MODELLING SMART CITIES WITH CITYGML

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ABSTRACT: The smart city concept is already widespread and multi-faceted, comprising several complementary definitions and dimensions taking us into the articulated and bidirectional relationship between ICT and urban dimensions.

CityGML, a free access modelling tool involving vast communities of developers, has been mainly used to assist in decision-making processes regarding a variety of the city's components by effectively articulating open, interoperable, multi-scale and multi-purpose information.

The dissertation focuses on assessing the global and local impacts of CityGML models in planning and managing a smart city, highlighting how they can be embraced in Portugal with all the existing national public policies.

CityGML applications fitting each dimension of a smart city (environment, mobility, living, people, governance and economy) will be presented and further reviewed to demonstrate their possible extrapolation to real use cases in Portugal. Additionally, policies and established international agreements to advance towards smart city goals in Portugal will be exploited and debated.

The results conclude that, when planning and managing a smart city, CityGML models provide good grounds to model its components, drawing considerations on future adjustments onto the Portuguese case, whose policies are also leading to goals towards the promoting of a smart city.

Key words: Smart City; CityGML; modelling; Portugal; policies.

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1 INTRODUCTION

There are currently numerous points of view regarding the definition of smart city, however all of them represent the common idea of a sustainable city integrating characteristics such as mobility, environment, public services and economy alongside public opinion and increase transparency of public governance. The articulation of said characteristics with ICT dedicated infrastructure allows the gathering of data in real time from several components of the city, thus being able to produce models used for decision making processes or even to promote a good performance for the city.

OGC's (Open Geospatial Consortium) CityGML (City Geographic Markup Language) is an open multi-purpose and multi-scale model that scaffolds a 3D geospatial visualization with analytic and simulation functionalities engendering open and useful models to store and exchange all the components of a smart city in one unique representative model that can be updated by everyone and for everyone.

In this dissertation the focus will be on two major questions:

1. To assess if CityGML models are affective in planning a smart city by analysing each of its representative components and comparing the model with similar other approaches and standards;
2. To investigate the development of strategic policies implemented by the Portuguese Municipalities to actually invest in smart cities.

To answer the first question, CityGML examples fiting one or more dimensions of the smart city will be presented and discussed. The second one will be assessed through the analysis of the Portuguese legislations and formally established goals towards the smart city concept.

2 BACKGROUND

2.1 SMART CITIES

There is a range of different characterizations for a smart city. However, it is commonly accepted that it embraces the ability of the city to dynamically adapt by collecting information from sensors to be utilised for decision making processes.

Quoting O'Grady and O'Hare, (2012) "there is neither a single template of framing a smart city, nor a single-size-fits-all definition of it.". It is important to underline that the current broader concept of smart city is no longer limited to the diffusion of ICT but is also spanning over to community needs. Some authors go further and consider the inhabitants of these cities as their main protagonists who shape it through their continuous interactions.

Among many others, there is an index (European Smart City Index) which breaks down the concept of smart city in six essential dimensions:

1. **Smart Economy** - the practice and application of digital circular economy with the use of collaborative simulation models exploring the creative and innovative potential of ICT skills specific to human capital;
2. **Smart People** – the combination of various factors such as lifelong learning, flexibility, creativity, open-mindedness and participation in public life and discussion, thus developing intelligent people able to generate clever solutions to urban problems;
3. **Smart Mobility** – an affordable transportation system, efficiently operating, using clean and non-motorized options and supporting a balanced regional development combined with limiting polluting emissions. It involves user centred approaches and promote an integrated mobility system;
4. **Smart Environment** – the implementation and effective use of policies focused on environmental management such as the investment in renewable energies, measurement and control of the pollution levels, construction of green buildings, risk management solutions and reducing total energy demand;
5. **Smart Governance** - fundamental to execute, manage and develop intelligent policies. The smart governance dimension revolves around the collaboration between governments, the creation of citizen involvement in opportunities, transparency orientation and open data;
6. **Smart Living** - the government's commitment in improving the level of public services and their articulation. It represents the investment in public services such as safety, health,

culture, education and leisure infrastructures and utility networks.

2.2 CityGML

CityGML is an open, multi-purpose and multi-scale model used for geospatial representation, data storage and database modelling.

The data model consists of a core module and thematic extension modules. The core module comprises basic concepts and components of the CityGML data model, and the extension modules deal with specific thematic fields of the virtual 3D city model including: Appearance, Bridge, Building, City Furniture, City Object Group, Generics, Land Use, Relief, Transportation, Tunnel, Vegetation, Water Body, and Textured Surface. There is also the possibility of developing and adding Application Domain Extensions (ADEs) which can specify additions to the CityGML data model.

Based on the standard GML3 of the OGC, CityGML focuses on five main aspects of 3D city models:

- 3D Geometry – all the geometric properties of the model;
- Semantics – the characteristics of each object;
- LOD (level of detail) – the resolution and scale for the represented objects;
- Appearance – the displaying of the 3D model's texture;
- Topology – refers to the mechanism used to store the interrelations between objects in the 3D city model providing consistency and connectivity between the individual elements of the model.

CityGML focuses mainly on constructing 3D GIS models targeted on the planning and management of multi-scale, large areas and geo-referenced 3D models. In a single CityGML model characteristics such as solar potential estimation, 3D cadastre, infrastructure planning, noise propagation, utility management, energy demand estimation and solar potential estimation among others are possible to be articulated and managed altogether.

CityGML documents can be generated from programs such as CityEditor, Random3Dcity, RhinoCity, AutoCad and others so they can, afterwards, be processed using APIs such as citgml4j, CodeSynthetis XSD, ogc-schemas. These models can be visualized in applications such as Google Earth, though they cannot be rendered directly on the web browser due to memory constraints and sometimes plug-ins might be necessary.

3 CITYGML MODELS VERSUS SIMILAR APPROACHES

3.1 CityGML standard versus Other exchange formats

Since CityGML doesn't present itself as an efficient enough standard to visualize 3D content directly from CityGML, it is needed to look for other 3D standards to which export the geometry and appearance of CityGML and compare them with its own standard.

Prieto et al., (2012), compared CityGML with exchange formats such as IFC, 3D PDF, X3D, VRML, KML and COLLADA in representative features such as geometry, topology, texture, LoD, objects, semantic, attributes, web and georeferenced. After analysing all the presented standards it was concluded that KML and COLLADA standards are designed for 3D world browsers so the export from CityGML is limited. X3D has a geospatial component and is able to represent different levels of detail which brings it closer to the CityGML representation philosophy concluding that it is a more adequate approach to represent 3D models on the web since it is compatible with HTML.

3.2 CityGML versus BIM

Building Information Modeling (BIM) is a 3D modelling procedure that describes the geometric and semantic properties of a building. It complies with the IFC standard which, similarly to the building module of CityGML, describes buildings as semantic objects with properties and relations. However, it lacks concepts for spatial objects like streets, vegetation or waterbodies so it is not an appropriate form for the representation of complex cities.

Although both BIM and CityGML are applied for similar application purposes, such as planning, asset management, infrastructure and buildings functionality they represent physical models at different representation scales, while CityGML focuses mainly on constructing models targeted on the management of multi-scale, large areas and geo-referenced 3D models, BIM has a more detailed approach since it is used in architecture and construction buildings.

3.3 CityGML versus Urban Platform by Ubiwhere

Ubiwhere has developed one platform that could be used for the planning and monitoring of smart cities called Urban Platform.

The Urban Platform represents the city as an integrated system with components such as: smart tourism, smart waste, smart lamppost, smart bike sharing, smart traffic, smart air quality, smart noise and smart parking. All these assembled in an easy and very friendly platform that allowing city management, whether it is traffic, mobility, safety, infrastructure maintenance or high-level decision making. The modelling of this platform involves the contribution of different stakeholders mostly from the private sector.

Ubiwhere presents the Urban Platform (with its complementary applications) as an advance highly capable instrument able to process and manage the city's information. However, these applications do not come for free and although some of them can be developed through open API's, the obtained information might not be so interoperable as expected. On the other hand, CityGML is an open and free path to represent data in a fully interoperable, multi-purpose and multi-scale model.

3.4 CityGML versus UrbanSim

UrbanSim is a platform for supporting planning, analysis and simulation of urban development, incorporating the interactions between land use, transportation, economy and environment allowing the 3D visualization and shared open data.

Two tools are provided to reach all its potential: the UrbanCanvas for scenario modelling (with the same properties as CityGML) and the Penciler for rapid site usefulness analysis.

The platform offers the ability of input data, track its developments, edit constraints, create and run simulated scenarios, visualise indicators and model adjustments.

All these advantages come with the downside of still not being an open source model which results in a permanent dependency between the user and the company as well as the disadvantage of not being a freeware platform leading to the requirement of payment for their services.

4 CITYGML MODELS FITTING SMART CITIES

4.1 CITYGML FITTING A SMART ENVIRONMENT

Krüger & Kolbe, (2012), focus on the identification, classification and integration of energy-related indicators for buildings and neighbourhoods within 3D building models (conformed to the CityGML standard). These can be related in the context of urban energy planning within the Energy Atlas of Berlin, thus forming an adequate image of the local energy situation. Furthermore, it is even discussed an approach for extending the CityGML standard for storing these indicators through the development of an ADE.

The 3D city model of Berlin will be an available core dataset allowing the visual interpretation of the represented urban environment by providing the building geometry as well as their basic information (addresses, usages and heights).

The project will study application fields such as geothermal heat potential, traffic and urban structure, energy characteristics of buildings and the creation of potential new business models.

The paper introduces the indicators (elementary and complex) and indexes necessary to integrate in this application considering the hypothesis of strong correlations between information about residential buildings and their energy consumption values and that that information can be derived from the geometry and semantics of the virtual 3D city model, cadastre data and statistical information.

This Energy ADE could be further developed to estimate the consumed, produced and wasted energy for all the composing sectors (housing, commerce, industry, agriculture, transportation and so on) of a city, which are contributing key factors for the design of an environmentally smart city by promoting the development of urban planning strategies addressing greater energy efficiencies.

Regarding software tools, the generated model and the ADE, it is possible to state that, at first sight, all these seem exploitable to any other city possessing the mentioned datasets. For example, in Portugal, all the parameters/indicators are possible to be calculated using the same exact formulas and the represented classes and attributes can also be attained using Portuguese datasets.

4.2 CITYGML FITTING A SMART MOBILITY

It is stated by various government agencies and municipalities that although many CityGML modules, such as Building, Bridge and Tunnel, are well developed, it was noticed that the Transportation model is not sufficient for most transportation applications. For this reason, Labetski et al., (2018), introduce four additions to improve CityGML's Transportation module such as Multi-LoD modelling of roads, carriageway representation, detailed intersection modelling (defining it as a separate class modelled in addition to the roads subclass) and introducing waterways.

The application endorses the idea that CityGML is, not only useful to promote a smart mobility, but also shows that there is already a huge investment taking place from governments and experienced developers.

Although there are developed transportation applications in cities such as Cascais and Lisbon, these are not articulated among themselves and between means of transport (there are different applications for each different transportation vehicle) as well. This can constitute one of the problems regarding Portugal's mobility. The use of the CityGML would enable the articulation of all the information collected from the existing applications in a single one. Furthermore, with the representation of roads at multiple levels of detail it would be easier to monitor and control accidents and allow Portugal to have better road maintenance.

Although in Portugal the need to introduce waterways as a new sub-class wouldn't be much of a priority as it is in the Netherlands, the applicability of these tools for a Portuguese example would be possible with the possession of the necessary datasets since all the software tools are currently available.

4.3 CityGML fiting a Smart Governance

Sindram and Kolbe, (2014) present an ontology for the formal modelling of planning actions as complex transactions on the entities of virtual 3D city models allowing to map the measures and actions described in legal documents and regulations as complex transactions on objects from virtual reality.

The developed UML diagram comprises the modelling of actions and operations (classified according to their category), their related units, the resources (produced outcomes) and the Key Performance Indicators (KPI's) to serve as performance evaluators for the goals set out to achieve with the performed actions.

This model will allow planning authorities to model and simulate urban operations and verifying their compliance with the legal urban planning instruments that already exist, and since it was developed for a generic purpose, it is possible to export this same application using Portugal's case incorporating the currently used legal planning instruments.

4.4 CityGML fitting Smart People

Prandi et al., (2013), introduce the i-SCOPE (interoperable Smart City) project methodology and implementations articulated with open standards, which aims to create an ecosystem made of public administrations, industries, universities and research centres to capture the user-driven requirements and promote their participation by including their feedback promoting the development of the smart people dimension.

Among the many possible appliances conceived for this project, Prandi et al., (2013) describes in detail the NoiseTube, an application that facilitates sound measuring at any place and any time through a simple mobile app, using simple features such as the phone's microphone, wireless connection and localisation through GPS, transforming the average mobile phone into a highly portable and accessible sound measurement device enabling all citizens to measure ambient sound levels whenever and wherever they can. The data collected allows the construction of noise maps combined with a 3D model of the city in the NoiseTube website available publicly.

It was originally developed by the Institute for Geodesy and Geoinformation Science of the Berlin University of Technology. However, the project aims to be the basis for the materialization of several future smart services projects employed in various countries, which can be Portugal's case since all the software tools and processes described can be utilised for every other country as long as the Municipalities are able to provide project information.

4.5 CityGML fitting a Smart Economy

Gozdz, Pachelski, Oosterom, & Coors, (2014), elaborate the possibilities of applying CityGML for cadastral purposes highlighting its use to the 3D representation of buildings. The representative use case is a practical application of the CityGML-LADM (Land Administration Domain Model) ADE model to demonstrate the benefits of establishing relationships between spatial objects from a legal and a physical point of view. The physical objects reference the location and size of the parcels whereas the legal information comes with remarks regarding land use (private or public space and residential, commercial, agriculture, etc) and other applied legislations attached to the parcel.

Since CityGML does not contain features that can describe the legal information attached to spatial objects, the paper proposes the integration of the CityGML-LADM, and an ADE aimed at indicating connections between legal spaces occupied by buildings and their physical complements. Although de model is developed using datasets from Poland, the same can be carried out for Portugal as well since it already exists a study (Hespanha, 2012) elaborating a LADM for Portugal and developing its combination with CityGML for cadastral purposes.

The use of this application could entail the managing of a physical model of a Portuguese city embedded with the legal policies and constraints regarding land administration, territorial management and urban planning which would also aid with the smart governance of the city by allowing public administrations, stakeholders and citizens to exchange the necessary information.

4.6 CityGML fiting Smart Living

Becker, Nagel, & Kolbe, (2013), developed an ADE for representing utility networks using CityGML models. While the core CityGML model covers the topological and topographic representations of the utility networks, the functional and semantic aspects will be defined with the ADE allowing the model (together with the ADE) to serve as a complete instrument for complex analyses and simulations.

The ADE comprises subclasses such as *DistributionElements* (used to transport the materials from producer to consumer or to connect different network users), *FunctionalElements* (operation and maintenance of the network), *Devices* (controlling, measuring, storing, transforming or amplifying the network), *TerminalElements* (end and enter points of the network) and *ProtectiveElements* (protection for the network).

