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Usman Mehmood[1], Syahiirah Salleh[2], Uznir Ujang[3],
Suhaibah Azri[4], Tan Liat Choon[5]

3D Spatial Analysis of Temporal Maintenance for Multi-use High-rise Buildings: Case Study

Abstract: Urbanization has sparked an increase in the construction of multi-use high-rise buildings which consists of commercial parcels on their lower floors and residential parcels on their higher floors. In contrast to conventional landed houses, the residents of high-rise buildings share common facilities and private parcels or spaces also differ according to ownership or use. The management and maintenance of these spaces are dependent on the ownership of the parcel where each ownership adheres to different rights, restrictions, and responsibilities (RRRs). Therefore, accurate representation and identification of those parcels affected by maintenance or renovation is crucial for assisting management bodies to improve the quality of life within a multi-use high-rise building. This study attempts to implement a temporal maintenance management for high-rise building parcels within a 3D spatial database. A 3D space segmentation was done to analyze the ownership and use of space in a high-rise building. Spatial queries were also performed based on the temporal maintenance of the parcels; in addition, 3D spatial relationships were used to determine adjacent parcels that were affected by the maintenance. Thus, the implementation of temporal strata database management with an accurate 3D representation of the space can provide management bodies with concise and comprehensive information on parcels with respect to ownerships and uses.

Keywords: high-rise strata, spatial relationship, segmentation, preventive management, strata management, common property

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[1] Universiti Teknologi Malaysia, Faculty of Built Environment and Surveying, Johor, Malaysia, email: usmanmehmood1991@gmail.com (corresponding author), https://orcid.org/0000-0003-1670-569X

[2] Universiti Teknologi Malaysia, Faculty of Built Environment and Surveying, Johor, Malaysia, email: syahiirahsalleh78@gmail.com, http://orcid.org/0000-0002-4694-6622

[3] Universiti Teknologi Malaysia, Faculty of Built Environment and Surveying, Johor, Malaysia, email: mduznir@utm.my, http://orcid.org/0000-0001-5281-8478

[4] Universiti Teknologi Malaysia, Faculty of Built Environment and Surveying, Johor, Malaysia, email: suhaibah@utm.my, http://orcid.org/0000-0001-7926-9608

[5] Universiti Teknologi Malaysia, Faculty of Built Environment and Surveying, Johor, Malaysia, email: tlchoon@utm.my, http://orcid.org/0000-0002-1548-3098

1. Introduction

High-rise buildings are common in developed and developing countries as well as being an indicator of urbanization and economic development; they also modify the landscapes of cities [1]. A high-rise building is a multi-story structure in which most residents transit between floors via elevators. Most countries designate large notable buildings as high-rise, whereas others classify them as tower blocks [2]. