Towards Precise Metadata-set for Discovering 3D Geospatial Models in Geo-portals

A. Zamyadi [a,*], J. Pouliot [a], Y. Bédard [a]

[a] Geomatics Department, Laval University, Université Laval, Québec (Québec), G1V 0A6, Canada
alborz.zamyadi.1@ulaval.ca (jacynthe.pouliot, yvan.bedard)@scg.ulaval.ca

WG II/2 Workshop (3D GeoInfo 2013 - - 8th 3D GeoInfo Conference)

KEY WORDS: Metadata, 3D Geospatial Models, 3D Geospatial Model Discovery, Canadian Geospatial Data Infrastructure (CGDI), Geo-portals

ABSTRACT:

Accessing 3D geospatial models, eventually at no cost and for unrestricted use, is certainly an important issue as they become popular among participatory communities, consultants, and officials. Various geo-portals, mainly established for 2D resources, have tried to provide access to existing 3D resources such as digital elevation model, LIDAR or classic topographic data. Describing the content of data, metadata is a key component of data discovery in geo-portals. An inventory of seven online geo-portals and commercial catalogues shows that the metadata referring to 3D information is very different from one geo-portal to another as well as for similar 3D resources in the same geo-portal. The inventory considered 971 data resources affiliated with elevation. 51% of them were from three geo-portals running at Canadian federal and municipal levels whose metadata resources did not consider 3D model by any definition. Regarding the remaining 49% which refer to 3D models, different definition of terms and metadata were found, resulting in confusion and misinterpretation. The overall assessment of these geo-portals clearly shows that the provided metadata do not integrate specific and common information about 3D geospatial models. Accordingly, the main objective of this research is to improve 3D geospatial model discovery in geo-portals by adding a specific metadata-set. Based on the knowledge and current practices on 3D modeling, and 3D data acquisition and management, a set of metadata is proposed to increase its suitability for 3D geospatial models. This metadata-set enables the definition of genuine classes, fields, and code-lists for a 3D metadata profile. The main structure of the proposal contains 21 metadata classes. These classes are classified in three packages as *General* and *Complementary* on contextual and structural information, and *Availability* on the transition from storage to delivery format. The proposed metadata set is compared with Canadian Geospatial Data Infrastructure (CGDI) metadata which is an implementation of North American Profile of ISO-19115. The comparison analyzes the two metadata against three simulated scenarios about discovering needed 3D geo-spatial datasets. Considering specific metadata about 3D geospatial models, the proposed metadata-set has six additional classes on geometric dimension, level of detail, geometric modeling, topology, and appearance information. In addition classes on data acquisition, preparation, and modeling, and physical availability have been specialized for 3D geospatial models.

[*] Corresponding author

1. INTRODUCTION

3D geospatial models are produced and employed for several applications such as urbanism (Oude Elberink et al 2013, Sheppard et al 2009), disaster management (Mertal et al 2012), geology (Jones et al 2009, Pouliot et al 2008), 3D cadaster (Oosterom 2013, Pouliot et al 2011), virtual globes with urban data (e.g. Google Earth, Bing Map), and video games and augmented reality (Zamyadi et al 2013, Thomas et al 2011). Besides, several free 3D modeling tools are emerging such as FreeCAD[1] and SketchUp[2] on desktop and Google Building Maker[3], 3DTin[4], and Tinkercad[5] on web platforms. In fact, 3D geospatial models have become popular receiving much attention, curiosity, and interest.

Interested citizens, college students, experts, consulting agencies, and officials, all together, expand the number and diversity of 3D geospatial models (Uden & Zipf 2013, Fischer 2012, Jones et al 2013, Zlatanova et al 2010). The producers publish their 3D geospatial models for open use, advertising, or sale. The user communities seek 3D geospatial models to avoid or reduce repeating production costs and preserve more resources for their main objectives like simulations and analysis (Pu et al 2007, Czerwinski et al 2006). In mass dissemination, like in Spatial Data Infrastructures (SDI), everyone publishes 3D geospatial models and everyone comes to discover them. Eventually, the users desire to discover the 3D geospatial models they need at spending less time and cost for finding the most appropriate resources (Czerwinski et al 2006).

Searching "3D Model New York" redirects users to more than 1300 resources[6] with various content and royalties on the first pages of Google search result. One way to narrow the search is with adding keywords while increasing the risk of overlooking several resources. For example, adding "GIS"[7] drops 90% of CAD[8], CAM[9], and CGI[10] resources which can be transferred to GIS friendly formats and databases. Another way is to check 3D model sharing portals one by one. Now, the user encounters distinct community expressions. Therefore, the user needs to study many descriptive tags, written summaries, and native technical terms to thoroughly learn about the available models. Such issues have existed since the early days of online data sharing (Létourneau et al 1998) and inherited by present-day dissemination of 3D models. Evans (2012), Pu et al (2007), and Funkhouser et al (2002) indicate that finding existing 3D models is a challenging task.

Therefore, as 3D geospatial models are widely produced and stored here and there (Stoter et al 2013, Terrace et al 2012, Breunig & Zlatanova 2011), metadata plays an important role in mass dissemination of such models which exist in various personal and official databases and file systems (Evans 2012, Cellary & Walczak 2012, Dietze et al 2007). Metadata is known to be a key component to publish and discover geospatial resources (Rajabifard et al 2006, Longhorn 2005, Ramroop 2004). Metadata describes various specifications of geospatial resources such as production affiliations, geographic extent, and internal contents. Despite the standardization of geospatial metadata in general like ISO 19115[11] and its communities' profiles, several practices indicate that successful dissemination of 3D geospatial models requires specific metadata (Uden & Zipf 2013, Schilling et al 2007, Zipf & Tschirne 2005, Anan et al 2002). 3D communities like Unidy3D[12], Layar[13], and mp3Car[14] forums[15] warn users about troubling costs of downloading 3D models without sufficiently knowing their specifications. Discovering 3D geospatial models fails when ambiguous metadata results in several irrelevant matches, or when uncommon metadata among providers and users ends in empty search results (Funkhouser et al 2002). Further problems are reported on malfunction of downloaded or purchased 3D models like incompatibility with applied analytic and rendering tools (Terrace et al 2012). In fact, it is easy to misinterpret unstructured descriptions of 3D specifications like mistaking 3D coordinates for 3D model (Scianna 2013), 2.5D representation for 3D mesh (Ledoux & Meijers 2011), and adjacent 2D objects in 3D space for true 3D objects (Scianna 2013, Penninga 2008). Hence, in response to the mentioned issues and anticipating the true open market of 3D geospatial models, we brought up two principal questions to investigate.

