Enriching Augmented Reality Games with CityGML 3D semantic modeling

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Abstract 3D representations are recognized as an essential component of Augmented Reality (AR) oriented applications. However, not many examples of AR-oriented applications employ structured 3D data models despite the existence of standard 3D information models like CityGML. One of the reasons for this shortcoming can be explained by lack of a step by step approach for enriching AR-oriented data models with 3D features. Therefore, a three step procedure is proposed to address this limitation such (1) back-ward engineering of an AR-oriented application to its current data model, (2) enriching the current data model with 3D representation features, (3) a mapping the enriched model to a standard 3D information model. A notable contribution of this work is that the procedure of data modeling has been subject to the UModelAR meta-model which has brought a complementary standpoint to 3D geospatial modeling in the adoption AR environments. Furthermore, the enriched data model has been mapped to CityGML information model with CityGML Application Domain Extension (ADE) concept. To demonstrate the feasibility of this approach, an operating mobile AR-oriented game has been used for the case study.

1 Introduction

Augmented Reality (AR) is defined as a live scene of reality in form of video streaming being supplemented by adding numeric representations as of graphics, annotations, images, sounds, videos, and other comments (Azuma 1997, Milgram et al 1994.). For instance, walking on a street in an urban area, one can see restaurant names, menus, and working hours at corresponding locations using an AR-oriented tourist guide. Indeed, the AR tourist guide application augments the live video capture on a user’s smart phone with certain information which is not accessible to the user on the street unless she or he walks into each restaurant. Therefore, the given information (e.g. restaurant names and menu) is virtual with respect to the user’s sensible reality and may appear as markers (2D or 3D graphics), annotations, or even voice guides. There are various types of AR-oriented applications operating in urban areas for examples tourist guides such as
Layar\(^1\), games such as ARhrrrr (Oda and Feiner 2010, Yang and Maurer 2010), urban design and monitoring such as VIDENTE (Schall et al 2009) which all employ 3D graphics or 3D geospatial data in various ways. Indeed, the exploitation of 3D representations has become subject to number of AR-oriented research initiatives considering 3D visualization (De Souza e Silva 2009, Lee and Park 2005, Liestol 2009, Zlatanova and Van Den Heuvel 2001), 3D data acquisition (Thomas et al 2011), 3D registration (Hölлерer and Feiner 2004, Thomas et al 2011) and data exchange (Badard 2006, Reitmayr and Schmalstieg 2003). A recent study by Hasse and Koch (2010) has employed an extended adaptation of City Geography Markup Language (CityGML) information model for Electronical Nautical Charts (ENC) alongside an AR engine. The output of their work has been a CityGML Application Domain Extension (ADE) upgrading a pre-known and well defined 2D thematic model (i.e. ENC) with 3D features. Finally, an AR-oriented interface has been developed with the AR engine employing the ENC ADE for displaying 3D representations and the corresponding electrical information.

The Open Geospatial Consortium (OGC) CityGML open standard is a well-known 3D information model which presents a well-structured information model including the most relevant urban objects and thematic classes (Kolbe et al 2005, OGC 08-007rl 2008). CityGML has been successfully employed by several types of applications as of Geographic Information System (GIS), web mapping, and navigation operating in various domains such as architecture, urban planning, transportation, and tourism (Dollner et al 2006, Kolbe et al 2008, Vanclooster et al 2009). CityGML has been also a preferable choice for upgrading existing geospatial-oriented applications from 2D to 3D since CityGML information model is extendible in different ways. CityGML data model can be extended either using the Generics or Application Domain Extension (ADE) concepts. The ADE concept enables augmenting the CityGML data model with structured thematic schemas. The main advantage of using ADE is that extensions are formally specified and can be validated against CityGML and respective schemas. Therefore, ADEs can be a potential way for creating CityGML-oriented data layer for common use communities who are interested in specific domains or application types including Augmented Reality (OGC 08-007rl 2008).

Indeed, the actual tendency in extending structured thematic models by CityGML ADE seems sufficient for enriching AR oriented applications with domain specific thematic information. However, a complementary standpoint for augmenting this tendency with application oriented needs (i.e. geospatial game events, constrains and behaviours) would improve the portability, interoperability, and reusability of AR-oriented systems employing CityGML.

