AUTOMATIC MODELLING OF PROPERTY OWNERSHIP IN BIM

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ABSTRACT:

A 2D land administration system is insufficient for managing private properties and common property areas in a multi-story structure. Building information modelling (BIM) can be used to provide a clearer representation and more efficient management of the rights, restrictions, and responsibilities (RRR) inside buildings and address the challenges of 2D representations. However, a land surveyor should still draw the legal boundaries and group ownership spaces manually inside 3D BIM authoring tools. This research aims to provide an automatic approach to define three different types of legal boundaries and group the common properties and private properties within a building. This work contributes to the use and development of BIM by providing an automatic technique to creating property ownership, allowing for easier search and retrieval of 3D property information. More significantly, it can potentially minimize the time and cost of creating BIM-based 3D cadastral data for complex multi-story structures and improve the efficiency in urban land administration.

1. INTRODUCTION

1.1 Background

In land administration systems, 2D plans are created for subdividing clear and unambiguous ownership spaces in buildings (Williamson et al., 2010). However, 2D-based land registration is insufficient for the management and identification of private property ownership and communal property areas in a multi-story building. To address the consequences of these 2D representations, land administration systems can adopt the building information models (BIM) to identify the rights, restrictions, and responsibilities (RRR) within buildings.

BIM can visualize the complex architectural and structural building elements in 3D space (Kalogianni et al., 2020; Rajabifard et al., 2019). It can also improve the sharing of both physical and functional building information and overcome the communication challenges in representing various legal boundaries (Atazadeh et al., 2017). Another point is that BIM currently improves productivity and reduces the cost and effort for changes significantly during the lifecycle of a building (Arayici et al., 2011). It has also been found that BIM can store all types of spatial data in buildings: geometry, topology, spatial relationship, quantity and specifications of details and properties, which also contributes to the integrated project management (Rezahoseini et al., 2019).

1.2 Research problem

BIM can provide the most detailed 3D information not only spatial but also semantic aspects. This 3D environment can assist in the definition of legal spaces (Sun and Paulsson, 2020). However, in practices, the legal boundaries are still defined by cadastral surveyors in 2D plans by referencing building elements. For different building types, the definition of boundaries may be varied on account of different standards, in particular for mix-used buildings. For example, the boundary lines of a wall are defined by three physical relationship structures: interior, exterior or the middle face of it. This may be confusing for someone who lacks land surveying and cadastral knowledge (Barzegar et al., 2020). At present, drawing these boundaries should be done manually by surveyors. This is time-consuming for complex or high-rise buildings having a considerable number of physical structures, and also some personal variances might be caused due to a huge volume of operations, which may potentially harm the interest of property owners. Although BIM is able to store information about property ownership, a land surveyor should draw the legal boundaries and provide cadastral attributes manually within 3D BIM authoring tools. Therefore, land surveyors cannot add legal information to buildings automatically in BIM. In addition, they cannot define different boundary types for spaces in BIM automatically. Grouping the common property spaces and private property spaces within building information models is also challenging.

1.3 Aim and scope

In order to overcome the research problem mentioned above, this research aims to provide an automatic functionality to:

1. Incorporate the property ownership data into BIM.
2. Define three different type of boundaries using different faces of walls.
3. Group and zone the common properties and private properties within a building.

The new functions contribute to the usage and creation of BIM and provide a new approach in defining property ownership, which would facilitate querying and retrieving 3D property information. More importantly, it reduces the time and cost in creating BIM-based 3D cadastral plans for complex multi-story buildings and improve the effectiveness in urban land administration.

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2. LITERATURE REVIEW

BIM is a tool used by architects, engineers and construction (AEC) firms to generate and manage 3D digital data in the building lifecycle (Isikdag, 2015). This information includes construction and non-construction data for buildings. BIM is increasingly popular in AEC industries because of its powerful functions. With the development of urbanization and the appearance of more complex high-rise buildings, the land administration system with 3D cadastral data is adopted worldwide. However, as the technology is still at the developing stage, there are some issues in each country when upgrading to 3D digital environments driven from BIM. There is significant research in different countries including Australia (Rajabifard et al., 2019), Iran (Einali et al., 2022), New Zealand (Gulliver et al., 2017), Malaysia (Rashidan et al., 2021), the Netherlands (Stoter et al., 2017), Sweden (El-Mekawy et al., 2014; Sun et al., 2019) and UK (Wong and Ellul, 2018) regarding the use of BIM and 3D digital data for land administration. Here, we will provide a review of some jurisdictional experiences.