Once more, this example can be adapted for Portuguese use since the software tools are available. As for the models developed either for the *UtilityNetwork* ADE core model or for the added specializations, these can also be exportable using Portuguese (adequate) datasets since all of them represent generic objects, and their shape, dimensions and materials can be modelled according to each specific use and even the transported materials can be specified as appropriate.

This is an excellent example of an application where CityGML models and the dimension of smart living are combined developing a data model for representation of different utility networks such as water, gas, long distance heating, and power supply. This integrated database should facilitate disaster management as well as the simulation of descending effects in case of network failures.

4.7 CITYGML FITTING A SMART CITY

Soon & Khoo, (2017) present a project developed by the Singapore Land Authority (SLA) called 3D National Mapping. Involving the construction and management of a 3D map, adopting for that purpose the CityGML standard, using the combination of 8 out of 10 existing modules: Building, Bridge, CityFurniture, Relief, Transportation, Tunnel, Vegetation and WaterBody. Allowing the extraction of information despite the used operating system utilised.

The LoD of each representative module varies from theme to theme:

- Relief – represented in triangulated surfaces in LoD0;
- Building – represented in LoD0 to LoD2;
- Transportation – represented in LoD0 to LoD2;
- Bridge – main structure and its elements represented in LoD2;
- WaterBody – represented in LoD1;
- Vegetation – represented as PlantCover up to LoD1.

For the validation of the results open-source software tools such as FZK Viewer, 3D CityDB Importer/Exporter, CityDoctor and Val3dity were employed.

This application proves that CityGML is a standard capable of articulating the dimensions of the smart city in a single model where they all work together. However, the question whether it is possible to relate all these dimensions remains.

The government has the opportunity to invest in green initiatives, to improve its citizen's living conditions by increasing the level of public services, developing public transportation systems, investing in more renewable sources of energy and endorsing projects promoting "smart" sustainable initiatives. All these decisions can be backed up by the citizen's opinion.

The development of public transportation systems and electric or non-motorized transportation (smart mobility) leads to a growing adoption of renewable sources of energy and, consequently, to a more effective control of pollutant emissions (smart environment). For both these dimensions there is added value in having the support of a smart economy enabling not only environmental and mobility projects to have financial aid but also to have more collaboration and back-up.

A smart living comprehends the investment in better life conditions (culture, leisure and transportation, etc) including people's primary needs such as security, health and education. Considering these necessities as public services they should all be developed by the partnership between the government and its citizens. By working on these basic needs it is fair to say that components such as the city's mobility, economy and environment are being improved alongside them.

It is possible to conclude that the components of the smart city all cooperate with each other and that it is denoted a certain hierarchy where the smart governance and smart people dimensions are above the four remaining since the close cooperation between the government and its citizens enables the control and improvement of all the other remaining dimensions (smart mobility, smart living, smart environment and smart economy).

5 PORTUGAL POLICIES TOWARDS A SMART CITY

5.1 THE NATIONAL PROGRAM FOR THE MANAGEMENT OF TERRITORIAL POLICIES (PNPOT)

PNPOT, is the National Program for the Management of Territorial Policies, in other words, it states the strategies and guidelines that are to be implemented for Territorial Management at a National level.

The program divides itself in ten Commitments for the Territory, operationalised in five Intervention Domains:

- D1 – Natural Domain;
- D2 – Social Domain;
- D3 – Economic Domain;
- D4 – Connectivity Domain;
- D5 – Territorial Governance Domain.

It's possible to say that almost all, if not all, of the political measures established in PNPOT represent resolutions going towards one or more than one of the dimensions of the smart city. However, it was possible to highlight measure 5.7 clearly declaring the goal of promoting intercity cooperation in order to achieve a sustainable smart city which intents on improving social inclusion, housing, health, infrastructures, mobility, economy and technological and digital intelligence. This translates the clear intention of working towards the materialisation of the smart city concept in Portugal.

5.2 INTELLIGENT TRANSPORT SYSTEMS AND SERVICES (ITS)

The Portuguese Law nº 32/2013 published on the 10th of May recognises the employment and utilisation of intelligent transport systems and services. It is implemented via collaboration between transportation and engineering companies (public or private sectors) and entities from the National Technological and Scientific System (SCTN).

The Activity Plan of the Portuguese Authority for Transportation Mobility (ATM) expressed the intent of the ITS to provide a more efficient and sustainable mobility for all the citizens, which can also be integrated in the smart city's component describing smart environment.

It is also mentioned that the development of ITS technologies is also integrated in the concept of Industry 4.0, which consists in the merging of the already existing production methods with the recent developments achieved in ICTs, promoting the Portuguese economy towards a smarter, and digital economy.

The adoption and implementation of this Law increasingly promotes the concept of a citizen driven smart mobility where the aim is to serve and connect the city's inhabitants turning their needs and opinions as priorities for the decision-making processes.

5.3 PORTUGUESE NATIONAL REPORT ON THE IMPLEMENTATION OF THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT

The 2030 Agenda for Sustainable Development is a universal agenda, based on 17 Sustainable Development Goals (SDGs).

The main goal of this report is to inform on Portugal's status on the implementation of the 2030 Agenda for Sustainable Development which calls for the integration of the SDGs into policies, procedures and actions developed at the national, regional and global levels.

These SDGs do not only promote a smart city approach but also ensure that Portugal (and the rest of the participating countries) make that a priority by implementing these guidelines in their development policies and regulations.

5.3.1 Law for the General Fundamentals regarding Public Land Policy, Territorial Planning and Urbanism

The purpose of this Law is to acknowledge and coordinate the use of Instruments for Territorial Planning (Plans and Programs), distinguishing between the different types of land use (rustic and urban) and help with the coordination between public administrations, institutions/companies and citizens when it comes to their intervention and participation in planning processes. It also states that it is the duty of these administrations (government and autarchies) to implement, evaluate and monitor the Instruments for Territorial Planning and urban operations.

To operationalise this Law regulations were developed using its fundamental guidelines: the Juridical Regime for Urban Development and Edification (RJUE), the Juridical Regime for the Instruments regarding Territorial Management (RJIGT) and the Juridical Regime for Urban Rehabilitation (RJRU).

This Law serves as a clear example for Portugal's evolution towards a smart governance. These regulations and guidelines could be further developed with their incorporation in a 3D city model using CityGML, resulting in a 3D model of the physical, geographical and legal aspects of the city which could be utilised by the public administrations, stakeholders (private and public) and the citizens.

6 CONCLUSIONS AN FUTURE WORK

After all the research presented about CityGML and smart cities, it is verifiable that both can help each other in mutual cooperation where a CityGML model would make it easier to establish the connection between the government and its citizens and, at the same time, allowing the representation of all the components of a city from transportation to health and risk management.

It is true that OGC's CityGML is already in an advance state of development relying on a huge community of software and data developers articulating itself with a distinct number of stakeholders (from public to private). However, more advances are needed in order to reach its full potential and gain more acceptance from the stakeholder's outlook when it comes to city development and modelling.

CityGML is able to represent physical and geographical descriptions of the city, however, it is not able to describe physically its activities, public services, companies or citizen's actions which represent crucial characteristics to be considered when describing a smart city. There is even the possibility of some of these variables representing unpredictable behaviours, so the fact that they are not in the least considered in a CityGML model for a smart city should be one of the considered future developments in both subject areas.

According to all the Portuguese legislations, it is valid to state numerous laws and goals regarding the establishment of smart cities. So if there are regulations going towards this concept, why not bring them altogether and model them in a single platform allowing the exchange of multi-dimension and interoperable information accessible to all the citizens? With the OGC's standard, CityGML, all this would be possible in a free open source database and data modelling.

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