The GeoEduc3D project funded by Canadian Network of Excellence - GEOIDE (GEOmatics for Informed Decisions)\(^2\) is a major academic project which has been carried out by several Canadian universities aiming at designing learning-oriented tools that foster enriched and augmented player experiences in real

\(^1\) [http://layar.pbworks.com/w/page/7783211/3D-objects-in-a-layer](http://layar.pbworks.com/w/page/7783211/3D-objects-in-a-layer)

\(^2\) [http://www.geoide.ulaval.ca/](http://www.geoide.ulaval.ca/)
geographies³. Energy Wars, one outcome of the GeoEduc3D Project, is an award winning educational game prototype (Dumont et al 2011) deploying a mobile AR interface in known urban geographies. The current version of Energy Wars mobile runs a game scenario (known as Energy Wars mini scenario) and employs 2D geospatial maps and 3D graphics capabilities. This paper presents a three step procedure for enriching (1) The Energy Wars mini scenario starting with the back-ward engineering of the game for identifying the current data model of the application. Thereafter, the current data model is extended with the essential 3D features. An important distinction of this work is that the procedure of data modeling has been subject to the UmodelAR meta-model which has brought a complementary stand-point to 3D geospatial modeling in the adoption AR environments (Zamyadi et al 2011). Furthermore, the extended model is mapped on the CityGML information model. Indeed, UModelAR has been used for analysing 3D CityGML information model in terms of AR oriented applications.

The paper is organized as follows. Section 2, explains the case study and the current data model of the case study which has been created by back-ward engineering in the first step. In Section 3 the required features of 3D representation for AR-oriented applications are mentioned from the relevant literature. Furthermore, the UModleAR meta-model would be presented for the guide to enriching AR-data model with 3D representations for the second step of the procedure. The third step of the work is in Section 4 in a way to show the progressive evolution of the work. This section is followed by the dissections in Section 5 where further guidelines and results would be presented enabling the globalization of the three step procedure for different applications. The Section 6 concludes this paper and gives the future possibilities ahead.

2 Back-ward engineering of Energy wars game

The Energy Wars prototype is a learning oriented game that is played in known urban areas employing an AR interface (Dumont 2011). The goal of this game is to help teenagers to learn about the issue of energy consumption alongside the geomatics domain. At this time, a simple version of this game has been implemented and tested in Laval University known as Energy Wars mini scenario. This game is played on a field (i.e. university campus) where certain buildings have been provided with energy consumption information. Each team, consisting of three gamers with different roles and role specific smart phone based mobile interfaces, must find the buildings with low energy efficiency, and earn enough money to come back to their whereabouts and improve their energy consumption. Money can be earned by answering to relevant questions about energy saying or finding bonuses. There are several locations whose coordinates have been marked in a database. Each location represents a game hint which might carry one or several

³ http://geoeduc3d.scg.ulaval.ca
questions, a money bonus, or money loss. These hints can be viewed on the screen of the smart phone as graphical cubes augmenting the reality and gamers can find out their content by arriving at their location. Only one of the gamers (based on her or his role) can see the augmented hint cubes if they are inside the visibility range of the gamer. The Figure 1 shows a screen shot from the AR-oriented game interface.

**Fig. 1.** Screen shot of Energy Wars game AR interface with augmented Game Hint cubes (image provided by Energy Wars mini scenario development team in Laval University)

The current version of the game uses 2D dimensional geospatial representations for locating buildings and (i.e. footprint of the building with 2D coordinate values) and game hints (i.e. points with 2D coordinate values). Furthermore, the 3D coordinates for each vertex of every graphical cube is stored for every game hint. Indeed, these coordinates are used by the rendering engine to create the corresponding graphics. Since the augmenting cube are supposed to hover above the ground surface, the base elevation for each cube (the Z coordinate of the lowest vertices) has been derived by adding a constant value to the average elevation of the ground surface of the Laval University campus. The use of the average elevation of ground surface has been sufficient for the Laval University campus since the target area on which the game has tested is flat. The diagram in Figure 2 shows the current Energy Wars mini scenario data model in UML formalism. Since we have not been involved in the implementation of the Energy Wars mini scenario, this data model is the result of back-ward engineering and has been created based on the discussions with the developers of the game.