In the United Kingdom, the significance of 3D geoinformation is realized in cadastre management. The barrier for this jurisdiction is the lack of relevant 3D national datasets from government agencies as well as user requirements. After investigating the user requirements, it is found that users are more interested in non-building features rather than geometries in BIM (Wong and Ellul, 2018). Another finding was that it is better to use multi-product approach to present 3D data rather than current one single 3D map. Another example is the New Zealand jurisdiction which has its own cadastral survey system for 3D cadastre. Currently, cadastral information in this jurisdiction is represented in 2D plans with extra static 3D situations. Current mission is to update previous 2D cadastral data into 3D models as the BIM can store all legal RRR data. The main approach is that applying the generic nature of spatial objects into other jurisdictions and utilize the 2D digital cadastre as the default layer to transit it into 3D digital data (Gulliver, 2015). Upgrading 2D land administration system to 3D environments is not only under process in developed countries but also some developing countries. In Malaysia, a technique for translating BIM data to CityGML was presented for 3D cadastre purposes. The IFC model's comprehensive physical information was used to enable 3D representation of legal boundaries, cadastral features, and 3D strata units (Rashidan et al., 2021). Despite significant research on the intersection of BIM and 3D land administration domains, researchers have not dealt with the automatic modelling of property ownership, in particular legal boundaries, in the BIM environment. The next section provides our proposed methodology for addressing this gap.

3. METHODOLOGY

The proposed methodology comprises four steps: Identify boundary types, identify legal information, create boundaries, and group ownership spaces.

3.1 Identify boundary types

Legal boundaries are the most important legal information in building subdivisions, which are defined by different locations utilizing the physical building structures. As stated in Building Subdivision Guidelines by Land Use Victoria (State Government of Victoria, 2015), the boundaries should be defined along the "Interior face", "Exterior face" or "Median" of the relevant physical building structures. More importantly, they should be defined unambiguously in subdivision plans so that owners, licensed surveyors, council officers and owner corporation managers can understand the location of boundaries in relation to the walls, floors, ceilings and any other structures in buildings. The interior boundary is defined as the interior face of the wall, floor (upper surface of an elevated floor), ceiling (underside surface of the ceiling), window, door or balustrade of the relevant part of the building if there is no other specific definition in the subdivision plan. When the boundary is specified by the interior face, the associated walls, floors, ceilings and relevant fixtures attached to or within them are deemed to be part of common property (Figure 1).

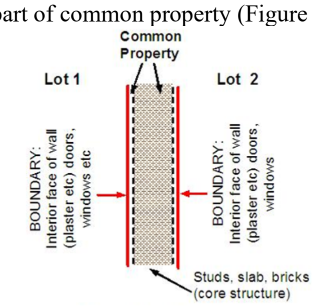

Figure 1. Interior boundaries defined by referencing a wall

The median legal boundaries refer to the middle surface of the walls, floors, ceilings and the relevant part of the building. When the legal boundary is defined as a median one, then the ownership of the building structure should be split among the adjacent legal interests (Figure 2).

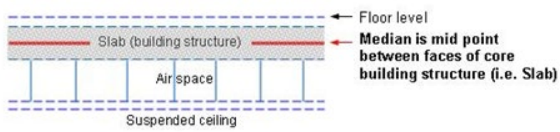

Figure 2. The median boundary in a ceiling

The exterior faces would be adopted when the ownership of the building should also include the roof, eaves and guttering, using the exterior face of walls, foundations, overhanging roofs, eaves or guttering and the relevant structures attached as the boundaries. The exterior legal boundaries refer to the exterior faces of the building. One example is shown in Figure 3.

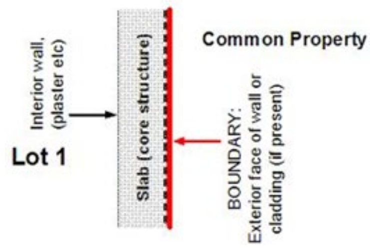

Figure 3. The legal boundary defined by exterior face of the wall

3.2 Identify legal information

The legal boundary defines the legal area spatially while the legal interests define the legal information semantically. The attributes of legal interests are brought in Table 1, which can help users to understand the ownership and legal information in the subdivisions. This legal information can also specify whether the legal interest is a private property and contains multiple parts or it is a common property that should be managed by owners corporation.

