THE USE OF CITYGML 3.0 IN 3D CADASTRE SYSTEM: THE CASE OF ADDIS ABABA CITY

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ABSTRACT:

The relevance of 3D cadastre is increasing from time to time as buildings become more complex. Modeling and storing the physical structure with all its elements in a standardized file format improve its usability in different sectors, reduces data redundancy, creates data consistency, maintainability and scalability would be more effortless. In cadastre, showing the legal right of a property is as important as showing the physical right. Especially when a property is multiple owned and has several uses where each use and owner have different rights, responsibilities, and restrictions. The current cadastral of Addis Ababa is a 2D parcel-based mainly focused on registering ownership and physical data. The system lacks to show overlapping ownerships and uses of multistorey buildings. This study solved this critical short come.
The primary goal of this study was to use CityGML to represent the physical and non-physical boundaries of building units. Prior to the release of CityGML 3.0, CityGML 2.0 was widely utilized in this field. However, there are several legal boundary modeling flaws in CityGML 2.0. Contrarily, those gaps were closed in the revised edition. Because of this, CityGML 3.0 was used in this investigation. Firstly, a sample building model was created and tested to demonstrate the concept sample. Then, the concept was realized on a model of an actual condominium building from the study area, Addis Ababa. The findings of the study demonstrate how CityGML 3.0 may be utilized for various 3D cadastre applications, including modeling the legal and physical boundaries of buildings.

1. INTRODUCTION

Worldwide, the urban population is constantly increasing. (Destatis Statistisches Bun desamt, 2021) stated that according to UN, currently, 57% of the global population is living in urban areas and by 2030 this figure is set to reach 60%. This phenomenon is pressuring city administrations to use systematic frameworks and technology that enhance efficient allocation and management of resources. Urban land is one of the scarce and limited resources that significantly impact a country's economy. The rapid urban population growth and the demands of inhabitants like housing, road network, recreational parks, services, and infrastructure are pushing cities to use land above and underground. Thus, multi-story buildings and infrastructures are becoming more and more common.

Cities have developed systems to control and register their land, buildings, and infrastructure. This system is called a cadastre. A cadastre is an up-to-date parcel-based information system that has the right, restriction, and responsibility (RRR) of a land (FIG, 1995, as cited in Enemark and Sevatdal, 1999). This system is a vital entity of land-related plans and policy implementation. Cadastre integrates the 3D building and its associated information into a two-dimensional (2D) geographic description (map). As cadastre is the heart of a land administration system, it must reflect the actual spatial information and its RRR in a comprehensive way (Kaufmanna and Steudler, 1998, as cited in Peter Van Oosterom, 2018) However, with the overlapping and intertwined ownership and multi-layered use, the 2D cadastre system has failed to show the reality and its right to use space above and below it. Despite the complexity, constructing houses on top of each other is an old incident in humanity. Yet the demand for visualizing and managing properties in three-dimension (3D) is recent. Thus, to visualize the actual case and optimize the use and registration of such complex realities, the need for a 3D cadastre is increasing. (Stoter & van Oosterom, 2006) summarized that the considerable increase in private property value, underground infrastructures, utilities, and buildings, and the future approach of 3D planning and 3D GIS are the significant reasons for the need for 3D cadastre.

In order to create a 3D cadastre, the city components must first be modelled with various levels of detail (LoD). These models are governed by a standard data model called CityGML. The Open Geospatial Consortium (OGC) has created CityGML as a standard for modeling, storing, and sharing semantic 3D city models. With the aid of these city models, urban geodata may be stored, managed, and used for various purposes, including risk and disaster management, smart city solutions, 3D cadastre, and building navigation systems.

Different versions of CityGML have been developed and used. The most recent is CityGML 3.0, which is the evolution of CityGML 1.0 and 2.0. This version incorporates all the functionalities and technologies the previous versions have, plus its new features previous versions have not like the ability to encode data in JSON schema, the ability to represent indoor spaces, and better interaction with building information models (OGC, 2021).

This study shows how CityGML 3.0 and its newly added features can be used to model properties and enhance the 3D cadastre system. The aim is to use CityGML 3.0 and model sample building with LoD 3. Then using Building-Room, the volume of spaces owned by a single household (the legal

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boundary of property) was visualized. In addition, the vertical and horizontal circulation that is used by each household to access a room is modeled.

2. STATE OF THE TECHNOLOGY

2.1 CityGML Overview

CityGML is XML (Extensible Markup Language) based data format used to store and exchange 3D city objects (OGC, 2021). Special Interest Group 3D (SIG 3D) has been developing CityGML since 2002. CityGML version 2.0 was adopted by OGC in March 2012. Since then, it was used in different areas including cadastre mapping. The new version 3.0 conceptual model was approved as the official OGC standard in 2021. The main target of the development of CityGML is to reach a common definition of basic entities and their attributes, and relations of a 3D city model. CityGML represents the graphical appearance and the semantic and thematic properties, taxonomies and aggregations of city models (OGC, 2021).