First, where can 3D geospatial models be published and discovered? Online geo-portals and commercial catalogues are among the popular options. Some geo-portals like Discovery Portal of the Canadian Geospatial Data Infrastructure (CGDI) are open to every type and theme of geospatial resources. Some like Trimble (Google) 3D Warehouse and 3D CAD Browser sharing portals are exclusive to native 3D models. Commercial catalogues like CyberCity 3D Inc. CAD and GIS 3D City Libraries and Visual Technology Services Ltd. PDF3D Gallery are exclusive to private businesses.

Second, which metadata are used to describe 3D geospatial models? Flotynski and Walczak (2013) describe the semantic of 3D web content. Focusing on X3D format, they overlook several types of 3D models. The 3D metadata framework by Doyle et al (2009) considers 3D human body digital objects and is short on 3D geospatial models. Boeykens and Bogani (2008) study metadata for 3D models in architectural repositories exclusively in geo-portals with native 3D models like Trimble (Google) 3D Warehouse. Dietze et al (2007) are closer to mass dissemination of 3D geospatial models by extending a generic metadata standard (i.e. ISO 19115). However, their extension remains almost exclusive to city models and CityGML[16]. Domain exclusivity of metadata helps communities with homogenous 3D models. But, mass dissemination of 3D geospatial models is not limited to specific domains with mutual repositories.

For this reason, this paper presents an inventory conducted on metadata resources from eight online geo-portals and commercial catalogues where various 3D geospatial resources are published. The inventory will show that the current metadata either neglects 3D geospatial modeling or is exclusive to native definitions of 3D models. Our investigation shows that

---

[1] http://www.freecadweb.org
[2] http://www.sketchup.com
[3] http://sketchup.google.com/3dwarehouse/buildingmaker
[4] http://www.3dtin.com
[5] https://tinkercad.com
[6] From Harvard University's city models, Google 3D model collections, and 3dcadbrowser, turbosquid, vizmod portals
[7] Geographic Information System
[8] Computer Aided Design
[9] Computer Aided Manufacturing
[10] Computer Generated Imagery
[11] ISO 19115 standard by International Organization for Standardization (ISO) on geographic metadata
[12] Developers' community forum of Unity3D game engine
[13] Users' discussion forum of Layer mobile augmented reality engine
[14] Discussion forum of mp3Car on vehicle and road transportation technologies
[15] "forums" is commonly used while the true plural form of forum is "fora"; www.merriam-webster.com/dictionary/fora
[16] CityGML standard for 3D city semantic models by Open Geospatial Consortium (OGC)

current metadata requires additional information on internal specifications of 3D geospatial models. This is why we then aim at proposing straightforward metadata fields, code lists, and domain values useful for 3D geospatial models.

The paper is organized as follows. Section 2 investigates required metadata for 3D geospatial models according to the literature on 3D reconstruction, and 3D model management and exchange. Section 3 presents an inventory on geo-portals and commercial catalogues to assess their suitability for 3D geospatial models. Section 4 presents the current version of the proposed metadata-set to describe 3D geospatial content, followed by Section 5 which compares it to the Canadian CGDI Discovery Portal upon three simulated scenarios. The paper is concluded and future perspectives are exposed in section 6.

2. LITERATURE REVIEW ON METADATA VERSUS 3D GEOSPATIAL MODELS

The literature on production, management, and utilization of 3D geospatial models is quite broad (Scianna 2013, Breuing & Zlatanova 2011, Zlatanova et al 2002). Many of the standards and commercial solutions have generic capabilities for producing and exchanging 3D models which permit distinct users to adopt them according to their needs and rationalities (Basanow et al 2010, Stadler et al 2009, Ravada 2008, Nagel et al 2008). To have interoperability achieved and data discovery facilitated, metadata should explicitly indicate which geometric and thematic modeling alternatives are employed in every 3D geospatial model.

Several metadata propositions have been tailored for 3D models regarding specific domains and applications such as 3D city models (Dietze et al 2007), architectural 3D archives (Boeykens & Bogani 2008), 3D web graphics (Flotynski & Walczak 2013), and human body 3D scans (Doyle et al 2009). These propositions agree on some metadata requirements such as geometric and thematic content, Level of Details (LoD), appearance information, and distribution formats. Dietze et al (2007) and Boeykens and Bogani (2008) also consider geospatial reference system, processing background, and coverage. All of these propositions try to propose specific metadata fields and code lists. However, they are not collective because they are domain and application specific according to the levels of ontology dependence stated by Guarino (1998). For instance, Boeykens and Bogani (2008) and Flotynski and Walczak (2013) focus on documenting 3D graphic formats overlooking 3D geospatial models in databases and semantic modeling. For another example, one may also refer to various expressions of LoD as it is a key point of discussion among producers and users of 3D geospatial models (Stoter et al 2011). Dietze et al (2007) document LoD according to CityGML LoD while Boeykens and Bogani (2008) disclose LoD by number of faces and vertices. However, the literature mentions numerous parameters only for disclosing geometric LoD such as point density (Emgard & Zlatanova 2008, Haala et al 1998), primitive counts (Mertal et al 2009, Badler & Glassner 1997) triangle sizes (Cretu 2003), pixel and voxel sizes (Penninga 2008), and single and multiple scales (Jones et al 2009). Furthermore, the definitions of LoD go beyond geometry with geometric-thematic LoD in CityGML (Kolbe 2009), attribute scale as thematic LoD (Hagedorn & Dollner 2007), and level of realistic visualization as graphical LoD (Badler & Glassner 1997). Furthermore, Building Information Modeling (BIM) introduces LoD as the abbreviation of Level of Development[17] which is the measure of how seriously one can consider the information which is provided by a BIM element (AIA 2013). Meanwhile, different BIM guide lines add exclusive terms and definitions of level of details such as Information Level of Detail (CIC 2013) and Graded Component Creation (AEC UK 2012). Therefore, enhancement of metadata profiles with a single property which documents level of details by one exclusive definition, like CityGML LoD in the proposition of Dietze et al (2007), is insufficient for documenting the 3D geospatial models which conform to other specifications such as BIM. Indeed, the more general ontology level of Guarino (1998) is required to achieve our goal of discoverability by mass web users.

Therefore, top-level metadata (i.e. higher level of abstraction than domain and application specificity) is required to accommodate whatever ontological level by providing generic information about the nature of the 3D geospatial models. However, ISO 19115 does not define 3D geospatial models generically. The closest literary indication is “Stereo Model” from “Spatial Representation Type” code list. But, “Stereo Model” is defined as a “*three-dimensional view formed by the intersecting homologous rays of an overlapping pair of images*” which is only specific to stereoscopy. In a similar sense, ISO 19115 defines LoD as “*a scale factor or a ground distance*” which is only relevant for cartography and neglects semantic considerations.