Attribute	Data Type
Number	Integer Number
Name	Text
Unit	Enumeration
State	Enumeration
Class	Enumeration
Area	Double Number
Land Use	Enumeration

Table 1. Attributes of legal interests

3.3 Create boundaries

Since there are three different boundary types, the automatic drawing of boundaries should have two functions: creating boundaries automatically as well as enabling users to change the boundary type automatically. To create boundaries, the selected boundary type should be first detected. When changing the boundary type, it should be checked whether there is a boundary already existing within the physical structure. If so, the new type of boundary should be created after deleting the previous one; Otherwise, a new boundary should be created directly. The previously drawn boundary is not associated with the physical structure (e.g., wall) and it is difficult to determine the boundary type. Therefore, the previously drawn boundaries are deleted first and then using the developed functions, new legal boundaries are created and semantically associated with their corresponding physical structure. The general workflow of this step is shown in Figure 4.

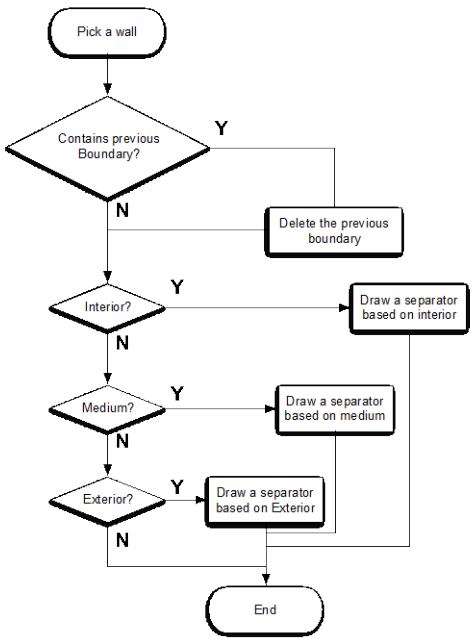

Figure 4. Workflow of creating boundaries

3.4 Group Ownership Spaces

Lots and common properties comprise various ownership spaces in buildings. More specifically, common property includes communal legal spaces (such as stairs and corridors) and the connected physical structures (such as walls and ceilings), which is defined to specify the ownerships and responsibilities among owners and owners corporations. The common property has two types, namely unlimited and limited. The unlimited type is the common property that is for use and benefit for all owners in strata title and company titles while the limited type means the common property should belong to a specific group, not all the owners within the building have the privilege of it. At present, the common properties in 2D subdivision plans are presented using additional notations, which is an ambiguous definition of common property. Moreover, walls are illustrated as notations in plan, in which the 2D plan is not capable of specifying the full extent of common property adequately. In BIM environment, this can be solved easily as it demonstrates the building in 3D with all physical information. In addition, the concept of zones provide the capability to group ownership spaces associated with the same RRR in BIM environment.

4. IMPLEMENTATION

This research used Revit which is a well-known BIM software from Autodesk. Revit provides APIs for developers to access their public functions and objects. Moreover, it helps developers to create macros to automate repetitive tasks. Thus, this project created several add-ins for Revit using its APIs to achieve the project goals. The details about the implementation of them will be described in this section as well as the challenges faced in the implementation process.

4.1 Add shared parameters

Revit gives users authority to add custom parameters into family types via "shared parameters" in project parameter setting by their own. The shared parameter is one kind of common family parameter used for specifying additional parameters in Parameter Properties dialogue in Revit, which can be shared among diverse projects and accessed by users. It is allowed to set the shared parameter as a type of parameter to specify the family type or an instance parameter. Users can also define the type of parameter; the discipline it belongs to and the group this parameter should be under. Meanwhile, this parameter can be adopted by one category or multiple families. Therefore, legal interest information can be easily added to BIM for family type "wall" and "space" with shared parameters.

In order to add legal information as shared parameter for all drawn walls or spaces, the project's active document data should be first accessed. Then the new shared parameter should be defined and added into the document file so that it can be applied to all projects and displayed in schedules and tags. The shared parameters for legal information are described in Table 2. When these new parameters are added into the active document of the application, the family types have been added correspondingly so that all walls and spaces would adopt these parameters and so do newly created objects. When having these parameters set in family types, cadastral surveyors can define the ownership of the spaces clearly. Owners, council agencies or owner corporation managers can query this legal information to retrieve the legal interests as well.

4.2 Create boundaries

Revit provides a function in its API called "NewRoomBoundaryLines()", which allows users to define the space boundary locations by drawing room separators. After a wall is picked by the user, this method will draw the room separators automatically according to its boundary type as well

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as the location of wall and its interior or exterior faces. It also provides the default creation in boundaries using the interior face of all physical structures. Users can directly implement the default setting, using the interior face of a wall as the space boundary, by ticking the wall's box attribute "Room Bounding". Therefore, to enable the creation of boundaries automatically, only the median and exterior boundary creation are developed in this research.

Category	Shared Parameter	Data type	Visibility
Wall	Centre Boundary	Boolean	Yes
	Exterior Boundary	Boolean	Yes
	Wall Separator	Integer	No
Space	Name	Text	Yes
	Unit	Integer	Yes
	State	Text	Yes
	Class	Text	Yes
	Area	Area	Yes
	Land Use	Text	Yes

Table 2. Shared parameters

Once having the boundary type parameters in walls, the type of boundary can be created using room separator at the relevant location of the wall by checking which boundary type has been selected by the user. The implementation of these functions requires obtaining and checking the boundary type parameters first. It can be completed by "LookupParameter()" function in wall type to get and check the shared parameter's content. The "get_Parameter" function in wall type is capable of checking whether wall attribute "Room Bounding" ("WALL_ATTR_ROOM_BOUNDING" in BuiltInParameter) is selected so that the boundary should be set as interior face of the selected wall. One exception handling in this function is that only one type of boundary should be selected for a wall object. When realizing what kind of boundary should be drawn for the selected wall, the function of creating boundary can be implemented. The result of adding boundary type attributes into wall's property is shown in Figure 5. They are grouped under the "Constraints" group and are visible to users so that users can define the boundary type by clicking corresponding attribute boxes.

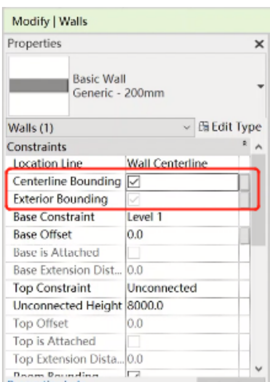

Figure 5. The added wall attributes

According to Revit API document, the wall class has a location attribute, which can return its physical location (the location of the wall's centerline). Therefore, the space boundary can be set based on this returned centerline location. However, the function "NewRoomBoundaryLines()" for drawing room separator requires a point array as the input parameter. This means the boundary should be created according to a point location list. In consequence, the XYZ coordinate in the edge of centerline is required to be extracted from location. First, the wall location data should be transferred to "LocationCurve" type and get the first and last point in the curve, which represents the endpoints at the location line. Then store these coordinates in a newly created "CurveArray". This array can be passed as the input parameter in "NewRoomBoundaryLines()" to create a room separator as the median boundary of a space in the active view. The process of implement this boundary creating function is illustrated in Figure 6.

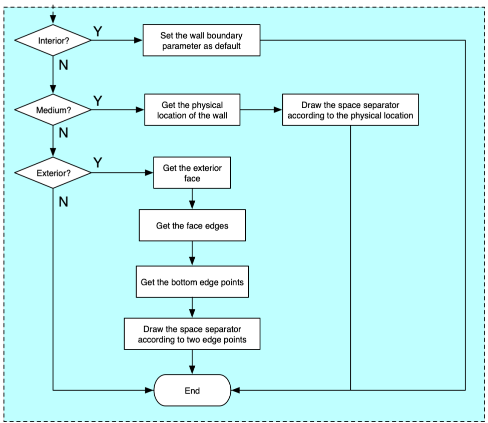

Figure 6. Creating a different type of boundary

The result of creating the median boundary automatically in Revit using this add-in is in Figure 7. The blue area is the "space" representing a private room with the boundary of this space is defined using the centreline of the connected wall.

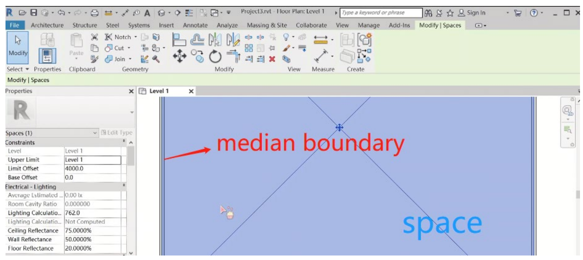

Figure 7. Median boundary in space

The location of the median boundary can be defined easily by retrieving the wall's physical centerline, but Revit does not provide any function to retrieve the coordinates of its exterior boundary directly. Therefore, it is quite challenging to delineate the exterior boundary. There are three possible solutions for solving this problem.

1. In Revit, the default physical location is based on the centerline of a wall. The physical location can set as the exterior location or the interior location in wall property. Therefore, the exterior location of a wall is possible to be obtained by changing the setting of physical location.
2. The location of the centerline and the width of a wall can be accessed from the document data. As a result of this, it is possible to calculate the location of an exterior boundary in a wall.
3. Revit provides a function to retrieve the exterior face of a wall. A face usually has 4 edge points, which are top left, top right, bottom left and bottom right. Two bottom edge points are the location of the exterior boundary. They can be used for drawing the exterior boundary.

The first solution is changing the wall location setting and acquiring the exterior line location as it is in creating the median boundary. However, when applying this algorithm, the physical location of the wall always remains as the centerline location in Revit, even if it has been set as the exterior location in wall physical location. Therefore, this solution probably is not helpful of setting the exterior as the space boundary.

The second solution is using a mathematical function to compute the location of the exterior boundary, utilizing two endpoint coordinates in wall centerline and its width. The extraction of edge points in wall obtains only two pairs of coordinates without the orientation of the wall. This means the exterior boundary location cannot be defined because of the lack of the orientation. Thus, the system does not understand which direction the width should been added to the original coordination. Moreover, even though the orientation can be retrieved via the built-in parameter in the wall, the computing of the boundary position is complex since walls might face the true North. Hence, the edge point coordinate cannot be computed by simply add the width to original wall centerline location. Therefore, it is hard to distinguish the edge points coordinates in the exterior boundary.

The third solution is retrieving the exterior face directly from the wall. Revit has a function called “GetSideFaces()” in host objects. Using the “exterior” attribute in “ShellLayerType” can retrieve the exterior side face of walls. It returns a List of “Reference” data, which can be extracted as “Face” by “GetGeometryObjectFromReference()” function.
In order to extract the bottom two edge points in wall face, it only has to get the first endpoint in the first edge curve and also the first endpoint in the last edge curve. Then creating the exterior boundary after utilizing function “NewRoomBoundaryLines()” to build a curve array storing these two coordinates.

The above-mentioned functions of creating boundary types can be applied to all active walls in the view to achieving the automatic creation of legal boundaries. Nevertheless, sometimes the boundary type might be changed due to modification in building planning or designing. In this case, it is better to allow users to change the boundary type by changing the attribute settings in its properties.

Before setting a new room separator, the previous room separator must be removed. In addition, a wall can only have no more than one room separator in each physical structure. Otherwise, the previous room separator may invalid the new separator. For example, the first room separator is a centerline, but the new boundary should be the exterior. Because the medium boundary is on the inner side, space will be bounded to the inner one no matter how many exterior boundaries are settled if the median boundary has not been deleted. As a consequence, the previous room separator should be deleted first. The flow chart of this process is shown in Figure 8.

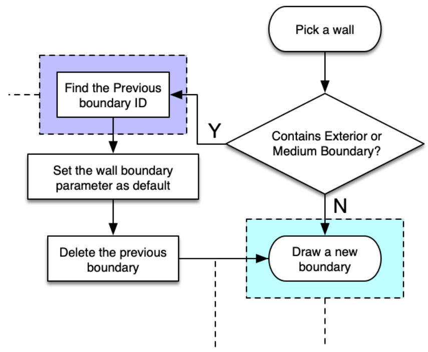

Figure 8. Changing boundary type

The challenge in this function is that the room separator is not associated with the physical structures. Once the wall is selected, the software has no idea of which room separator is inside this structure and which boundary should be deleted. One possible solution is to compare the locations of all room separators with the location of the selected wall, and delete them if it matches (Figure 9).

Although this operation can realize the function, there are some issues with this operation. This process has to traverse all room separators, the efficiency of which might be low in a complex building with a large number of walls. As a result of this, the indexes of room separators have been adopted as an invisible attribute in wall. The entire process of automatic creation of legal boundaries in BIM is shown in Figure 10.