CityGML employs the geometry model for different thematic fields like buildings, bridges, tunnels, vegetation, land use, water bodies, transportation facilities, and city furniture. Generic objects and attributes can be used to model an object if it is not explicitly modelled. In addition, the Application Domain Extensions (ADE) can be used for a specific application (OGC, 2021). The latest version 3.0 of CityGML has the following main new features

• The conceptual model and data encodings formats are separated. And the encoding is based on ISO 191XX specification.
• New modules like dynamizer, versioning, point cloud and construction were introduced.
• Existing modules were revised like building, transportation, generic and CityGML core.

3. CADASTRE IN ADDID ABABA

To have Spatial Data Infrastructure (SDI), spatial (land) data must be collected, stored and managed in a consistent way. A seamless system for sharing information with land management sectors, service providers, developers, banks and other interested groups is essential for urban areas. In addition, the system should align with the contemporary demand of society, allowing a combination of land administration data with other data sources for further use. In this way, sustainable and reliable development can be achieved. One way to achieve this is to develop a land administration standard (Lemmen et al., 2015).

Ethiopia has passed through 3 main regimes. As a result, the land ownership, administration, and registration system were different from time to time. However, cadastre mapping in Ethiopia mainly focused on the urban area. In 1996 the capital city, Addis Ababa City Administration, attempted to develop a multi-purpose cadastre system to enhance the land valuation, taxation, title issuance, and building permit process. By then, the digital map did not cover the entire city, and the numbering of buildings and parcels lacked consistency. Therefore in 2009, the city administration decided to upgrade the system to introduce extra features, including real property registration and land information (cadastre) system (Brüggemann et.al, 2013). The newly developed system has improved numerous gaps of the previous system. The city is currently using this system as a land and property registration system.

Despite the difference in RRR for various property types, the city administration has a similar cadastral system in place for all real estate properties. Land parcels, row-houses, buildings, condominium houses, and other property types have the same registration system. The current cadastral system of Addis Ababa is a 2D parcel-based cadastre mainly focused on registering ownership, physical boundaries, and land use of a parcel the target property is on. These attributes are very crucial for policymakers, urban planners, and other decision-makers. Maybe it would be enough to reflect the reality in the case of row houses. But this does not reflect the reality in some properties like condominium houses. This housing scheme needs a more detailed and precise system that shows the horizontal and vertical reality. The system is also not in a condition where other sectors like banks and utility providers can access it. As a result, all sectors are collecting fragmented data independently.

3.1 IHDP and Legal framework of 3D property ownership in Addis Ababa

IHDP (Integrated Housing Development Project) is a social housing scheme launched in 2003. As a capital city, Addis Ababa started to experience rapid urban population growth, leading to a housing shortage. As a result, the city administration started the Integrated Housing Development Programmer (IHDP). This program planned to construct 40,000 condominiums housing yearly for low and middle-income households (UN-Habitat, 2011).

The Ethiopian Federal condominium proclamation No 272/2003 defines a condominium as a building for residential or other purposes with five or more separately owned units and common elements, in a high rise or a row of houses and includes the landholding of the building.

The construction of IDHP is financed by the government. Interested individuals can register for this scheme for free. Once the major construction is done, the government will announce the winners from the registered individuals using a lottery system. Then the winners will make a down payment of 10-20% of the total cost and sign a 20-year loan lease agreement committing to fully paying the construction costs. Until the owner pays the full payment, the government owns the building unit. Depending on the scheme, the mortgage duration might differ from project to project, but at some point (usually in 20 years) the owner must pay the construction money including interest. This means the ownership of each unit in a building will change from government to private ownership.

These buildings are mainly used for residential but commercial activities are common on the ground floor. When the owners start living in the building, they are expected to form a committee to administer the building, communal properties and resolve security issues. Before IHDP there were apartments, but the private sector constructed those apartments. As a result, individual owners were entitled to their unit only, and the rest of the common spaces were owned and managed by developers. However, in IHDP, each household is entitled to their unit and equally shares ownership of communal spaces like staircase corridor elevators and other building facilities. Furthermore, the condominium site on which the buildings are built is owned by all households on that site.

There are several proclamations and regulations related to condominiums. For instance, proclamation No. 19/2005 deals with the eligibility criteria, the selection process, penalties in case of defy. Proclamation No. 370/2003 and regulation No. 12/2004 outlines the condominium. Even though the development is vertical, none of the proclamations mentioned 3D ownership or law. Therefore, it can be concluded Ethiopia has no 3D property ownership right and the concept of property right is related to land. However, the condominium households committee has the right to draft its rules and regulations in which the common properties are administered.

3.2 Extension and New Class Definition

The use of cadastre is for land management. However, in the land management process, different sectors outside the land management office are involved. A very good example of this senior is the banking sector. In Addis Ababa banks are highly involved in property valuation, collateral, loan and transaction processes.

