(((s_o + d + f) / 3) + s_d) / 2) \text{ x } (v + u_{ae} + p) / 3)]$$

Where, I_p is hazard prevalence intensity index which is the product of hazard prevalence parameters that s_o is speed of onset, d is duration, f is frequency, s_d spatial dispersion and urban evaluation parameters that v is land vulnerability, u_{ae} is urban areal extent and p is population density parameters.

$$D = I_{pnorm} + i/2$$

Where, D is detail decision, and I_{pnorm}, normalized hazard prevalence intensity index and i is indoor penetration.

Indoor LoD is controlled by the parameter “i” in the object representation definition decision rule of the framework. If there is an indoor penetration, decision rule is taken into account by adding a half to the integer LoD result. The “i” parameter may also be used if there is an indoor detail request by the user.

4. CONCLUSION AND FURTHER WORKS

This paper presented our first ideas on indoor LoD, which can be used to estimate the needed 3D urban visualization model for risk management and with respect to specific disaster type. The proposed indoor LoDs are complementary to the outdoor LODs of CityGML. The purpose is to establish a mechanism to work with the interiors of buildings even at a low outdoor LoD, and to be able to reflect the possibility of moving mass (flood, mud, land slide, etc.) to get into interior of a building.

The first feedbacks from the interviewed risk managers show that the proposed LoD hierarchy is quite promising. Further developments in CityGML, 3D data sources, data processing and 3D visualization can easily be adapted to the framework, enclosing the proposed LoD hierarchy. The next steps with Developments in CityGML, 3D data sources, data processing and 3D visualization can easily be adapted to the framework, enclosing the proposed LoD hierarchy. Concentrate on tests with different real city textures, containing buildings with different architectural structure, and with different applications endowed with different modeling contexts are needed.

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