**Fig. 2.** The current data model of Energy Wars mini scenario
In the current data model, the building whereabouts is represented by the Footprint class derived from the Building class composed of one or several connected line segments. The building energy properties are represented by corresponding attributes in the Building class indicating the actual energy consumption (the Energy Consumption attribute), the classification of energy consumption (The Energy Efficiency Level attribute and the Energy Efficiency Level domain value), and the required amount of money for improving the building energy consumption (the Needed Money attribute). Furthermore, the Game Hint class represents the Energy Wars mini scenario game hints. The Hint Type attribute defines the type of the game hint and has three possible values indicated in the Game Hint Type domain value. Two classes are inherited from the Game Hint class for addressing the game hint location (the Punctual Position class) and the coordinates of the augmentation cube vertices (The Marker class). Finally, the Hint Question class enables storing the corresponding question of each game hint (Question attribute), the question right answer (Correct Answer attribute), the wrong choices (Wrong Choice attribute), and the amount of the money that can be earned (Question Score attribute). Every instance of Game Hint class is related to an instance of Hint Question class if only the respective Hint Type value corresponds to “Question” indicated by the domain value.

3 The basis for enriching AR-oriented games with 3D features

The next step of the proposed approach is enriching the current model with 3D features. In order to progress towards an AR-oriented game with 3D geospatial representation capabilities, some important features have to be taken into account. These features can be studied by referring to the definition AR and the used of 3D features in AR-oriented applications. The AR environments appear at the near left part of the mixed reality continuum by Milgram et al (1994) where virtual features are superimposed on real environment (Figure 3).

![Fig.3. Millgram's continuum of mixed reality (Milgram et al 1994)](image)

Azuma (1997) has defined three conditions that should be satisfied in order to create an AR environment: First, combining real and virtual; Second, being interactive in real time (interactions may occur at certain coordinates or with certain objects); Third, being registered/combined in/by 3D (i.e. comprehending 3D position and orientation of real world objects and augmenting features). In agreement
with the latter, Höllerer and Feiner (2004) have classified the principal roles of 3D models for creating AR environments: (1) improving the visual quality of augmentation scene with reach and realistic features (i.e. providing detailed information for rendering graphics), (2) 3D registration of augmented features (position and orientation), (3) resolving occluding objects with respect to observers’ standpoint (i.e. identifying the hidden part of a building which is covered by a foremost wall).

A literature review has shown that AR applications have been applying different sources of 3D representation such as independent file formats such as computer aided design (CAD) formats like STL, DXF, and DGN (Lee and Park 2005) or 3D graphics like 3ds and obj (Liestol 2009), 3D textual mark-up formats like KML and X3D (Thomas et al 2010, Wojciechowski et al 2004), and standard semantic information models like CityGML and Building Information Model (BIM) (Woodward et al 2010 and Hasse and Koch 2010) or structured geospatial database systems (Schall et al 2007b). From an applied point of view, the various features of 3D representations including geometry, appearance, and thematic descriptions have been employed for addressing multiple levels of AR experiences such information display and sharing (Badard 2006, Schall et al 2007a), simple and occluding-aware graphical visualization (Thomas et al 2010, Schall et al 2007a, Zlatanova and Van Den Heuvel 2001), and advanced behaviour-aware interactions (Harrap and Daniel 2009).

However, our earlier studies which has taken into account the miscellaneous aspects of the employment of 3D representations in AR-oriented applications has shown that AR-oriented use of 3D features has not been portable, interoperable, and reusable (Zamyadi et al 2011). Meta-modeling was suggested as the prerequisite for modeling AR environments. Meta-model is defined as the structured abstraction of model concepts that formalize the specification of model components prior to building new models or upgrading the existing ones (Caplat 2008). The principal idea has been derived from the additional features and considerations that exist in AR environment comparing to the ordinary reality. There are different thematic points of view for modeling the reality. However, complementary meanings and relations are superimposed to the known thematic viewpoints requiring a complementary outlook by which 3D models could adopt AR concepts. The output of this proposal, named as UModelAR, is a meta-model which has brought a complementary standpoint to designing 3D semantic models in respect to AR (Zamyadi et al 2011). UModelAR has followed a top down order for representing the relation between virtuality and the associated reality in AR environments trying to bring multiple viewpoints coming from AR and 3D model conceptualizers, developers, and users closer to each other. UModelAR consists of five packages as (1) Augmented Reality Interface (2) World and Associated Representations (3) Acquisition of Physical Reality (4) Model Localization (5) Model Description.
4 Mapping the enriched data model of the game to CityGML

The last step of the procedure is mapping the enriched data model with 3D features to the CityGML information model. As mentioned the Energy Wars mini scenario is a good example of an AR application that operates in a known urban area. Hence, it has the potential to be implemented in multiple urban locations all around the world (i.e., in any university campus or city neighborhood). Profiting from 3D geospatial urban representations. However, as mentioned the current Energy Wars mini scenario data model has not covered AR oriented 3D geospatial modeling concerns. Therefore, the current data model will be upgraded with the essential features that should be addressed by AR oriented geospatial representations according to the UModelAR approach to modeling AR environments and by exploiting 3D geospatial information models like the Geospatial Consortium (OGC) CityGML standard.

CityGML allows addressing the representation of thematic properties of city objects alongside their geometric properties. The base class of all thematic objects is _CityObject (an abstract class) from which they inherit the basic properties from the CityGML core module such as Appearance feature and External References to corresponding objects in external datasets. The actual thematic module of CityGML is composed of the most relevant urban fields including Digital Terrain Models, Buildings, Vegetation, Water Bodies, Transportation Facilities, and City furniture. CityGML can represent objects in five consecutive Levels of Detail (LOD) where objects become more detailed as LOD increases. In other words, the same object may be represented by one or several different LOD enabling different degrees of resolution in respect to the essential needs (OGC 08-007r1 2008, Kolbe et al. 2005).

Furthermore, the features which have not been modeled by CityGML, can be supplemented either by using the Generic Objects and Attributes (from CityGML core module), or by extending the CityGML data model using the CityGML Application Domain Extension (ADE) concept. While Generic objects and attributes allow extensions only during applications runtime the ADE enables structured additions to the CityGML data model that are portable and reusable. An ADE can be defined by common use communities who are interested in specific domains. Therefore, the advantage of using ADE is that the extensions are formally specified and can be validated against CityGML and respective schemas (OGC 08-007r1 2008, Kolbe et al. 2005).
Fig. 4. Energy Wars mini scenario new data model which is enriched with 3D features according to UModelAR approach and mapped to CityGML 3D information model.
The UML class diagram in Figure 4 shows the Energy Wars mini scenario data model enriched with 3D features from CityGML information model based on the UModelAR approach to modeling application-oriented AR environments. In the diagram of Figure 4 the White classes are from the current data model, the Gray classes represents the essential features that have been supplemented based on the UModelAR standpoint for enriching AR-oriented applications with 3D features, and the Light Orange classes are CityGML features indicating the corresponding CityGML ADE extension. There are 11 classes added to meet the needs of UModelAR and 18 classes are needed to ensure the link with CityGML. The following paragraphs will explain the reasoning behind the class diagram of Figure 4 considering The Energy Wars mini scenario, UModelAR as the modeling guideline for extending 3D features, and CityGML as the target 3D information model.

At first, in order to enrich an AR-oriented data model with 3D features, the localized feature of the AR environment has been identified. UModelAR indicates that an AR environment is created by the representation of its localized features assigning multiple descriptive features like attributes and appearance to the environment. The representation of localized features should be addressed by the notability of their measures (i.e. shape and size). It means that a localization feature has an explicit geometric representation such as 0D, 1D, 2D and 3D geometric primitives or aggregations if the scale, precession, and accuracy of its location, shape and size are notable considered. Otherwise, it would be represented by symbols.

In the Energy Wars mini scenario, Building has a localization feature that corresponds to its footprint on the earth as the corresponding events occur when the users arrive at its whereabouts from each building side. Accordingly, the building footprint location, shape, and size are notable and derived from measurement methods (e.g. LIDAR mapping). In the current game scenario, building shape is not addressed in any AR or game specific action. Indeed, there have been certain ideas about augmenting real building faces with different colors that correspond to their energy efficiency level. For this reason, buildings must have another notable geometry as a block with bounding faces.

Second, in order to enable mapping the representation of AR environment to 3D information models like CityGML, UModelAR has indicated the necessity to classify the AR environment with respect to the correspondence of the associated features to the reality. This means that every localized feature of the Energy Wars mini scenario which is derived from a known urban object has an equivalent CityGML thematic object or is extended in a CityGML thematic module. On the other hand, every localized feature of the Energy Wars mini scenario which is not derived from the known urban area should be inherited form the new Game Element class that is extended from the CityGML _City Object class.