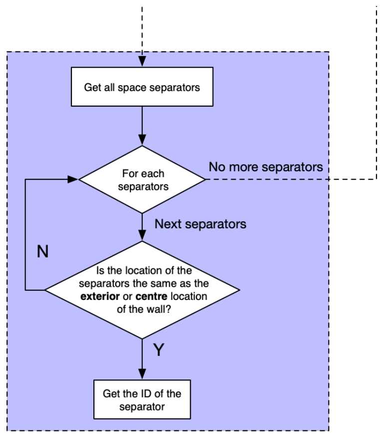

Figure 9. Deleting previous room separator

4.3 Group common walls

After creating different types of boundaries, the ownership of the legal interests is defined in BIM. Nevertheless, it is still difficult for owners who have no engineer background to understand the legal information clearly. In order to solve this problem, the best approach is zoning the properties together so that owners can query the spaces easily by lot number or owner name. In addition, the common property includes physical structures. For instance, walls that adopts the interior faces as the space boundary. Thus, common walls should be added to common property zones as well. However, Revit does not support zoning physical structures or fixtures. Instead, it provides another option for surveyors to clarify whether the wall is common property or not. The “group” function allows users to group elements such as walls, corridor walls, doors, plumbing fixtures and other non-hosted items together. With common walls been grouped together, they can be queried in

BIM managing software like BIM server, or optionally group other common properties into the same group afterwards.

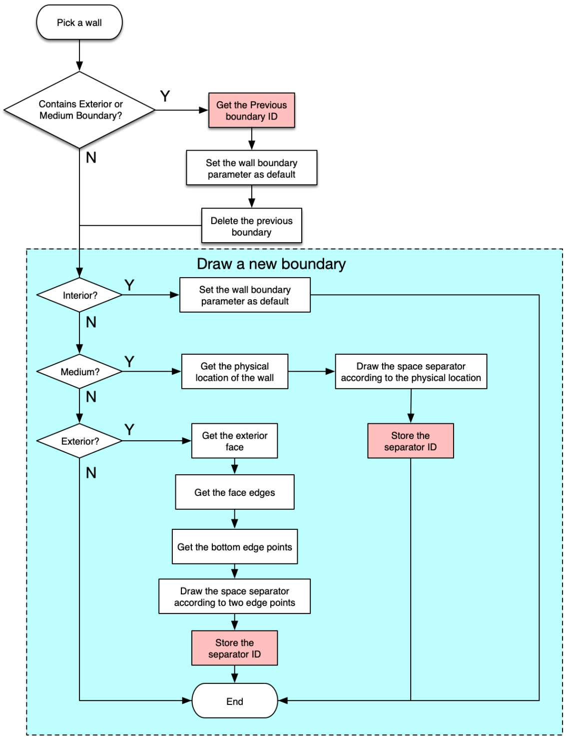

Figure 10. Creating the boundary flowchart version 1.1

Figure 11 shows the process of grouping common walls. Firstly, an empty list is created in order to store all wall IDs that are required to be grouped. Then all the walls are considered in BIM model and their attributes are checked to verify whether the boundary is set as the interior face of the wall (the "WALL_ATTR_ROOM_BOUNDING" is set as "1" in built-in parameter). If so, it is considered as a common wall and its ID should be added into the wall ID list. After traversing all walls in the BIM model, creating a new group with the ids in that list and give the group a name, "CommonWalls".

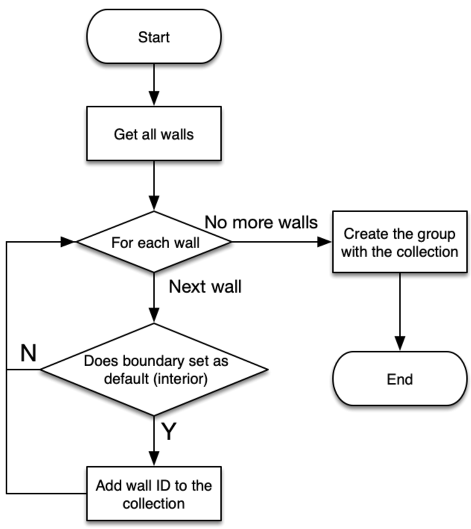

Figure 11. Flowchart of grouping common walls

Figure 12 shows the result of this function after grouping all common walls together. Only if all the boundary types have been set, this function can help users to group all common walls automatically.