In IHDP, the process of binding contracts between housing agency (government organization responsible for constructing condominiums and announcing winners) and condominium winners is done through the Commercial Bank of Ethiopia (CBE). Once the lottery winners are announced, the sub-city land administration office where the buildings are located will provide working space for CBE stuffs. CBE stuffs will go to the sub-city to do document verification and other paper works. Winners must go to wereda (the second smallest city administration next to sub-city), the sub-city land management office, the housing agency and to bank several times to submit documents and letters from one office to another before signing an agreement receiving the key to the apartment. Not only the winner but also officers from land management office and banks must go to other sectors office to get pepper works done. A winner could spend 3 to 5 weeks to get those things done. The collateral process also has some similarities with the loan process. If one wants to use his/her property to get money from the bank, engineers of the bank will go to the site and measure the entire property and register the building material. Once they did that, they will estimate the cost of the property and based on that estimation the bank will offer money. If the owner did not agree with the bank, he/she has the right to go to other banks. And engineers of the second bank will do the same thing again.

During this process, owners tend to bribe the engineers to falsify the data to add the value of the property. Suppose the owner and the bank reached an agreement. In that case, then the banker will go to the sub-city office where the property is located and inform the land management office to ban further transactions on that property. Before this process begins, the banker will go to the sub-city and check if there is any unpaid loan or transaction restriction on the property. To do these activities, banks must send their professionals to sub-city to do all the work manually. This process is continuously found to be time-consuming, cost ineffective, redundant, and highly corrupted. Another use case of building materials is building valuation during the redevelopment process. During the urban renewal or upgrading process, if a property must be demolished partly or wholly, the urban renewal office of the sub-city sends engineers to measure the building parts and its materials. Again, this process is known to be time-consuming and the most corrupted task during urban redevelopment.

As the city's population increased, the utility demand skyrocketed and caused scarcity. Since 2012 provision of water for villages has been based on a schedule, meaning villages have access to tap water on a specific day of the week. It could be two days or three days per week. The idea behind this strategy is to balance the consumption demand by saving water. However, this schedule was not drafted based on actual household or village consumption, rather, it was based on the convenience of pipeline installation and the administrative unit boundary. "Ketena" is the smallest administrative unit in the city. For example, if Ketene 1 has access to water on Monday and Wednesday, then Ketene 2 will have it on Tuesday and Thursday, and Ketene 3 will have it on Friday and Saturday or Friday and Sunday.

Therefore, a system that improves those processes and enhances the decision-making process could help the mentioned organizations to function efficiently and satisfy their customers' needs.

4. RELATED STUDIES

The use of CityGML for cadastre purposes is not a new phenomenon. Deferent studies have shown how CityGML can be used in cadastre systems. For example, (GÓŹDŹ et al.,2014) showed how CityGML can be used for 3D modeling of buildings for cadastre use by integrating the LADM standard with the CityGML OGC standard. To do that, CityGML-LADM ADE was developed by the researchers. After that, the model was demonstrated by three different types of properties with different scenarios. The proposed model has two classes, namely PL_LegalSpaceBuilding for legal space representation and PL_Building for physical building representation. Representing legal space was not in the scope of the study; therefore, the study focuses on the PL_Building part only. The study shows the flexibility of the CityGML conceptual model by adapting LADM ADE for cadastre purposes. However, because CityGML has no dedicated counterpart to represent legal rights and administrative units of buildings, the study countered some difficulties in representing those rights of a building.

(Dsilva, 2009) also conducted a feasibility study on CityGML for cadastre purposes. This study aimed to develop an automated way of extracting legal information like ownership rights, ownership boundaries from building floor plans and conduct a feasibility study on CityGML to represent those extracted legal rights.

CityGML is not developed for cadastre purpose. Therefore, to embed legal information into building models, the researcher developed a special extension for cadastre purpose. CityGML supports two ways of doing extension and the researcher used ADE for this study. An extension called KadasterApartment was proposed. This extension has properties like ownership right, floor number, apartment number, apartment owner, ownership type, number of inhabitants in the apartment, room count, detached room and detached room count.

After the definition of an extension, the study presented the workflow of how extracted information can be used as an input to develop a CityGML model with legal information. The extracted information has height, width, ownership, ownership right, floor number and coordinates of each region. Once the information is extracted from floor plans, the following series of actions were followed.

1. Separation of objects into ownership rights, floor number and regions - in this stage the extracted information each region was grouped based on the floor number and the ownership right.

2. Identification of unique ownership rights and unique floor number – using the input from the previous step, a floor plan was regrouped based on similar ownerships.

3. Grouping of regions with same ownership rights – in this step regions separated from the main floor but still owned by a single owner like underground parking space are identified and grouped.

4. Transformation/translation of coordinates based on floor number – once the regions are grouped, height information was of each region was used to place the floors in 3D space.

5. Representation in CityGML format- after regrouping and providing height information, it was represented in CityGML format.