ISO 19109 defines model as an “*abstraction of some aspects of a universe of discourse*”. So, is 3D geospatial model an abstraction of some aspects of a 3D universe? Although true, such perception is not enough to differentiate between simple processed abstractions such as 3D line drawings with geometrically modeled ones such as solids. Apel (2005) and Dollner & Buchholz (2005) indicate that many users associate 3D geospatial modeling with visual 3D scene. As a result, terms like 3D and Volumetric Models and Analysis are mentioned for on-the-fly extrusion in ESRI ArcScene while points and lines suddenly become 3D objects when integrated in a 3D universe, surface extrusion in virtual globes and thickness in AutoCAD, surface analysis in GIS, and thematic definitions like 2D footprints extruded based on building prices. Many GIS users consider 3D city models as thematic-geometric structures that explicitly differentiate terrain, buildings, and streets (Dollner et al 2006, Dollner & Buchholz 2005). Meanwhile, 3D city models among many CAD and CGI users comprise implicit geometries (e.g. sub-objects) with realistic textures. Penninga (2008), Bédard et al (2002), and Pilouk (1996) present another point of view that associates 3D geospatial modeling with certain 3D reconstruction methods and dimension of geometric primitives. In this point of view, Digital Elevation Model (DEM) and extruded surface are 2.5D models (Gorte & Lesparre 2012, Kessler et al 2009) and multiple dimensions such as Multi 2.5D (Penninga 2008), 2.75D (Moenickes et al 2002), and 2.8D (Groger & Plumer 2011) exist before arriving at 3D models. Therefore, 3D and Volumetric Model and Analysis are mentioned exclusively with 3D geometric primitives such as solids, tetrahedrons, and voxels.

Cellary and Walczak al (2012) and Funkhouser et al (2002) indicate that mass dissemination of 3D geospatial models requires enriching metadata and search interfaces with specific fields and code lists. This has an impact on the terms found in metadata with regards to 3D. When using more rigorous definitions, one will rather find "2.5D", "2.75D", and "2.8D" than "3D" datasets. Inversely, one may find metadata loosely labeled "3D" while, in fact, it is a 2.5D dataset according to a rigorous definition. These ambiguities in the meanings of "3" and "D" must be removed with appropriate definitions of 3D concepts in metadata.

[17] In this paper, LoD stands for Level of Details unless indicated

3. INVENTORY ON METADATA IN SHARING 3D GEOSPATIAL RESOURCES

Metadata for mass dissemination of 3D geospatial models requires facing the current and anticipating the upcoming diversity among the providers and users. To assess the current metadata or the new proposals upon 3D models, the impact of the actual practitioners has been studied within a small number of the existing sharing portals like two in Evans (2012) and one in Boeykens & Bogani (2008). To expand this scope, an inventory is performed on multiple metadata resources. Inventory targets were chosen among geo-portals and commercial catalogues which have diverse addressees in North America and present 3D geospatial resources significant in a number or contents. Thus, eight inventory targets were chosen from seven governing bodies as listed here:

- CGDI: Canadian Geospatial Data Infrastructure Discovery Portal[18] permits Canadian providers to present their free and commercial geospatial resources; assorting more than 300 records under "Elevation and Derived Product" category.
- QCOD: Quebec City Open Data[19] publishes free geospatial datasets from municipal departments; currently hosting 48 datasets including three civil 3D blue-prints.
- LID: Canada LIDAR Metadata Repository[20] gathers and publishes metadata of airborne LIDAR projects across Canada; thirteen of them in Quebec province.
- MRN: Quebec Ministry of Natural Resources - Department of Mines[21] exhibits 3D geological models of four distinct mining camps in an exclusive webpage.
- CBW: 3D CAD Browser Sharing Portal[22] permits freelancers to exhibit CGI, CAD, and CAM 3D models; currently hosting more than 150 models from US[23] and Canada under "3D Cities/Cityscapes" and "3D Maps/Landscapes" categories.
- TRL: Trimble (Google) 3D Warehouse permits SketchUp users to share 3D models; currently hosting more than 380 models in Google Earth 3D Building layer tagged in Canada.
- CTY1: CyberCity3D 3D-GIS City Library[24] exhibits 56 US and 4 non-US city models produced by CyberCity3D Inc. (ESRI partner) for 3D GIS environments.
- CTY2: CyberCity3D 3D-CAD Building Library[25] exhibits 20 US and 1 non-US city models produced by CyberCity3D Inc. (Autodesk partner) for 3D CAD

The inventory demonstrates how the actual practitioners encounter metadata upon sharing 3D geospatial models. Based on the most mentioned topics in the literature, the inventory looks for the details which by our knowledge acknowledge the distinctive content of such models by addressing "3D Spatial", "LoD", "3D Appearance", and "3D Format" aspects. For each metadata resource, the informing details are labelled by "E" for noticed in explicit fields, "I" for noticed in implicit fields (e.g. written summaries), and "Ø" for not noticed at all (Table 1). It should be remembered that Table 1 relies upon the verified metadata samples and investigator's knowledge. The inventory resulted in several conclusions; some briefly listed here:

- 3D models are either not particularly defined by metadata or, if so, by inconsistent proprietary properties regarding community or commercial interests. In CGDI, terms like Stereo Model, 3D Dataset, and 3D Topography are used for 3D representations; none contains volumetric geometries. CBW defines 3D models as NURBS/Solid (NURBS are surfaces) versus Polygonal models while TRL, CTY1, and CTY2 relate Polygonal models to AutoCAD 3D Faces, ESRI Multi-patches, and SketchUp Flat Faces which are not solids. Besides, Table 1 indicates that the documentation of Primitive Dimension, when available (7/8), is implicitly expressed despite its importance in the definitions which are given for 3D models by various experts.
- 3D models are difficult to discover and to compare based upon their internal specifications and details. The geometric primitives that reconstruct 3D geospatial resources are often mentioned but in different manners; (4/8 "E"s and 3/8 "I"s for Primitive Type under Information Details in Table 1). Indeed, they are expressed with proprietary terms like Polygon, 3D Face, and Multi-Patch at software specific level. Hence, one needs to learn about the specific tools' vocabulary used to create the 3D model. Interestingly, 3D Pre-Processing, under Information Details in Table 1, is explicitly addressable only in 1/8 of the resources. Similarly, LoD is addressable with uncommon parameters; Scale in 1/8, Object Count in 3/8, and Primitive Count in 3/8 of metadata resources.
- The effectiveness of 3D models is difficult to evaluate. Certain applications look for particular indicators such as Vertical Reference and Coverage for 3D integration, Vertical Precision, Elevation Encoding, and Proprietary Format for 3D analysis, and 3D Appearance for 3D visualization. Table 1 indicates that except for Propriety Format which is explicit at a rate of 75%, the rest of the mentioned indicators (when available among various metadata resources) are collectively explicit at a rate of only 20%.
- Metadata depends on individual and organizational rationalities and creativity with more than half of the noticed metadata are implicit (Table 1). Implicit metadata generates descriptions with different topics and writing skills. Furthermore, interaction with metadata occurs at two levels as simple and advanced query modes or as tables of content with hyperlinked metadata documents. In either case, the lack of a rigorous background in metadata structures is commonly observed; In Table 1 (excluding CGDI), only 21% of the entire metadata is explicitly modeled (79% missing and implicit).

[18] geodiscover.cgdi.ca
[19] donnees.ville.quebec.qc.ca
[20] agrg.cogs.nscc.ca/projects/LiDAR_Metadata
[21] mrn.gouv.qc.ca/english/mines/geology/geology-3dmodel.jsp
[22] www.3dcadbrowser.com
[23] The United States
[24] cybercity3d.com/index.php?option=com_content&view=article&id=106&Itemid=77
[25] cybercity3d.com/index.php?option=com_content&view=article&id=129&Itemid=16

Information Category	Information Details	CGDI	QCOD	LID	MRN	CBW	TRI	CTY1	CTY2
3D Spatial	Primitive Dimension	I	Ø	I	I	I	I	I	I
	Primitive Type	I	Ø	E	I	E	E	E	I
	Elevation Encoding	E	Ø	Ø	Ø	I	Ø	Ø	Ø
	3D Pre-Processing	E	Ø	I	I	I	I	I	I
	Vertical Precision	E	Ø	E	I	I	Ø	E	E
	Vertical Coverage	E	Ø	Ø	Ø	I	I	I	I
	Vertical Spatial Reference	E	Ø	Ø	Ø	I	Ø	Ø	Ø
LoD	Object Count	Ø	Ø	Ø	Ø	E	Ø	E	E
	Primitive Count	Ø	Ø	Ø	Ø	E	E	I	Ø
	Scale	E	Ø	Ø	Ø	Ø	Ø	Ø	Ø
3D Appearance	Texture and Material	Ø	Ø	Ø	Ø	E	I	I	I
3D Format	Proprietary Formats	E	E	Ø	E	E	E	E	I

Table 1. The metadata noticed among eight inventoried resources are labeled by “E” for noticed in explicit fields, “I” for noticed in implicit fields (e.g. written summaries), and “Ø” for not noticed at all. In header row, the acronyms (e.g. CGDI) represent inventoried resources. For full names see Section 3

4. PROPOSAL OF A METADATA-SET FOR GEOSPATIAL 3D MODELS

The literature and inventory indicate that the existing metadata are not explicit and collective about 3D geospatial content in many topics such as the notions of dimension, contextual information, and level of details. Our objective is to propose a top-level metadata-set to improve the explicitness and integrity of the mechanism to document 3D geospatial data resources. The proposed metadata-set considers the academic communities and actual practitioners by citing more than 60 papers, standards, and software environments as well as the inventory described in the previous section. In such a sense, a variety of domains including geology, urbanism, cadaster, topographic mapping, and computer graphics were cited. These resources were investigated to identify the topics, definitions and terms which are used to describe 3D geospatial content and to regard their influence among various communities.

The first priority of the proposed metadata-set is to provide 3D information allowing for as many explicit classes as possible. Thus, the first concern is to identify a rigorous structure which helps users to follow the topics that interest them. Figure 1 presents the abstracted main structure of the metadata-set with what we called the *Metadata Target (MD_TRGT)* core class and its 20 metadata classes (i.e. topics) grouped in three UML packages (i.e. *General*, Complementary, *Availability*).

The *MD_TRGT* class represents the subject of documentation at the levels that institutional and software environments constitute 3D geospatial content (e.g. dataset, thematic or implicit classes or layers). The UML classes presented in Figure 1 have already covered the entire inventoried topics in an explicit way. Compared with Table 1, the proposed classes are superior in number because several topics have been enriched with the requirements deduced from our literature review. In Figure 1, *General* and *Complementary* UML packages comprise the contextual and structural information. The difference between the two packages is that the *General* package contains the metadata requirements we found to be endorsed by at least half of the investigated references. *Availability* package documents the path from storage to delivery, comprising the repository technologies, services, and potential information loss en route.

The second step is to improve the main structure of the metadata-set with further details mainly from technical resources. Figure 2 demonstrates a subset of the *General* package at this step where the bold classes are the ones from Figure 1. The first question to ask is about the additional classes to include in Figure 2. Depending on the importance and specificity of details, they are added to the main structure of the metadata-set as either class properties with potential domain values (i.e. *enum* for enumeration in Figure 2) or as aggregate and component classes. The following paragraphs explain this step with some examples from Figure 2.

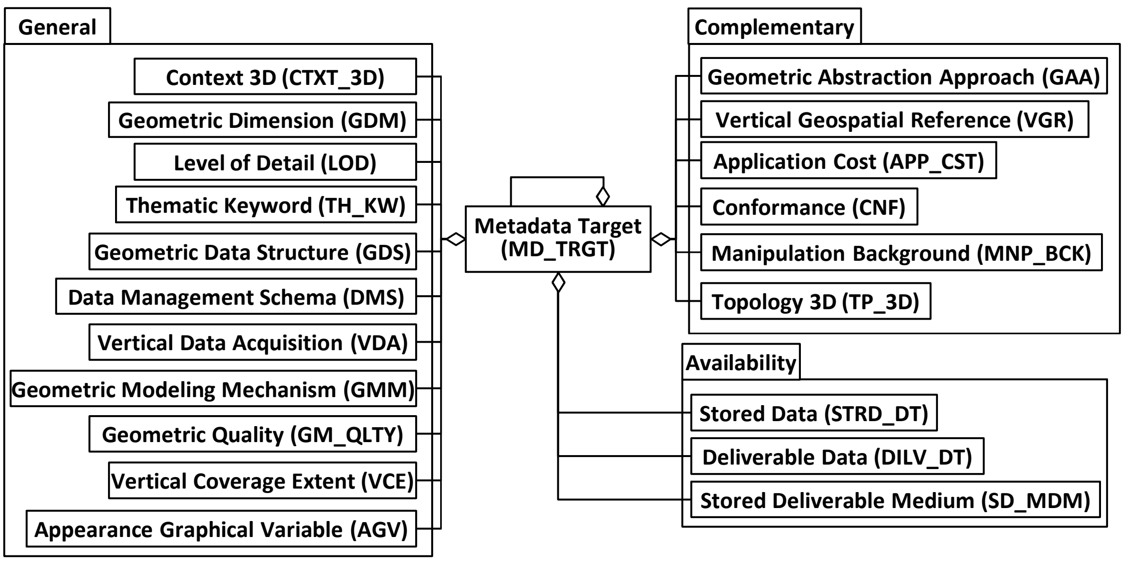

Figure 1. The main structure of the current version of the proposed metadata-set with *MD_TRGT*