The Building class corresponds to the building concept from the reality. Therefore, it is equivalent to the CityGML Building class that is derived from the CityGML _Abstract Building class. The most relevant CityGML concept to building footprint is the CityGML Terrain Intersection Curve (TIC) denoting the exact position where the building touches the earth surface. Therefore, the Footprint
class is an extension from the CityGML _Abstract Building class and is defined by a LOD-1 TIC. It should be mentioned that according to CityGML, TIC does not exist in LOD-0. Accordingly, the building shape block is addressed by CityGML LOD-1 Building which is addressed by _Solid abstract geometry composed of bounding Multi Surfaces. Finally, the Energy Wars mini scenario assigns number of energy consumption properties to the Building class as shown in the class diagram of Figure 3. The current formation of the energy properties of the Building class from the current data model satisfies UModelAR criteria since the descriptive properties have been already defined upon a localized feature. The _Building Energy Measure abstract class in the diagram of Figure 4 defines the complementary energy attributes that will be added to CityGML _Abstract Building class for this reason. CityGML External Code Lists have been used for defining the domain values (Enumeration classes in Figure 4).

Respectively, the similar reasoning can be followed for every other localized feature from the current data model. For instance, In the current Energy Wars mini scenario data model, Game Hint has two localization features (the Punctual Location and Marker classes) and number of descriptive properties as of attributes and relational classes. The Punctual Location class in the new data model is identical to that of the current data model and is mapped to CityGML by LOD-0 to LOD-2 Point with the horizontal and vertical accuracy varies between 2 and 5 meter. However, the LOD-0 3D point accuracy (around 5 meter) would be sufficient for a mobile scenario. In the current data model the augmentation component of the Game Hint (the Marker class) is limited to a box like cube. Indeed, in the new data model the Marker class may either consists of specific parts with notable size and shape for each marker composed of different 0D, 1D, 2D, and 3D geometric primitives and aggregations as CityGML Explicit Geometry from LOD-0 to LOD-3, or be assigned with repeating shape as CityGML Implicit Geometry (for Symbols) from LOD-0 to LOD-3. The use of implicit geometry enables referencing to external 3D graphics like VRML or X3D from any source. This may be preferable for localized features with duplicating shape like a cube. However, it should be remembered that each source of an implicit 3D geometry (e.g. VRML or X3D) has a local spatial reference which is oriented to the CityGML dataset global spatial reference by an anchor point and a transformation matrix. For a mobile scenario, with several numbers of visual augmentations the additional metrical calculations could be a drawback. In the new data model, the Hint Question class becomes an abstract class which is extended by two further classes. The new Internal Question class has the similar formation of the Hint Question from the current data model in Figure 3 and is used for storing the questions inside the storage layer. The new External Question class is used for referring to web based question pages by the Question URL attribute.

Finally, in order to address Appearance information of the AR environment CityGML Appearance from the CityGML core module has been used. Indeed, the new Augmentation Appearance derived from CityGML Appearance is a particular class exclusively for visualizing the features that augment the real scene.
5 Discussions

What can we now learn from this three step procedure for enriching AR-oriented applications with a structured 3D data model mapped to CityGML data model?

The refinement of the existing classes from the back-engineered data model (i.e. step one) enriches the current state of the application with 3D localized feature and their associated descriptive and appearance features. However, a main advantage of UModelAR approach is its mechanism for building application-oriented AR environments where complementary features which have not been addressed in the current data model can be identified and modeled in the second step of the procedure and mapped to CityGML in the third step.

Each AR oriented application may classify the AR environment with specific themes organizing the associated features with respect to application events and actions. An application specific theme is complementary to the existing thematic classifications organizing existing and new thematic features. UModelAR has foreseen a particular standpoint for creating the application themes in an AR oriented data model. According to UModelAR, an application theme should be created considering the localization hierarchy of its components partitioning the AR environment (Zamyadi et al 2011). These hierarchical partitions indicate the spaces where specific application events occur addressed by the UModelAR Space features. Each UModelAR Space feature, except the top most space may partition one or many super UModelAR Space features. The lowest level of an application theme hierarchy is the UModelAR Object feature and is not partitioned any more. It means that no other localized feature is part of an UModelAR Object feature or no application event is localized inside it. In CityGML, the UModelAR application theme hierarchical relationships are shown with aggregations in the class diagram and will be created by GML XLinks for implementation.

The extent of the game with respect to the real urban area where the game is played is an important UModelAR Space Feature for deciding the spatial extent, complementary features, and the application specific relationships of the data model. For example, in the Energy Wars mini scenario users are only part of the game while they are within a particular extent. This particular area corresponds to a top most UModelAR Space Feature and is represented by the new Game Area class. Furthermore, users can not enter buildings and there is no specific event that occurs inside buildings. Therefore, Building class corresponds to an UModelAR Object feature and is directly related to the Game Area class. Likewise, Game Hint is also an UModelAR Object for the same reason.