6. Converting the 2D model into a 3D model. Figure 1 shows the final output of the process. The model indicates similar ownership with a similar colour.

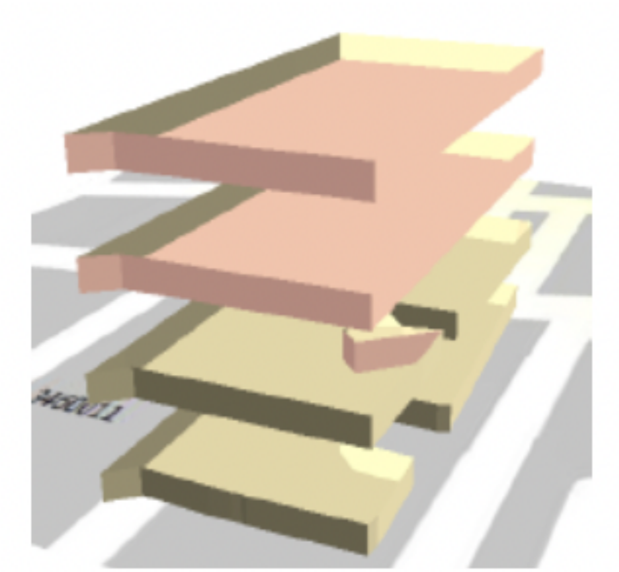

Figure 1. Sample 3D building with ownership data. ©Image Copyright Dsilva, 2009

After developing an extension and following the data extraction and representation staps, the study showed how CityGML can be used for 3D cadastre.

5. CONCEPT DEVELOPMENT

The focus of this study was to represent the legal and physical boundary of a property in a 3D model so that it can be used in cadastre system in Addis Ababa Ethiopia. To do so, the new CityGML 3.0 building subdivision category "Unit" was used. A ground plus 1 building with 6 separated units was developed to demonstrate the concept. The common space that is used for circulation was also developed. Figure 2 shows the building with the physical boundary of each unit. Figure 3 is a 3D floor plan of the building, which was developed to visualize the units clearly.

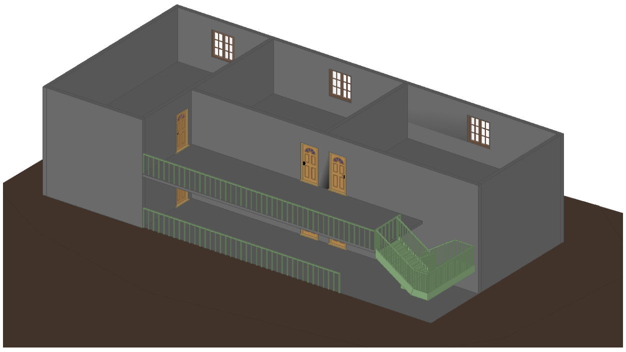

Figure 2. Building with physical boundary.

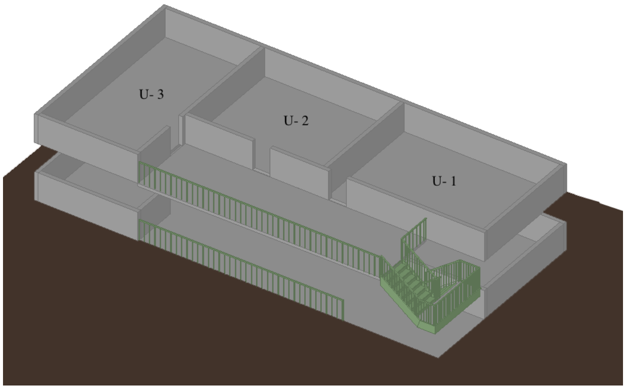

Figure 3. 3D floor plan with a physical boundary.

Once the building and its physical boundaries are modeled, using "Unit" the legal boundary of each unit was developed. Figure 4 shows the 3D form of the physical boundary of all units on both floors and all legal boundaries of units on the first floor. Furthermore, the vertical and horizontal circulation used to access each unit was modeled. Figure 5 shows the vertical circulation space (cyan coloured box) and horizontal circulation space (yellow-coloured boxes) circulation space of the two floors.