Clearly defining the meanings of “3” and “D” is a key element to avoid confusion in the specifications of 3D geometric content (Larrivée et al 2006, Bédard et al, 2002). Accordingly, the *Geometric Dimension (GDM)* class decomposes the notion of dimension into generic components that include the dimension of the global universe and local referencing sub-universes (i.e. 3D or 2D or 1D where the two latter potentially exist in 3D datasets for thematic data such as speed limits located using linear referencing on roads and street signs located with left/right offsets added to linear referencing), and the number of dimensions of the geometric primitives (i.e. 0D to 3D). This proposal adheres to the definitions of (Larrivée et al 2006, Bedard et al 2002) and is necessary to follow the proposed model dimension which can be either 2D+1D (Larrivée et al 2006), 2.5D, 2.75D, 2.5D+3D (Penninga 2008), and etc. or real 3D. This proposed notion of dimensions in *GDM* class is more explicit than in the North America Profile (NAP) of ISO 19115 where the number of dimensions is specific to grid representations (excluding vectors) and has varying definitions among vertical axis, direction of motion, and sensor scan line. Knowing that a large number of multi-dimensional models are not grids, NAP’s suitability is short on this issue.

The literature indicates that users prefer to discover the 3D geospatial content which is close to their needs like volumes in 3D geology and boundaries in 3D city visualization. *Geometric Data Structure (GDS)* class prepares the metadata-set for describing various 3D representations (e.g. 2D with elevation attribute, 3D points, Interpolated surface, surface extrusion, patches, B-Rep, and voxel) in *Geometric Content* property.

Moreover, *GDS Object* class is an additional component to specify the comprising 3D geometric objects (e.g. curve, triangle, and boundary or volumetric solids). Unlike NAP meta-data, this assembly permits distinguishing boundary solids like in CityGML from volumetric solids like in IFC models.

The literature and inventory show that LoD is expressed by various parameters which are sometimes borrowed from other application topics. For example, the number of geometric objects in a model is a self-demanding parameter which also refers to LoD. Thus, *Level Of Detail (LOD)* class aggregates several parameters from other parts of the metadata-set with association classes (e.g. *LOD GDS Content* association class having different definitions based on the *Geometric Content* property of *GDS* class). Besides, some particular definitions of LoD are globally accepted among specific domains (e.g. CityGML LoD in semantic city modeling). The *LOD Particular* abstract class permits generating such definitions as sub-classes. The *LOD* class permits users to assess various aspects of LoD collectively. For example, a 3D city model can be documented by multiple definitions of level of details simultaneously (and distinctively) under *LOD Particular* abstract class (e.g. CityGML LoD 3 and CIC/BIM Information LoD A).

Some of the metadata classes in Figure 2 such as *Thematic Keyword (TH_KH)*, and *GDS* classes are related with 0 to N associations. When metadata is generated at detailed granularity (e.g. multiple instances of *MD_TRGT* class for each layer), every instance of these metadata classes become coherently coupled (e.g. layer X is building and modeled by B-Rep solid). But, when metadata is roughly defined (e.g. dataset X represents building and terrain and contains polygons and 3D points) the 0 to N associations help to relate corresponding information. Indeed, for some important topics, the metadata-set tries to preserve the information as explicit as possible no matter the level of *MD_TRGT* class.

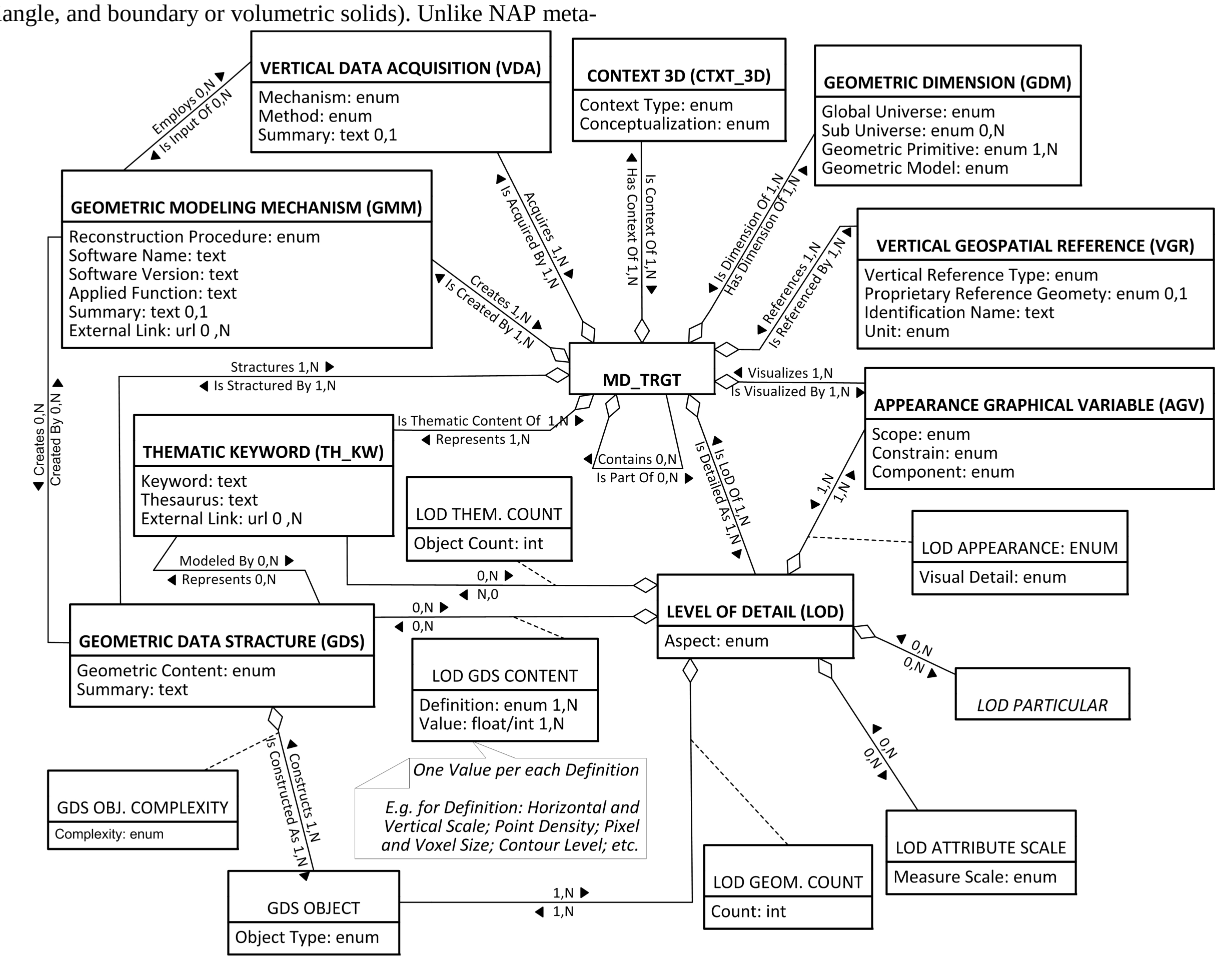

Figure 2. A subset of General package of the proposed metadata-set representing the metadata elements in detail

5. COMPARING THE PROPOSED METADATA-SET WITH CGDI DISCOVERY PORTAL METADATA

For the next step, as the first validation attempt, CGDI Discovery Portal was selected for comparison since its metadata partially conforms to North American Profile (NAP) of ISO 19115. Besides, regarding the importance of documenting 3D information explicitly, CGDI Discovery Portal provides the highest rate of explicit fields according to Table 1.

