


A Descriptive 3D City Information Model Built From Infrastructure BIM: Capacity Building as a Strategy for Implementation

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ABSTRACT

This study developed a descriptive 3D city information model (CIM) using only infrastructural building modeling tools to create maps and analyzed the model according to needs identified in interviews with public-sector actors and a bibliometric analysis. The interviews assessed the challenges of implementing CIM in the Brazilian city of Curitiba, while the literature study determined that current academic production reflects the current reality, calling attention to relevant issues. The experimental software solution successfully created 3D informational modeling of cities for passive use as well as maps to support decision making, although it did not offer advanced parametric tools for urban analysis. Still, this model provides a flexible approach to overcoming the challenges reported by interviewees, which included financial limitations and organizational culture.

KEYWORDS

3D City Models, BIM, CIM, Infrastructure

INTRODUCTION

The creation of informational 3D city models has become a central theme in urban studies (Amorim, 2015; Beirão et al., 2009a; Chen et al., 2018; Duarte et al., 2012; Gil et al., 2011; Gil et al., 2010; Gil & Duarte, 2008; Montenegro et al., 2011; Simonelli & Amorim, 2018; Stojanovski, 2013, 2018; Xu et al., 2014). One regularly debated concept is the city information model (CIM) which combines BIM (building information modeling) and GIS (geographic information system) technologies (Sun et al., 2020; Xu et al., 2014). Informational modeling of cities is still an emergent research field (Almeida & Andrade, 2018); the objective is to reproduce physical aspects of the city while adding information (Gaillard et al., 2020). This tool can add value to the construction of urban space and its management (Xu et al., 2014). While discussions and applications of CIM have evolved in recent years, some issues remain central. In some settings, such as Brazil, adoption of BIM is still incipient (Sotelino et al., 2020); consensus is also lacking on the tools and means of creating a 3D city information model.

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Table 1. Requirements for inclusion in the survey

Minimum Requirements	Desirable Requirements
Actor in the public sector	Executive position inside the agency
Experience with public projects, programs, and policies	Experience with human resources capabilities, updating programs and methods
Knowledge of technologies to support urban projects	Knowledge of GIS or BIM tools
	Advanced degree in urban planning or urban management
	Experience with innovation policies
	Knowledge of CIM, its potential and limitations

Some software studies have been undertaken specifically to develop new tools (Gil et al., 2010), while other research has addressed using BIM and GIS tools to develop CIMs (Chen et al., 2018). Recent advances in BIM studies have granted it a key role in CIM debates, although GIS is still the main platform used in 3D city model studies.

Brazil's problems implementing public policies are well-known (Arretche, 2010); even though the federative design encourages innovation on local scales (Samuels & Abrucio, 2000), the organizational culture in public agencies tends to have contrasting characteristics (Melati & Janissek-Muniz, 2017), leading to fragmented good practices for the adoption of BIM, which is supported by capacity building and empowerment.

The focus of this study, Curitiba, is no different. While this city has been ranked first in the Brazil's Index of Digital Cities (Duarte et al., 2014), it faces these same challenges related to technological implementation and management inside public agencies. This research contains two preliminary studies for further discussion: one is a set of interviews with public agencies to determine their perceptions of the challenges of implementing CIM in Curitiba according to their perceptions, while the second is a bibliometric review of research on 3D city information models in order to determine whether the literature reflects the findings of the interviews.

The main goal of this research is to develop a 3D CIM model that uses only infrastructure-related BIM tools and to create themed maps. By investigating the development process and structural findings, this investigation of how tools are applied can contribute to capacity building and empowerment, both of which are at the core of innovation processes and perceived by many of the interviewees as a necessity.

BACKGROUND

Local Context

In 2017, actors in the public sector in Curitiba were surveyed to identify what they considered the challenges to implementing CIM in the city as an urban management and planning tool. Minimum and desirable requirements for inclusion were established and applied (shown in Table 1) in order to ensure credibility of the collected data.