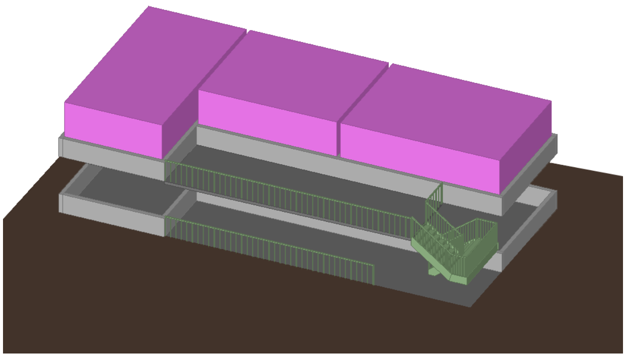

Figure 4. 3D floor plan with legal boundary

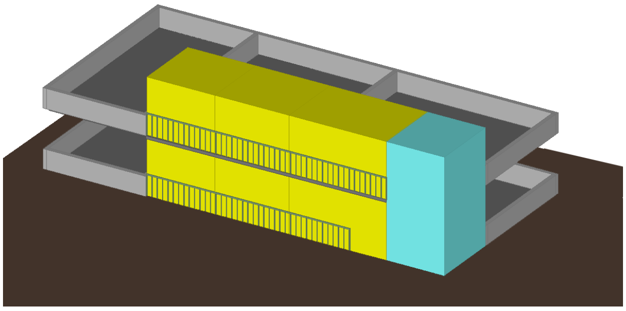

Figure 5. Horizontal and vertical circulation space.

Based on this, legal boundary of a unit is the combination of the unit itself and the horizontal circulation space and/or the vertical circulation space used to access the unit. To access the unit on the ground floor the use of stairs is not needed. So in this case units on the ground floor are not entitled legal right to use a staircase. Furthermore, each owner on the same floor level may not use the whole corridor to access their unit. For example, the unit close to the staircase uses the first section of the corridor while the unit far from the staircase uses the whole section of the corridor. In this sense, units have a different legal right to corridor based on their position. This concept is demonstrated in the figures below. In the figures the yellow box shows the horizontal circulation space the cyan box shows the vertical circulation space whereas the pink box shows the building unit. Figure 6 shows the legal boundary of unit number 1 on the ground floor. As it is shown in the figure the unit has the legal right to use the first section of the corridor only and has no legal right to use vertical circulation space. Correspond figure 7 shows the legal boundary of unit 1 on the first floor. This unit also uses the first section of the corridor on the first floor and vertical circulation space since it is on the upper floor.

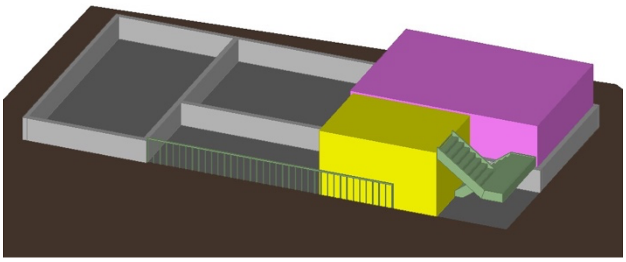

Figure 6. Ground Floor Unit 1 Legal Boundary.

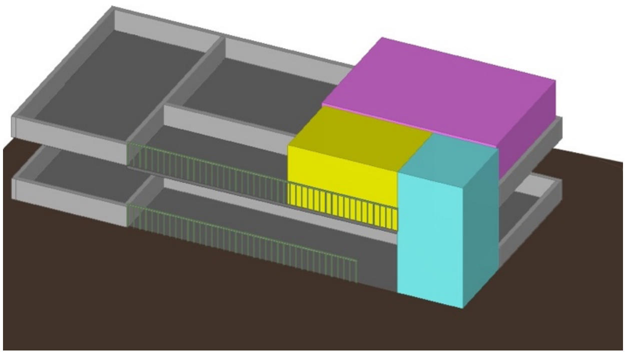

Figure 7. First Floor Unit 1 Legal Boundary.

Similarly, figure 8 shows the legal boundary of unit number 2 on the ground floor. This room has the legal right to use the first and second sections of the corridor and has no legal right to use vertical circulation space as it is on the ground floor. Figure 9 shows the legal boundary of the same unit on the first floor. This unit use the first 2 sections of the corridor on the first floor and vertical circulation space.

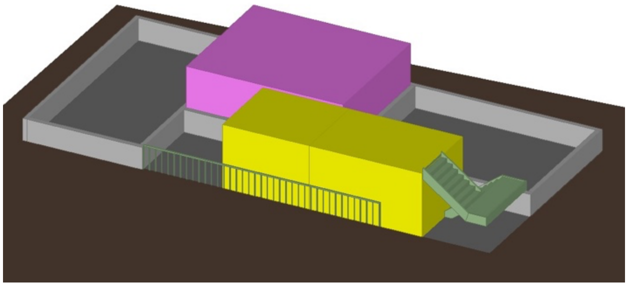

Figure 8. Ground Floor Unit 2 Legal Boundary.

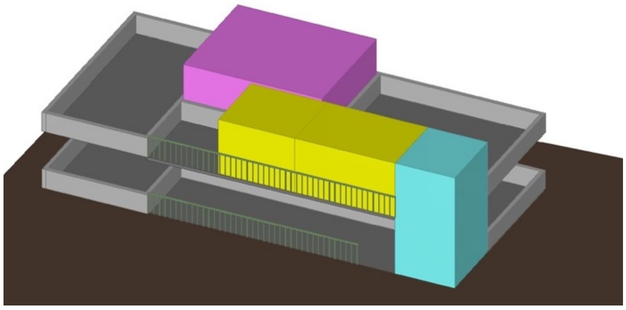

Figure 9. First Floor Unit 2 Legal Boundary.