First, the proposed metadata-set is 100% explicit on every detail of the inventory table while CGDI's rate is 58%. In such sense, the proposed metadata-set brings up six new topics for documenting 3D geospatial content with *CTXT_3D*, *GDM*, *LOD*, *GMM*, *AGV*, and *TP_3D* classes from Figure 1 as large as 38 properties, and 97 potential domain values.

Second, the explicit metadata topics of CGDI Discovery Portal (Table 1) and their counterparts in the proposed metadata-set are assessed based on simulated scenarios for discovering 3D spatial datasets. Following are three scenarios of some simulated requirements about documenting 3D information and how the request is analyzed by each metadata resource. These scenarios will help us to express the similarities between the two metadata and the differences (advantages) of our proposal.

Scenario 1: To attach energy efficiency data to each building face, city planners or environmentalists need datasets which encode building shapes.

- CGDI Discovery Portal metadata is only explicit on how altitude or depth is encoded in the dataset (e.g. coordinate values or attribute). Therefore, to learn about shapes one needs to refer to free-text summaries (if applicable) or make assumptions.
- The proposed Context 3D (CTXT_3D) class describes the nature of vertical dimension in Context Type property as position, shape, and thematic expression (e.g. vertical lines representing value of sampling points). Furthermore, Conceptualization property of the class informs users whether the given context (here shape) is encoded generically (e.g. geometric or attribute data types) or by exclusive rules (e.g. <extrude> tag in KML or methods of database classes).

Scenario 2: To create an integrated city model, one needs to know about the multiple vertical references which may exist in one single dataset or among various resources. Some city objects like street and terrain are usually mapped with reference to known vertical datum like geoid or ellipsoids. However, in many civil maps and blue-prints, underground infrastructures like sewage networks and pipes are represented by profiles which are vertically referenced to street axis or cross sections.

- CGDI Discovery Portal defines vertical reference with regard to the surface from which depth or altitude is measured. The reference surface can be freely named in datum name property but restricted to mean sea or average ground level domain values in vertical datum property. Although being explicit on the topic, CGDI Discovery Portal becomes confusing with redundant properties. Another issue is that CGDI Discovery Portal permits one single vertical reference per dataset.
- The proposed Vertical Geospatial Reference (VGR) class recognizes three types of references as mean sea level, geodetic ellipsoid, and proprietary (e.g. street for pipes). If the type is proprietary, VGR class defines the geometry of the vertical reference (e.g. point, line, surface). VGR class is the only place to define the topic and is in 1 to N relation with the metadata core class.

Scenario 3: A recent search on "3D model" term in Google Trends showed "3ds", "3d max", "maya", "sketchup" and "blender" among the top and rising related search terms. Indeed, many users describe or search 3D models by software specific terms because of the functionalities developed on top of them or institutional preferences. As a result, metadata needs to specify the software environment and functions which have been used to create the 3D geometric content.

- CGDI Discovery Portal permits documenting multiple pre-processing steps under quality information section with a free-text property which highly depends on users' creativity and writing skills.
- The proposed Geometric Modeling Mechanism (GMM) class considers this matter specifically for 3D modeling by providing explicit properties such reconstruction procedure type (i.e. interactive or parametric functions), software name and version, applied functions, and a free-text summary. If further historic information is required, Manipulation Background (MNP_BCK) class documents every precedent cartographic step.

6. CONCLUSION AND FUTURE WORK

Many individuals and agencies intend to cut or reduce re-production costs by discovering exiting 3D geospatial models when applicable. The literature and prior experiences clearly show that mass dissemination of such models requires particular metadata. However, various application and domain specific points of views on 3D geospatial content including the context of 3D, expression of geometric dimension (i.e. definition of "3" and "D") and structures, and levels of detail become fragmented in applied documentations. This results in empty or irrelevantly overloaded discovery results when users with distinct rationalities search online 3D geospatial resources. An inventory on eight online metadata which are used to publish and discover various 3D geospatial resources shows that the 3D geospatial content is documented by proprietary concepts and uncommon information. A main challenge with the inventory was to investigate multiple metadata samples often in form of implicit summaries depending on distinct rationalities and writing skills.

In response, our goal was to find the requirements for documenting 3D geospatial content and model them at higher level of abstraction than being domain and application specific. The requirements were identified by studying the concepts and terms by which the academia and actual practitioners denote their 3D resources. In result, a metadata-set was proposed to integrate the required information on contextual and structural specifications of 3D geospatial content with as many explicit classes as possible. At early assessment stage, the proposed metadata-set is compared with CGDI Discovery Portal metadata which partially conforms to North American Profile (NAP) of ISO 19115. The comparison shows that the proposed metadata-set is 42% more explicit compared to CGDI while CGDI proposed the most complete and explicit metadata according to the inventory of eight geo-portals. Based on three simulated scenarios about discovering 3D datasets, our proposal shows promising results. The proposed metadata is noticed beneficial by being extensive and explicit on the nature and conceptualization of the 3rd dimension, 3D geometric structures and modeling, vertical referencing, and various aspects of LoD.

Currently, all of the proposed metadata classes which are directly aggregated to the core class in Figure 1 are mandatory. It may be required in future works to bring constrains of the proposed metadata classes closer to users' preferences. The proposed metadata-set is technical on some of the proposed domain values. Although this helps with semantic coherence, further work is certainly required to make the proposed domain values more accessible (i.e. covering the technical expressions and keeping the domain values simple for public). These amendments are important to decrease the chance of redundancy of information and probable confusions for non-expert users when encountering the proposed metadata-set.
Despite the preliminary assessment, the metadata-set needs to be validated at larger scale. History of queries about 3D geospatial models extracted from relevant geo-portal such as CGDI Discovery Portal, Princeton University 3D Model Search Engine, and Turbo Squid Portal would be analysed against the proposed metadata-set. The future works also include receiving the recognition of beneficiary stakeholders by implementing a prototype system comprising simplified interfaces.