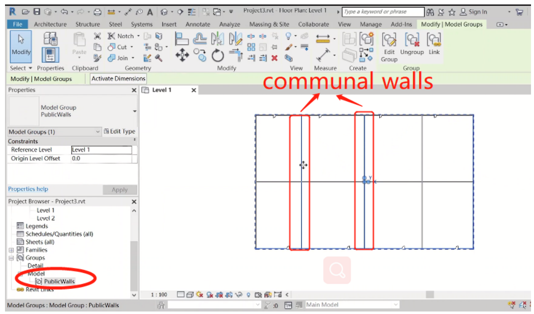

Figure 12. Result of grouped communal walls

4.4 Zone common properties

Revit has a tool called "Zone". Users can use this tool to define spaces that under the same environmental control systems, for instance, the heating, cooling and humidity control systems. It allows users to add spaces on any level into the same zone manually. It enables users to perform analysis procedures on a building model. Once space has been created, it will be added into a default zone in Revit. This space will be removed from the default zone automatically after users moving the space into another zone. The default setting can help users understand relationship between space and zone. Moreover, it assists users to check whether all spaces belong to a custom zone. However, the phase of the zone should be the same as it is in newly added space.

Moreover, after exporting the BIM into IFC format, zones can be queried in the BIM managing software, which provides a more visualized view of the ownership data within a 3D model. Revit provides an additional tool for zones, the "zone schedules", which can be used to modify zones. This tool makes the zone more flexible in BIM during the design stage. Since the new space attributes has been added to space properties, surveyors can zone the spaces that belong to the same owner together to integrate the ownership in a building.

Figure 13 shows how to implement this function in Revit. The first step is to access Revit's active document and filter it to all the spaces in the view. Next, creating an empty list in order to store the space number. Since the phase of the zone should be equal to the added spaces, it is of significance to acquire the phase at the beginning. Then it should be checked whether the legal interest number in each space is in the space number list as well. If not, this number should be added to the list and all the spaces should be traversed again to chase down all spaces with the same legal interest number as a newly added number. The equality in the legal interest number indicates that they share the same ownership and should be zoned together. Because they are of the same ownership, they should be inserted into a "SpaceSet" afterwards. The "SpaceSet" is a collector of spaces and it is the input parameter for "Zone" function. When "SpaceSet" contains all spaces with the same legal interest number, passing it as the parameter to create a new zone. On the other hand, if the interest number is already stored in the list, there is no other operation in demand for this space. This loop will end after checking the attributes for all the spaces in the active document.

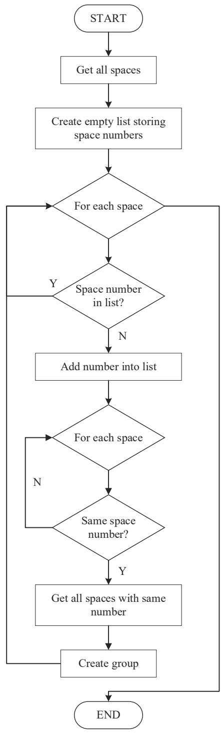

Figure 13. Flowchart of zoning common properties

This process seems simple and straightforward, but the complexity is n2, which signifies in reality its performance is limited especially if it is applied to complex buildings with a large number of spaces. A new tool from Revit API has been adopted in order to enhance its performance -- the "ElementParameterFilter". The first step is to use the element ID of the built-in parameter "ROOM_NUMBER" as the input parameter for a "ParameterValueProvider". This step aims to create a provider for the system to understand which parameter value should be filtered. Then set the "FilterStringRule" for the filter. The string rule tells the rule for the filtered parameter and how to filter the input data. In this function, the string rule specifies whether the interest number in spaces is the equal to the current one. After setting all filter rules, it will create an "ElementParameterFilter". The last step is to use two "FilteredElementCollector" with two different filter rules to filter the target spaces. The first rule is the customized string rule, the other is the rule for acquiring all spatial data. The result of integrating these two filter collectors together is all spaces equipped the same legal interest number as the current one. The new version improves the efficiency of this function as well as its performance under big data by utilizing two filters to obtain all spaces that should belong to the same zone.