Figure 10 shows the legal boundary of unit number 3 on the ground floor. This unit has the legal right to use the whole corridor and has no legal right to use vertical circulation space. Figure 11 shows the legal boundary of unit 3 on the first floor. This unit also has the legal right to all the vertical and horizontal circulation space.

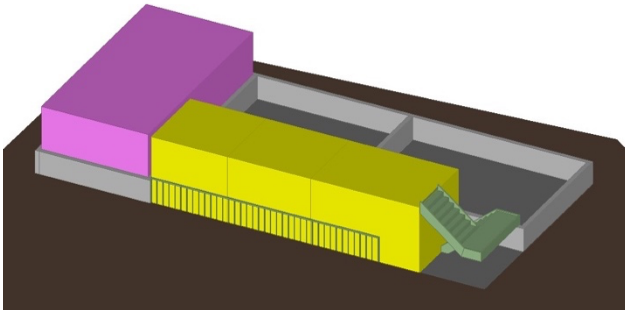

Figure 11. Ground Floor Unit 3 Legal Boundary.

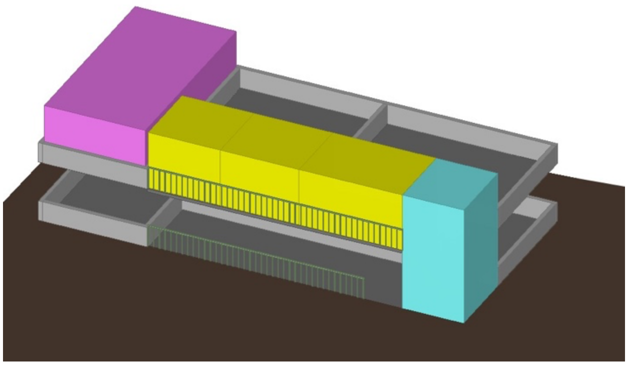

Figure 12. First Floor Unit 3 Legal Boundary.

From the above model parcel to building to units and circulation space can be formulated as such. One parcel can have many buildings, but a building belongs to a single parcel. The same logic applies for units. Building can have one or more units, but one unit belongs to one building. In this model floors are on the same level as units. Owner has unit on a floor as shown on the above models. However, it is also possible to have multiple units on different floors. A unit can have zero or many staircases and a staircase belong to at least one unit. In this model each units have corridor access. Therefore, unit to corridor relation is a unit has at least one corridor and corridor belongs to at least one unit. But this is not true in all cases. Depending on the design of the building those relations can be redefined.

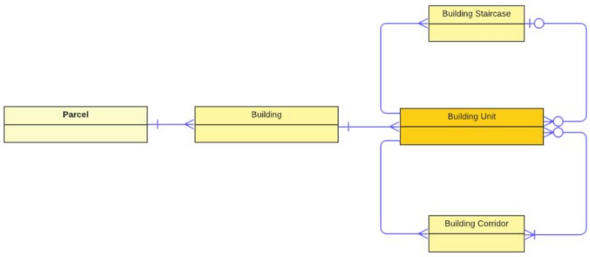

Figure 13. Relationship between parcel, building and units.

6. METHODOLOGY

The study has utilized the AutoCAD floor plan of the building datasets. This data has all the physical boundaries of each unit and the circulation space like staircase and corridors. Thus, it was the input used to develop the 3D model of the building and its units.

The conceptual model was developed by coding only. For that visual studio integrated development environment (IDE) was used along with the OGC CityGML 3.0 encoding standard. Revit Autodesk was used to develop the actual 3D model of a sample building. It is building information modeling (BIM) software for architectural elements. Revit is selected as modeling software for the following main reasons. First, it supports dwg files. Second, it has a detailed semantic definition of building parts that can help later the conversion of the building to CityGML. Units can be defined using "space" without the need for the physical space-defining element. Lastly, it can export 3D models into CityGML2.0 and International Foundation Class (IFC) files format, a file type used in the next step. Thus, Revit was used for modeling. FME Workbench was the second tool used in the process. The tool was used to develop a transformation model that reads the Revit 3D model (IFC file) and writes it into the CityGML file. Visual studio code was also used as an IDE to write, modify and debug codes in this process. FZK Viewer was used to display the converted CityGML file.

The First step was to import the DWG floor plan and model the building and its units. This task was done using Revit Autodesk. Revit building model has different elements. These elements includs doors, floors, railings, roof, space, stairs, topography, walls, and windows that were used to model a building. From the listed building elements, space was used to model the building unit, and topography was used to model the plot of land. So far, Revit can export 3D models to CityGML 2.0. But no BIM software exports 3D models to CityGML 3.0. Therefore, further transformation or manual coding must be done to develop the CityGML3.0 model.