7. ACKNOWLEDGEMENTS

The authors wish to give their sincere acknowledgements to Natural Sciences and Engineering Research Council of Canada and Canada's GEOIDE Network of Excellence for funding this research.

8. REFERENCES

AIA, 2013. Project BIM Protocol. American Institute of Architects

Anan, H., Maly, K., Zubair, M., 2002. Digital library framework for progressive compressed 3D models. *Proceedings of SPIE*. pp. 138-147

AEC UK, 2012. Implementing UK BIM Standards for the Architectural, Engineering and Construction Industry. V 2, September 2012. Architectural, Engineering and Construction (AEC) CAD and BIM of United Kingdom

Apel, M., 2006. From 3d geo-modelling systems towards 3d geoscience information systems: data model, query functionality, and data management. *Computers & Geosciences*, 32, pp. 222-229. Elsevier

Badler, N. I., Glassnerm A. S., 1997. 3D Object Modeling. *Proceedings of SIGGRAPH 97*, Introduction to Computer Graphics Course Notes

Basanow, J., Neis, P., Neubauer, S., Schilling, A., Zipf. A., 2010. Towards 3D spatial data infrastructures (3D-SDI) based on open standards – experiences, results and future issues. In van Oosterom. P., Zlatanova. S., Penninga. F., Fendel, E. (eds) *Advances in 3D Geominformation Systems*, pp. 65-86. Springer.

Boeykens, S., Bogani, E., 2008. Metadata for 3D models: how to search in 3D Model repositories?. *Proceedings of International Conference of Education, Research and Innovation*. pp. 11. Madrid, Spain

Breunig, M., Zlatanova. S., 2011. 3D geo-database research: retrospective and future directions. *Computers & Geosciences*, 37, pp. 791-803. Elsevier

Bédard, Y., Pouliot, J., Larrivée, S., Frenette, P., Brisebois, A., Normand, P., 2002. Création d'un modèle 3D urbain: de la recherche de données à l'exploitation du modèle 3D. Research Report, 162p, Département des sciences géomatiques. Université Laval, Canada

Cambray, B.,1993, 3D modeling in a geographical database. *Proceedings of the 11th International Symposium on Computer-Assisted Cartography*

Cellary, W., Walczak, K., 2012. Issues in creation, management, search and presentation of interactive 3d content. *Interactive 3D Multimedia Content*, pp 37-54. Springer

CIC, 2013. BIM Planning Guide for Facility Owners. V 2, June 2013. Computer Integrated Construction (CIC) Program at Penn State

Cretu, A. M., 2003. 3D object modeling - issues and techniques. Technical Report. University of Ottawa.

Czerwinski., A., Kolbe, T., Plumer, L., Stöcker-Meier, E., 2006. Spatial data infrastructure techniques for flexible noise mapping strategies. *Proceedings of the 20th International Conference on Environmental Informatics - Managing Environmental Knowledge*. Graz, Austria

Dollner, J., Buchholz, H., 2005. Continuous level-of-detail modeling of buildings in 3D city models. *Proceedings of the 13th Annual ACM International Workshop on Geographic Information Systems*. pp. 173 – 181. New york. USA

Dietze, L., Nonn, U., Zipf, A., 2007. Metadata for 3D city models analysis of the applicability of the ISO 19115 standard and possibilities for further amendments. *Proceedings of the 10th AGILE International Conference on Geographic Information Science*. pp. 1-9

Dollner, J., Kolbe, T., Liecke, F., Sgouros, T., Teichmann, K., 2006. The virtual 3d city model of berlin - managing, integrating and communicating complex urban information. *Proceedings of the 25th Internaitonal Symposium on Urban Data Management*. Denmark.

Doyle, J., Viktor, V., Paquet, E., 2009. A metadata framework for long term digital preservation of 3D data. *International Journal of Information Studies*. 1(3).

Emgard, L., Zlatanova, S., 2008. Design of an integrated 3D information model. In Coors, Rumor, Fendel, Zlatanova (eds.) *Urban and Regional Data Management*, pp. 143-156.

Evans, B., 2012. 3D Models from the Cloud. *Practical 3D Printers*, pp. 75-97. Springer.

Fischer, G., 2012. *Meta-design: empowering all stakeholder as co-designers*. Paper Handbook.

Flotynski, J., Walczak, K., 2013. Describing Semantics of 3D Web Content with RDFa. *Proceedings of the First International Conference on Building and Exploring Web Based Environments*

Funkhouser, T., Min, P., Kazhdan, M.,Chen, J., Halderman, A., Dobkin, D., Jacobs, D., 2002. A search engine for 3D models. *ACM Transactions on Graphics*. 22(1), pp. 83-105

Gorte, B., Lesparre, J. 2012. Representation and reconstruction of triangular irregular networks with vertical walls. *Proceedings of the 7th 3D GeoInfo Conference*. Quebec. Canada

Groger, G., Plumer, L., 2011. How to achieve consistency for 3D city models. *GeoInformatica*. 15(1), pp. 137-165. Springer

Guarino, N., 1998. Formal Ontology and Information Systems. *Proceedings of FOIS'98*. Trento, Italy

Haala, N., Brenner, C., Ander, K-H., 1998. 3D urban GIS from laser altimeter and 2D map data. *IAPRS*. 32, pp. 339–346.

Hagedorn, B., Döllner, J., 2007. High-level web service for 3D building information visualization and analysis. *Proceedings of the 15th International Symposium on Advances in Geographic Information Systems*.

Jones, K., Devillers, R., Bédard, Y., Schroth, O., 2013. Visualizing perceived spatial data quality of 3D objects within virtual globes. *International Journal of Digital Earth*, Taylor & Francis.

Jones, R., McCaffrey, K., Clegg, P., Wilson, R., Hollimanb, R., Holdsworthc, R., Imberc, J., Waggottd, S., 2009. Integration of regional to outcrop digital data: 3D visualisation of multi-scale geological models. *Computers & Geosciences*. 35, pp. 4-18. Elsevier.

Kolbe, T., 2009. Representing and exchanging 3D City models with CityGML. *Proceedings of the 3rd International Workshop on 3D Geo-Information*. Seoul, Korea.

Kessler, H., Mathers, S., Sobisch, H-G., 2009. The capture and dissemination of integrated 3D geospatial knowledge at the British Geological Survey using GSI3D software and methodology. *Computers & Geosciences*. 35, pp. 4-18. Elsevier

Larrivée, S., Bédard, Y., Pouliot, J., 2006. Fondement de la modélisation conceptuelle des bases de données géospatiales 3D. *Revue internationale de géomatique*, 16(1), pp. 9-28

Ledoux, H., Meijers, M., 2011. Topologically consistent 3D city models obtained by extrusion. *International Journal of Geographical Information Science*. 25(4), pp. 557-574.