A total of 12 individuals working in urban management and planning were interviewed. While all 12 fulfilled the minimum as well as the desirable requirements for inclusion, 7 of these held a managerial or strategic position inside their agency, with the remaining 5 included due their technical capabilities. The saturation technique was also used to confirm that the interviewees met the requirements, looking for specific keywords in the answers indicating minimal knowledge of technologies and innovation related to urban management. After reaching the saturation point, data collection can stop since no new element will further increase the findings related to the object or

Table 2. Challenges to implementing CIM

#	Challenges identified by interviewees
I	Excessive bureaucracy involved in contracting, acquiring, and updating software and hardware
II	Availability of funds
III	Human resources training
IV	Lack of synergy between agencies and municipal departments
V	Lack of understanding among leadership
VI	Technology-related challenges
VII	Choice of which technology to implement
VIII	CIM not a priority
IX	Short deadlines to produce concrete results from investment in CIM technologies
X	Lack of synergy between public and private sectors
XI	Data organization and processing
XII	Culture change is necessary
XIII	Dependence on specific technological tools

phenomenon analyzed (Thiry-Cherques, 2009). A total of 7 individuals reached the saturation point, 4 during the 5 first interviews. Eight interviewees also reported knowledge of CAD tools, 4 GIS tools, and 2 BIM tools.

Discourse analysis was used to identify the main challenges involved in implementing a CIM model in Curitiba, producing 13 central themes (Table 2). Acquisition of software and hardware was cited by various respondents as an obstacle, because of the bureaucracy involved in public purchasing procedures as well as financial limitations. Curitiba's main urban planning and management agency, IPPUC, has 200 employees, most of whom operate CAD, GIS, or BIM systems. Network licenses were described as a common if incomplete solution, since the same individuals reported problems when all the licenses for a specific tool were taken, causing staff to have to work in shifts and reducing efficiency. Open source software was also tested, but interviewees reported problems switching between different platforms, which is necessary because tools developed by large corporations (Autodesk, Esri, and Graphisoft, for example) are commonly used by the firms that provide services for public projects. This reflects a lack of synergy between the public and private sectors in terms of adopted and functional technology, and this mismatch is likely to become more frequent as Brazilian public-sector agencies have widely adopted BIM software after the implementation of new public policy goals requiring BIM for new contracts as of 2021 (Sotelino et al., 2020).

Because of this reality, staff at public agencies must adapt tools to achieve their desired goals. Combining methods to develop a 3D city model presents a solution to circumvent this obstacle and boost efficiency. Furthermore, since CIM represents a link between GIS and BIM, good understanding of these resources is required to produce a city information model that can be truly useful in planning and management. In this sense, Curitiba is lagging behind, since BIM has only been adopted on a larger basis since the city began to contract projects using this methodology in 2020 (Curitiba, 2020).

The objective of this research was to determine the reality in public agencies, and the results indicate that the contributing factors are not local and specific; the challenges identified in Curitiba's urban management and planning may be present in other Brazilian cities as well as other developing countries. The experimental combination described herein offers a potential solution to these obstacles by combining different BIM tools to create a 3D city information model.

Table 3. Top 15 keywords

# Records	Keyword
37	CityGML
30	GIS
25	3D city model
16	3D city models
15	LiDAR
14	BIM
13	3D modelling
10	3D modeling
10	Point cloud
9	3D cadastre
8	3D GIS
8	Building
8	Photogrammetry
8	Urban planning
8	Visualization

Theoretical Context

A bibliometric study was conducted to explore research conducted on 3D informational city models, using the Web of Science (Clarivate, 2018) main collection and the keywords “3D,” “city,” and “information model.” These terms were searched using the topic filter to select only articles for the final analysis, yielding a total of 457 articles. The objective was to compare the local context (determined through interviews) with the scientific context related to 3D city modeling. First, the keywords were examined, indicating the themes discussed (especially BIM and GIS), then the publications were evaluated to determine country of origin.

This analysis found that GIS was more frequent than BIM in studies on 3D city informational modeling. The 15 most frequent keywords are shown in Table 3.

An autocorrelation network map of these findings was created using Vantage Point (Search Technology, 2006) software based on Pearson’s correlation coefficient, and showed a network made from a single field. This map (Figure 1) was constructed using keywords with 2 or more records, generating a total of 220; GIS (red spot, right center) is visibly more central than BIM (red spot, upper right).

Publications came from a variety of countries (Table 4), most notably China, Germany, the United States, Spain, and Italy; Brazil appears near the bottom of the list with only 7 articles.

The findings indicate that discussions of 3D city modeling tend to focus on GIS rather than BIM. The share of publications from Brazil was quite modest, in line with the degree that BIM has been adopted (as mentioned earlier); only 1 of the Brazilian studies addressed BIM, while 3 focused on GIS.