Two methods were tried by the researcher to get the most accurate 3d model with less manual intervention and coding. The first method was to export the 3D model to CityGML 2.0 and then export the CityGML2.0 to CityGML3.0 using the FME workbench. The second method was to export the model to IFC format and then, using the FME workbench, export the IFC file to CityGML3.0. Both workbenches are initially developed by the Technical University of Munich Chair of Geoinformatics. Minor setting adjustments were needed in both workbenches.

The main difference of these two methods is that, the first method (CityGML2.0 > CityGML3.0) exports walls as wall floors and other constructive elements to their respective categories whereas the second method (IFC > CityGML3.0) exports all building constructive elements into one category which is building constructive elements. The second main difference is the second method grouped surfaces that defines the same unit into one building room element. On the other hand, the first method doesn't group surfaces; rather, it groups all the room defining surface of the building into one solid building (bldg:lodsolid) element. Therefore, manual grouping was carried out by the researcher.

Since FME doesn't support CityGML3.0 yet, it is not possible to write Building Rooms. As a result, manual codding is needed in both cases. For example, in method 2 spaces used to model the units are transformed into building rooms. Therefore the first <bldg:buildingRoom> to <bldg:buildingSubdivision> and <bldg:buildingRoom> to <bldg:buildingUnit>.

7. SUMMARY AND FUTURE WORK

7.1 Summary

This study clearly shows how CityGML 3.0 can be used in cadastre system to model legal rights of individual units in different scenarios. After minor adjustments, the objective of modelling legal rights was achieved in both methods. However as shown in figure 14 and 15 and discussed in the methodology section, the models have some visual and structural differences. Figure 14 shows the result of method 1. The first method categorizes building constructive parts accordingly. Figure 15 shows the result of method 2 and as shown on the result all building constructive parts are grouped into one class. One of the structural differences comes from this classification difference.

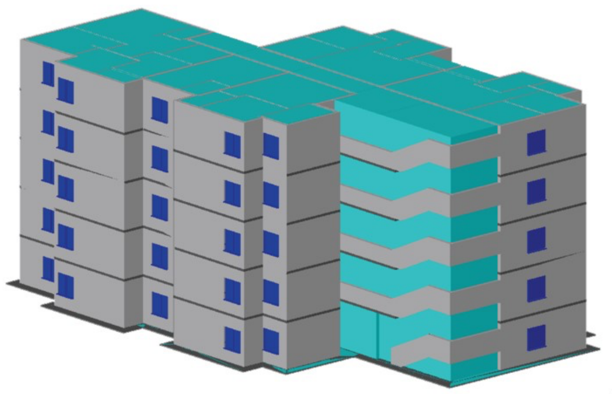

Figure 14. Result of method 1

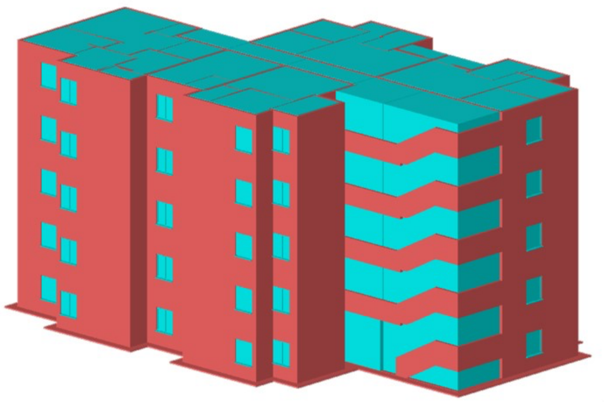

Figure 15. Result of method 2

Regarding legal right representation, both methods have the same output. Figure 16 and 17 show the legal rights of different units on the 4th floor. Figure 16 shows the legal right of unit 5 whereas figure 17 shows the legal right of unit 1.

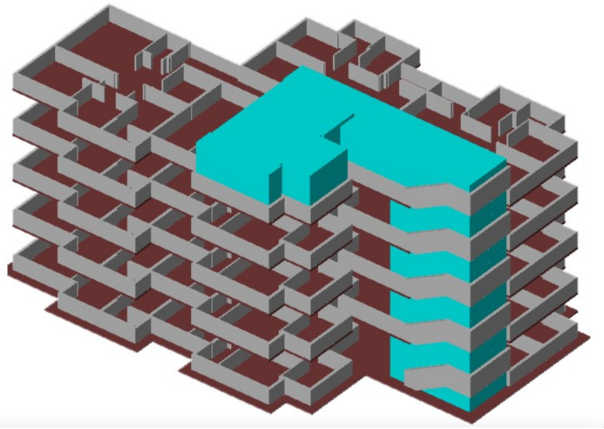

Figure 16. Legal right of Unit 5 4th floor (method 1)