Létourneau, F., Bédard, Y., Moulin, B., 1998. Perspectives d'utilisation du concept d'entrepôt de données pour les géorépertoires sur Internet. *Geomatica, Journal of the Canadian Institute of Geomatics*. 52(2), pp. 145-163

Longhorn, R. A., 2005., Geospatial standards, interoperability, metadata semantics and spatial data infrastructure. *NIEeS Workshop on Activating Metadata*. Cambridge, UK.

Metral, C., Ghoula, N., Falquet, G., 2012. Towards an integrated visualization of semantically enriched 3D City models: an ontology of 3D visualization techniques. Cornell University Library

Metral, C., Falqueta, G., Cutting-Decelleb, A.F., 2009. Towards semantically enriched 3d city models : an ontology-based approach. *ISPRS proceedings XXXVIII*

Moenickes, S., Taniguchi, T., Kaiser, T., Werner, Z., 2002 - A 2.75D finite element model of 3 d fracture network systems. *Proceedings of the 11th International Meshing Roundtable*. Ithaca, NY, US

Nagel, C., Stadler, A., Kolbe, T., 2008. Conceptual requirements for the automatic reconstruction of building information models from un-interpreted 3d models. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 34, Part XXX.

Oosterom, P., 2013. Research and development in 3D cadasters. *Computers, Environment and Urban Systems*, http://dx.doi.org/10.1016/j.compenvurbsys.2013.01.002.

Oude Elberink, S.J., Stoter, J., Ledoux, H., Commandeur, T., 2013. Generation and dissemination of a national virtual 3D city and landscape model for the Netherlands. *Photogrammetric Engineering and Remote Sensing (PE&RS)*, 79 (2), pp.147-158.

Penninga, F., 2008. 3D Topography: a simplicial complex-based solution in a spatial DBMS. PhD Thesis. Delft, The Netherlands

Pilouk, M., 1996. Integrated modelling for 3D GIS. PhD thesis. ITC Enschede. Netherlands.

Pouliot, J., Bédard, K., Kirkwood, D., Lachance, B., 2008. Reasoning about geological space: Coupling 3D GeoModels and topological queries as an aid to spatial data selection. *Computers & Geosciences*. 34, pp. 529–541. Elsevier

Pouliot, J., Roy, T., Fouquet-Asselin, G., Desgroseilliers, J., 2010. 3D Cadastre in the province of Quebec: A First experiment for the construction of a volumetric representation. In Kolbe, Konig, Nagel (eds) *Lecture Notes In Advances in 3D Geo-Information Sciences*, pp.149–62. 3DGeoInfo conference, Berlin, Nov. 3-4.

Pu, J., Kalyanaraman, Y., Jayanti, S., Ramani, K., Pizlo, Z., 2007. Navigation and Discovery of 3D models in a CAD Repository. *IEEE Computer Graphics and Applications - CGA* , 27(4), pp.38-47.

Rajabifard, A., Binns, a., Massera, I., Williamsona, I., 2006. The role of sub-national government and the private sector in future spatial data infrastructures. *The International Journal of Geographical Information Science*, 20(7), pp. 727-741

Ramroop, S., 2004. Issues regarding geographic metadata standards in GIS interoperability. *International Conference on Advances in Geographic Information Systems*.

Ravada, S., 2008. Oracle Spatial 11g. Avilable at (31 May 2013):
http://download.oracle.com/otndocs/products/spatial/pdf/osuc2008_presentations/osuc2008_techover_ravada.pdf

Schilling, A., Basanow, J., Zipf, A., 2007. Vector based mapping of polygons on irregular terrain meshes for web 3D map services. *3rd International Conference on Web Information Systems and Technologies (WEBIST)*. Barcelona, Spain.

Scianna, A., 2013. Building 3D GIS data models using open source software. *Applied Geomatics*, 5(2), pp. 119-132

Sheppard, S.R.J., Cizek, P., 2009. The ethics of Google Earth: Crossing thresholds from spatial data to landscape visualization. *Journal of Environmental Management*, 90, pp. 2102-2117.

Stoter, J., Beetz, J., Ledoux, H., Reuvers, M., Klooster, R., Janssen, P., Penninga, F., Zlatanova, S., van den Brink, L., 2013. Implementation of a National 3D Standard: Case of the

Netherlands. In Pouliot, Daniel, Hubert, Zamyadi (eds.) *Progress and New Trends in 3D Geoinformation Sciences*, pp. 277-298. Springer

Stadler, A., Nagel, C., König, G., Kolbe, T., 2009. Making interoperability persistent: a 3D geo database based on CityGML. *Proceedings of the 3rd International Workshop on 3D Geo-Information*. Seoul, Korea.

Stoter, J., Vosselman, G., Goos, J., Zlatanova, S., Verbree, E., Klooster, R., Reuvers, M., 2011. Towards a National 3D Spatial Data Infrastructure: Case of The Netherlands. PFG(Photogrammetrie, Fernerkundung, Geoinformation). 2011. 6, pp. 405-420.

Terrace, J., Cheslack-Postava, E., Levis, P., Freedman, M.J., 2012. Unsupervised conversion of 3D models for interactive metaverses. *Proceedings of the 2012 IEEE International Conference on Multimedia and Expo,* pp. 902-907.

Thomas, V., Daniel, S., Pouliot, J., 2010. 3D modeling for mobile augmented reality in unprepared environment. in Kolbe, Konig, Nagel (eds.) *Lecture Notes In Advances in 3D Geo-Information Sciences*. 3D GeoInfo conference, Berlin. Springer

Uden, M., Zipf, A., 2013. Open building models: towards a platform for crowdsourcing virtual 3D cities. In Pouliot, Daniel, Hubert, Zamyadi (eds.) *Progress and New Trends in 3D Geoinformation Sciences,* pp.299-314. Springer

Zamyadi, A., Pouliot, J., Bédard, Y., 2013. A three step procedure to enrich augmented reality games with CityGML 3D semantic modeling. In Pouliot, Daniel, Hubert, Zamyadi (eds.) *Progress and New Trends in 3D Geoinformation Sciences*, pp.261-275. Springer.

Zipf, A., Tschirner, S., 2005. Finding GI-datasets that otherwise would have been lost -GeoXchange - a OGC standards-based SDI for sharing free geodata. *Proceedings of the 2nd International Workshop on Geographic Information Retrieval at the Fourteenth ACM Conference on Information and Knowledge Management*. Bremen, Germany.

Zlatanova, S., Itard, L., Shahrear, M., van Dorst, M., 2010. A user requirements study of digital 3D models for urban renewal. *Open House International*. 35(3)

Zlatanova, S., Abdul Rahman, A., Pilouk, M., 2002. 3D GIS: current status and perspectives. *Proceedings of the Joint Conference on Geo-spatial theory, Processing and Applications*. Ottawa, Canada