DIFFERENT WAYS TO APPROACH 3D CITY MODELS

Studies on CIM have advanced in the past decade; initial works described cities as street systems (Beirão et al., 2009b), followed by the establishment of the concept and profound debates on its structure and applications, as seen in Gil et al. (2011), Stavric et al. (2012), Stojanovski (2013, 2018),

Figure 1. Autocorrelation map of keywords related to “3D city information model”

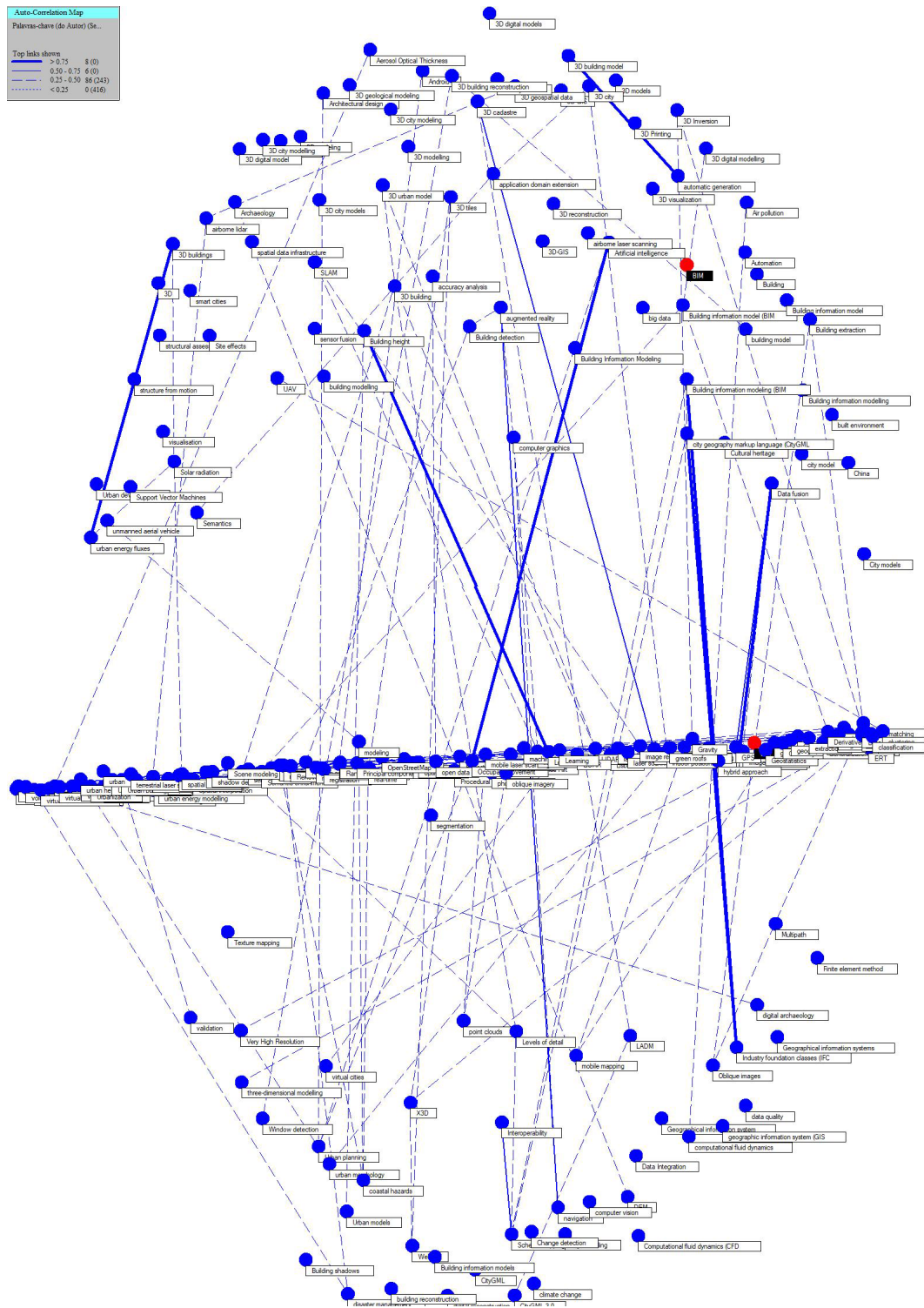


Table 4. Top 25 countries producing publications on “3D city information model”