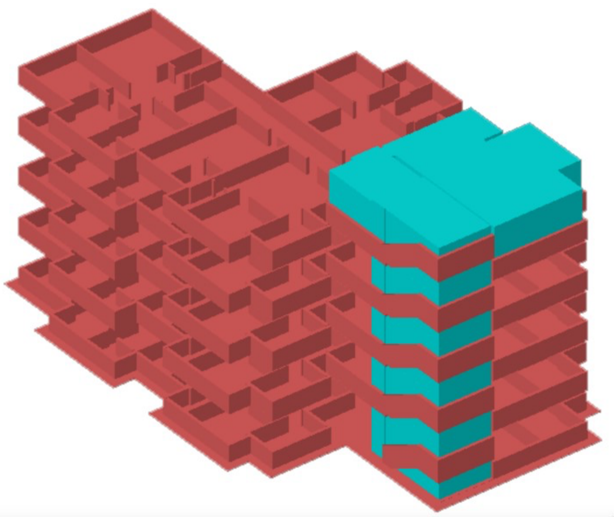

Figure 17. Legal right of Unit 1 4th floor (method 2)

Here again figures 18 and 19 show the legal rights of different units on the 3rd floor. Figure 18 shows the legal right of unit 4 whereas figure 19 shows the legal right of unit 2. To enhance the visibility of the legal model, transparencies of physical boundaries are adjusted.

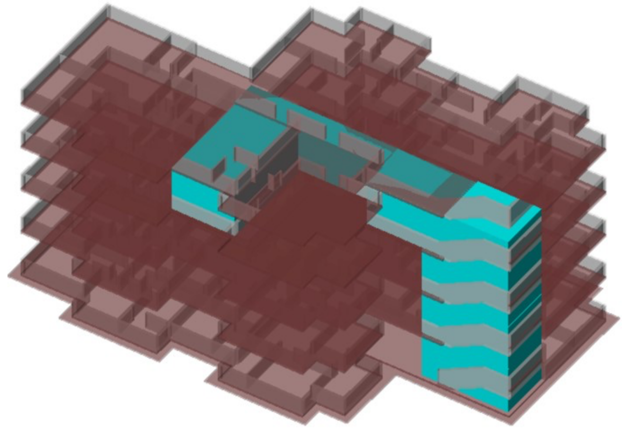

Figure 18. Legal right of Unit 4 3rd floor (method 1)

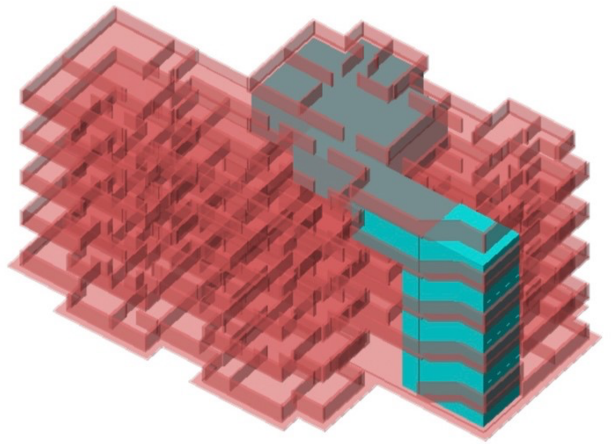

Figure 19. Legal right of Unit 1 3rd floor (method 2)

7.2 Future work

This study used a simple building model to demonstrate the idea of legal rights. Interested researchers could develop models for complex legal rights with complex properties and see how legal rights can be modelled. Because of the lack of software supporting CityGML 3.0, hosting the model on a web client was not accomplished. For future work, software developing companies can implement the new version of CityGML to conduct further uses cases and implementations. Modeling each building is time taking and prone to error.

Therefore, to implement it on a large scale, an automated model development is the best way forward. Using available software, researchers can work on the automation process so that models can be generated easily. Otherwise, the actual implementation of this model would be much more time taking or not feasible. City administrations utilize different sectors' data to facilitate land and property management systems. For Addis Ababa city land management office, the following external ADEs can be used. Further use of data can be studied based on the city land administration preference and can be integrated to the system.

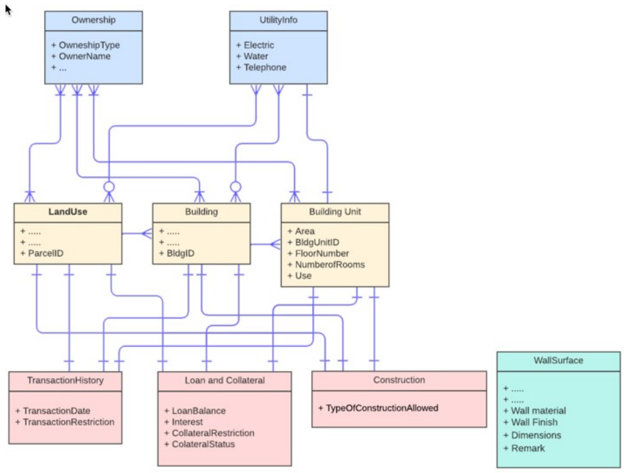

Figure 20. Extended ADE for cadastre system of Addis Ababa.

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