Figure 14 demonstrated how spaces are zoned based on their space number. As for spaces with the same interest number, they are added to the same property named by the space number. The integer number indicates the space is a private property and may contain multiple units for its owner. The zone named "CP" or "Common Property" is the common properties in the building.

5. DISCUSSION

This project has implemented four functions in Revit, which is a commonly used BIM authoring tool, to achieve the automatic modelling of legal boundaries. It assists cadastral surveyors to add the legal information and legal boundaries in BIM. This automation will bring the following advantages:

1. Improving the efficiency in delineating legal boundaries in multi-storey buildings.
2. Since the creation and modification process are partly automated by software, once cadastral surveyors set the space and wall attributes, it can avoid user errors, which would facilitate the validation of BIM-based 3D digital subdivision
3. Because BIM contains more relevant information in buildings, it would be promoted in land administration system by automating the boundary creation process.
4. The attributes about legal interest information and three different types of legal boundary could assist surveyors to specify the ownership within buildings. The created ownership zones can be visualized more obviously in 3D models with these attributes. It is more intuitional for property owners, owner corporation managers or council agencies without engineering backgrounds to understand BIM-based 3D digital subdivisions. Furthermore, property ownership can be queried in BIM tools easily for further building management or analysis.

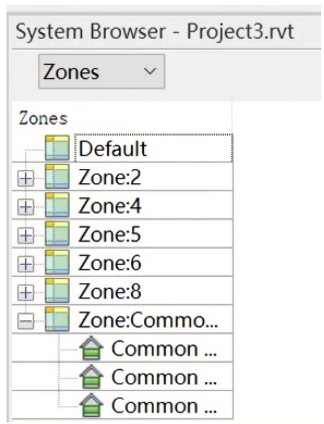

Figure 14. Zones & Spaces

Besides the benefits listed above, there still are some shortages in this project. As it is mentioned in section 3.2, the boundary type should include the relevant physical building structures and fixtures. However, in this project, the boundary only takes walls into consideration without ceilings and floors. In reality, in the car park area and storages in a building, the legal interests might exclude ceilings with pipes and electrical wires on it, while for the living area, the boundary may be specified as the centerline in ceilings and floors. In this situation, the boundary creation function has its limitation. It can be solved by defining the height of the private spaces to define the boundary is using the exterior face or median of ceilings and floors.

There are some limitations in defining common property areas. In this project, the common properties consist of spaces owned by all owners or a particular group of people in this building. It also adds the communal walls that using the interior face as the boundary to the common properties. However, the equipment within walls and columns in the building are excluded. Sometimes, even the boundary is defined as the centerline of the wall between two connected apartments for example, but the wires, pipes and other fixtures within might be shared among all owners in the building. Since owners use the services, they might share the ownership as well. That means, not only the ownership of the wall but also the facilities within the wall should be split into two equal parts. Thus, the definition of boundaries should specify whether the fixture in walls is common property or not. Moreover, there are some other physical structures, such as columns, should be considered when defining the spatial structure of common properties.

6. CONCLUSION

In this article, it was elucidated that 3D BIM can provide a more visual way in creating a building subdivision, but it encounters some challenges in how to subdivide buildings efficiently. There are some repeatable fussy steps required to be done manually in BIM modelling. To increase the effectiveness, four functions were created to achieve the automatic accretion of semantic legal information and legal boundaries in a BIM authoring tool. This project tested the performance of the developed function under various algorithms. The boundary definition has not considered the suspending ceilings as well as the floors.

Some further development in BIM-based 3D cadastral plan management should be done in the future. Although the wall boundary can be created automatically in Revit, it still acquires manual creation in spaces. When creating a space, the user should define its type in associated wall attributes and implement the function to create the boundary. After that, using tools in Revit to create spaces serially by clicking the area where the space should be placed. Even it is much simpler than defining and creating a different boundary, but it still cost much time in complex buildings. Therefore, another tool can be developed to achieve the automatic creation of ownership spaces after defining all the legal boundary types. The proposed approach may also not support the creation of boundaries associated with roofs and curtain walls and it can be extended for these scenarios in future studies. In this study, we have not examined the time savings quantitatively using the proposed approach. This also depends on the complexity of a building and number of various ownership spaces to be subdivided within a building. Our proposed approach can facilitate the boundary creation process; however, a detailed examination of the time saving requires conducting several case studies

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