# Records	Keyword
86	China
62	Germany
56	USA
36	Spain
30	Italy
23	France
23	Netherlands
21	Australia
20	Turkey
18	England
18	South Korea
16	Austria
16	Switzerland
14	Canada
14	Japan
13	Sweden
12	India
12	Portugal
9	Taiwan
8	Belgium
8	Finland
7	Brazil
7	Greece
7	Israel
6	Czech Republic

Xu et al. (2014), Simonelli and Amorim (2018), Almeida and Andrade (2018), Beirão et al., (2015), and Thompson et al. (2016). Later work described the encoding standard for CIM (OGC, 2012) and actual cities such as Helsinki using CIM as a management tool (Higgins, 2017). Other studies focused on methods for 3D city modeling under suboptimal conditions, like the study by Biljecki et al. (2017), which explored and assessed alternatives for 3D modeling without elevation data.

Many studies have also focused on the uses of models. For instance, Jung & Joo (2011) pointed out that models can be used passively for simple visual analysis or to extract information. On the other hand, active use of 3D models incorporates intelligence and provides the additional dimension. In debating the functions of the model, Gil et al. (2010) listed ten necessary features for the CityEngine (Esri, 2017) CIM tool: i) incorporate urban ontology; ii) respond to the planning regulations and strategies defined for the site; iii) consider the context, combining information on the site as well as the population; iv) support the formulation of programs for urban intervention; v) provide a selection of urban design patterns; vi) include a generative design model; vii) analyze sustainability indicators;

viii) permit interaction between data and design; iv) provide an interactive visualization of data; x) evaluate and rate different designs.

According to this definition, a model designed for passive use should fully cover the first four items, and partially address items 7–9; with these functions, they can passively generate elements for urban diagnostics, for example. The remaining items are intended only for models to be used actively, which should address all the items on the list.

Integrating GIS and BIM

Emulating the complexity of cities presents a major challenge to urban researchers. The goal is not only to reproduce the morphology of the city, but also to incorporate information in order to address a series of processes such as urban analysis, simulations, and design (Gil et al., 2010). Though discussions and applications of CIM have evolved in recent years, some issues remain controversial; software/tool compatibility is one such aspect, especially since GIS files and IFC files are semantically different (Dall'O' et al., 2020).

GIS models are the precursors to information modeling technologies, and first appeared in the late nineteenth century. This tool is commonly used to model objects that already exist on the urban and regional scale (Xu et al., 2014). The methodology is traditionally based in 2D maps where information and geographic data are linked to two-dimensional entities, which in turn are tied to latitude and longitude coordinates. Three-dimensional GIS is more recent, and provides improved functionality (Deng et al., 2016).

BIM technology is considered an evolution of CAD tools. The main advantages of BIM in the building design process are parametric modeling and interoperability (Deng et al., 2016; Lima, 2016). These provide designers with a model that responds to specific parameters connected to geometry and concentrate information from many different disciplines in one file (regardless of file origin), respectively. Essentially, BIM is the digital representation of the functional and physical attributes of a building (Przybyla, 2010), and focuses on smaller scales (Xu et al., 2014) due to their richness of information: the urban nanoscale (Yigitcanlar & Lee, 2013). As a result, CIM is an analogy of BIM in the urban scale and context (Stojanovski, 2013) that combines the functionalities of a 3D GIS system. Furthermore, BIM has been used to conceive CIM models (Chen et al., 2018); the leading BIM software developers, i.e. Autodesk and Bentley, have extended their tools in an attempt to close this gap (Dall'O' et al., 2020).

Developer Advances In CIM Tools

CityEngine (Esri, 2017) and 3D Cities (Bentley, 2017) are city modeling tools. Autodesk in turn, has promoted its Autodesk Digital Cities project to select cities for pilot projects focused on developing and applying solutions within the CIM context (Stavric et al., 2012). However, this manufacturer still does not offer specific software for city information modeling, and instead has expanded its BIM tools to cover infrastructure domains, creating InfraWorks (Autodesk, 2018b).