However, the application extent in an AR environment should be seamless. Otherwise, the relation between the virtuality and the target reality may be lost. For example in Energy Wars mini scenario, Game Hints are situated on the certain area that is not covered by buildings. This area may include any part of the target urban area that is traversable except streets. Therefore, the Game Hint must be a part of a superior UModelAR Space feature that covers the rest of the Game Area.
This UModelAR Space feature is represented by the new Land Cover class in the new data model. The new Land Cover class has been extended from CityGML Land Use because the game scenario addresses the Land Cover area by its urban use. Additionally, CityGML Land Use objects can sufficiently represent the Land Cover area since they must have 3D coordinate values.

The position of users (e.g. gamers) corresponds to a localized feature in the AR-oriented location-based applications where users immerse in the interactions (e.g. game events). For instance in the Energy Wars mini scenario, the position of the Gamer affects the appearance of augmenting features like game hint markers. Land Cover is the only partition of the Game Area that users can traverse. Therefore, the Gamer class corresponds to UModelAR Object feature whose superior UModelAR Space feature is Land Cover. Since Gamer is only part of Land Cover partition it can only interact with other parts of the Game Area that are part of Land Cover (like Game Hint) or are adjacent to it. Indeed, the definition of UModelAR Space and Object features would help to indicate the topological relationships.

Finally, an AR-oriented data model may include number of localized features who are not part of the application theme but would be useful to improve the sensitivity of the computer based system to the surrounding reality. In this case study, Street is not part of the game scenario but could improve the awareness of the system by its presence, like warning the users about the possible danger of cars as they enter the street area.

The package diagram in Figure 5 shows the Energy Wars mini scenario CityGML ADE extension package diagram as the sketched arrows mark the dependencies to CityGML modules. Dependencies occur when classes from a package are related to or derived from classes of another package. The direction of the arrow indicates the direction of dependency. The Energy Wars mini scenario CityGML ADE has dependencies to the CityGML Core, Building, Land Use, and Transportation modules. According to this resolution, The Energy Wars mini scenario game can be implemented in every urban area around the world which has been presented by CityGML datasets improving the portability, interoperability, and reusability of existing resources.

![Fig.5. The dependency model of Energy Wars Mini Scenario 3D extensions to CityGML](image-url)
6 Conclusions and Future Work

Despite several experiments on interface design and system tiers, issues of visualization, 3D graphics, and data transfer, no publication has been found employing a step by step approach for developing AR-oriented 3D representation information/data structure. Indeed, AR domain is relatively young and most of the attention has been drawn to experimental prototypes. However, it should be remembered that 3D geospatial data is going to be a main basis of AR domain. Therefore, robust resolutions for defining proper 3D data/information modeling procedures would increase the opportunities to take advantage of interoperable resources and decreases the possibility of reproducing sparse and duplicate 3D data sources.

In this paper we proposed a three step procedure to enrich the Energy Wars mini scenario with a structured 3D data model based on CityGML data model. At first, the back-ward engineering step permitted us to know the current data model behind the game. The current data model (Figure 3) has shown the missing presence of 3D representations. Therefore, the current data model has been then subject to the UModelAR meta-model analysis during the second step for being enriched with 3D representations. In the third step, the enriched data model has been mapped to CityGML information model. The class diagram in Figure 4 shows the outcome of steps two and three in a way that addresses the evolution of the current data model to the new state with 3D representation capabilities.

For the given case study, the presented steps became feasible in a two week effort which is promoting for the test on other cases. This procedure have been also encouraging since the outcome of UModelAR analysis facilitated identifying the required 3D features and mapping to CityGML information model. Indeed, CityGML has shown enough completeness and flexibility for supporting these features either by its original thematic modules and objects, or the ADE concept. Another advantage of this mechanism is that the Energy Wars mini scenario application model has not subject to change or transformation.

Furthermore, this resolution supports the proposed suggestion for the definition of the CityGML Terrain Intersection Curve (TIC) in LOD-0. Indeed, we have been obliged to use LOD-1 TIC while a LOD-0 horizontal and vertical accuracy would have been sufficient for mobile prototypes.

This work has organized a mechanism for the adoption of 3D representation capabilities in AR-oriented applications increasing the productivity of data modeling procedures from data model design to implementation. The comparison between the diagrams from Figure 3 (the current data model) and Figure 4 (the enriched data model) shows the increased productivity in design level. However, the next steps ahead is the actual implementation of the enriched data model for Energy Wars mini scenario and implementing the presented three step mechanism for different case studies in order to verify the achieved portability, interoperability, and reusability in implementation step.
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