One application of these tools was the informational model by the city of Helsinki using Bentley solutions, combining the existing GIS database with captured data depicting the 3D reality (Higgins, 2017). Meanwhile, Harvard's CityFormLab developed tools for urban network analysis and metropolitan form analysis; both were built to work with ArchGIS 3D (Esri, 2019) and Rhinoceros (Rhinoceros, 2020), GIS and 3D conceptual modeling tools, respectively (CityFormLab2017). Rhinoceros also provides the base for CityMaker, an advanced parametric tool that uses information to simulate typical operations in urban projects (Beirão et al., 2015). Faced with a wide variety of CAD, BIM, GIS, and CIM solutions, architects and engineers must decide which tools best suit their projects. These solutions often change from one project to another, especially when urban design and analysis are involved. Professionals waste time whenever they have to test a new tool to determine its suitability, and because most of those evaluations are not conducted formally or published, it is likely that these problems are widespread.

Some years ago Gil et al. (2010) assessed some of the software available for urban design at that time to determine its suitability in project applications. This study, which became a major reference in creating and solidifying the CIM concept and its applications, concluded that no single comprehensive platform could best fulfill these authors' objectives, but they noted AutoCAD Civil 3D (Autodesk, 2018a) as the best overall option. Note that the Autodesk solutions are fragmented, providing specialized solutions per city modules. An additional tool that has not been mentioned is Revit, one of the main BIM tools used in the Brazilian construction market.

BIM Adoption In Brazil

Implementation of BIM only became a federal public policy mandate in Brazil in the late 2010s. In comparison, Singapore began this process in the 1990s, and the UK currently has a strategic plan to bring BIM maturity up to Level 3 (Harun et al., 2016). In the public sector, Brazil clearly lags behind other relevant nations, but BIM is more developed within the Brazilian academic environment. Although it was first discussed and applied in 2006 (Ruschel et al., 2013), adoption of BIM in Brazil is still incipient (Sotelino et al., 2020); this is one indicator of the mismatch between the level of maturity for BIM adoption between public and private sectors. The public policy was only implemented after the technology had been studied and taught in universities for over a decade, which means that the construction industry was already absorbing professionals with BIM knowledge during that period of time.

Although BIM has not been widely adopted, some positive initiatives illustrate good practices related to BIM development in Brazil. A few years ago the military implemented an integrated BIM-based system to manage all of its projects and facilities; the system is georeferenced and offers 2D and 3D map views, and is also linked to BIM models of the facilities, making it a CIM platform (Fitzner et al., 2015). Other subnational initiatives in the states of Santa Catarina and Parana include regional standards for contracting and developing BIM projects, and share human resources training and empowerment (Lima, 2018).

Brazil's historical challenges related to inequality are reflected in the implementation of public policies, and there is an acknowledged perception of inefficiency on the federal scale in this area (Arretche, 2010). For technology, especially information communication technologies, the panorama again reflects only isolated good practices which tend to appear in more autonomous organizations such as the military or subnational and local agencies. While the Federalist structure provides a mechanism to stimulate innovation on regional levels (Samuels & Abrucio, 2000), public organizations in Brazil have recognized cultural aspects related to stability and compliance with or adaptation to circumstances and influences (Melati & Janissek-Muniz, 2017), two factors that corroborate the need for cultural change expressed in this current research.

In order to implement BIM, organizations must adapt their organizational structures, strategies, and processes (Sackey et al., 2015). Along these lines, this exploration of infrastructure BIM tools to conceive a 3D city informational model creates a space for discussion of how application of these tools is not only connected to public policies, but also the organizational culture of local agencies.

Using Infrastructure BIM To Develop A City Model

Infrastructure BIM tools are mostly used to model streets and roads, while buildings are left to architectural, structural, and MEP BIM tools. Understanding that urban ontology is covered by both of these groups and their subsystems, the challenge was to model LoD1 buildings inside a platform designed to handle streets, roads and their complements. Because the complexity of these tools is a typical concern in implementing BIM (Dall'O' et al., 2020), LoD1 buildings were prioritized since this is the simplest level of detail these features can assume in 3D city models (OGC, 2012).

Table 5. Data Categories

3D Entity Modeling Data	Assigned Information Data
Terrain and Topography	Building Height
Building Footprint	Building Use
Building Height	

METHODOLOGICAL PROCEDURES

Territorial Delimitation

The Vale do Pinhão region of Curitiba, Brazil was chosen for analysis because of its diversity and scale; this zone was established by the current city administration as an “innovation ecosystem” to stimulate innovation and entrepreneurship, akin to places like Silicon Valley (Agência Curitiba, 2018).

Data Collecting Procedures

The modeling data were extracted from two main sources: Open Street Maps (OSMF, 2018) and Google Maps (Google, 2018). Open Street Maps offered a primary data source with direct incorporation of topography into the model, while Google Maps provided observational data to analyze buildings according to footprint, height, and use. This strategy of modeling from observation was specifically adopted to ensure the inclusion of informal settlements or irregular constructions (which do not appear on deed maps).

The topography data were imported from the geographical information database in Civil 3D and InfraWorks. The territorial delimitation was imported from this database with no 3D entities except from the terrain (in other words, without any buildings or roads).

First, the information used to feed the model was separated into two categories of data: 3D entity modeling data and assigned information data, as shown in Table 5. Because this was a pilot analysis of the workflow for modeling georeferenced 3D entities and linking data to this geometry, two categories of information were selected to model the buildings: height and use. Height was chosen because it is the only legislation parameter already accessible inside the InfraWorks standard platform, while use is not only a built-in parameter but can also easily be surveyed in field observation.

Floors were counted to determine building height; 3.0 meters were considered per floor, within the range found in the literature (2.8–3.5 m) by Biljecki et al. (2017).

Information about buildings, including their footprint, was obtained via two strategies; first, an open database published by the public administration itself was utilized (IPPUC, 2018). Next, this data was confirmed through direct field observation, since this is the most appropriate way to deal with informal constructions and include them in the model.

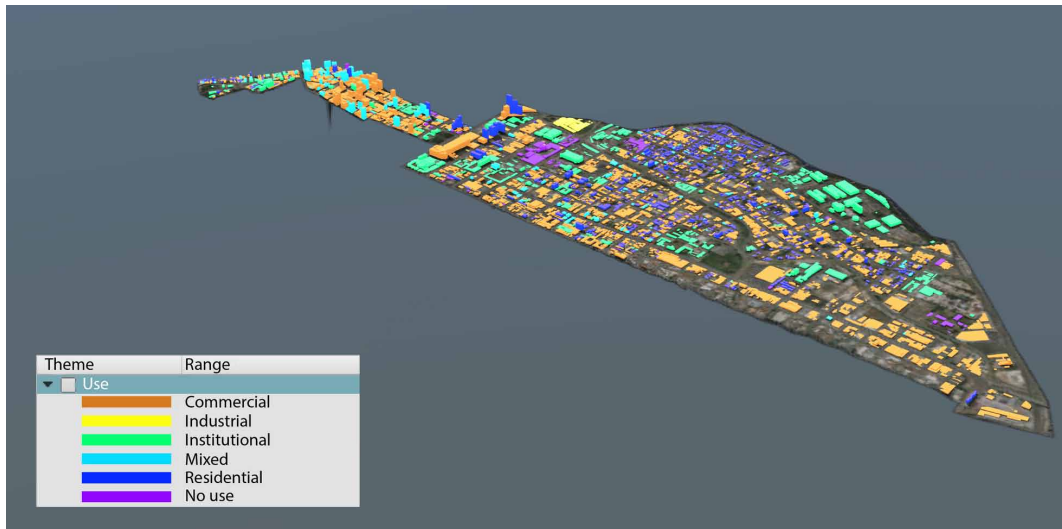
Modeling and Data Linking Procedures

The modeling procedures involved two main steps, one inside the Civil 3D environment and another inside the InfraWorks environment, as described below.

First Stage: Civil 3D

The Civil 3D tool was used to define the perimeters of the territory and the footprints of all the buildings. The polygons were designed over a 2D georeferenced picture of the site, which was imported from the Civil 3D base of available data. As the polygons were created over this georeferenced base, the buildings were also georeferenced. Building height and use data were subsequently added.

Figure 2. Map: building use



Second Stage: InfraWorks

First, the definition of the territory was loaded from the software's base of available data. The loaded terrain was 3D and georeferenced. Because Civil 3D and InfraWorks share the same base data, the two files should be compatible. A larger area of the city containing the defined region was loaded, and then cut to the exact perimeter.

After the site was defined, the polygons were imported from Civil 3D into InfraWorks, and building geometry was also extruded. At this stage, the InfraWorks Schema Editor tool was implemented to customize the interface and create a field for building use data, since this parameter is not included in the standard software interface.

RESULTS AND DISCUSSION

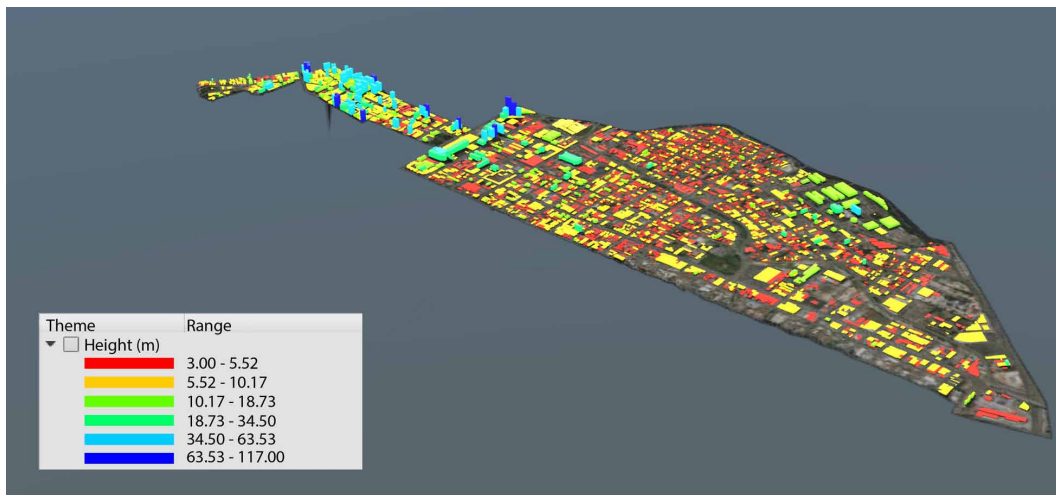
In the final model, nearly 5,000 buildings were modeled in an area of approximately 300 hectares; the region has an estimated population of 20,000. Georeferenced and 3D maps were created to illustrate the building use and height data and create a descriptive model of the selected region. (Figures 2 and 3).

Operational Observations

Interoperability between the two tools was confirmed during the first process of importing the polygons from Civil 3D to InfraWorks. The georeferenced polygon of the region overlapped the 3D terrain created inside InfraWorks, as expected, but part of the building footprint data was not available inside this environment. The first import loaded only the height parameter (which is already available in the InfraWorks interface); it is important to note that once the height parameter was created in the Civil 3D platform using the same assignment recognized by the InfraWorks platform, the footprints were extruded automatically, again reinforcing the interoperability between these tools.

Building use could only be imported after customization with the InfraWorks Schema Editor; this tool provides important options to create and assign any type of necessary data in the software interface, allowing users to adapt the software to local legislation and needs.

Figure 3. Map: building height



CONCLUSION

Using BIM infrastructure tools for passive uses permitted the creation of an informational 3D city model that expanded in respond to specific needs, and created maps on a neighborhood scale. The limitations of this model lie in active use, with analysis inside the platform or at a broader scale, but GIS or 3DGIS can be applied to address these issues. An important caveat is that profound knowledge of the tools was necessary to obtain the final model; most of the interviewees did not have BIM skills, and acknowledged that personal training and culture change were among the main obstacles to implementing CIM into local urban management. This indicates that while the lack of a specific tool for informational 3D city models is not harmful, competence building is essential among the staff who will use these tools. Exploring the applications of these tools is one way to address both of these challenges, building competence and empowering human resources inside the public agencies.

Further limitations included small scale and sampling from a single case study, as well as the small number of tools tested. In terms of scale, the object of study was a metropolitan center, which theoretically concentrates technology, money and capacities; smaller territories should be also analyzed in terms of technological capacities and aptitude, while multiple case studies could indicate pathways toward implementing and institutionalizing technology in public organizations. As for the number of tools, a wide variety of options are currently available for BIM, GIS, and CIM technologies. Specifically with regard to CIM, interoperability is essential; further research on tool capacity could determine whether it is still relevant in complex urban planning and management scenarios where different sectors must exchange information despite using different platforms.

In conclusion, this type of study demonstrates the practical applications of technologies in urban planning and management. Instead of adding complexities, expanding the capabilities of specific tools can create multiple ways to obtain the same results, permitting more creative applications in a variety of settings.

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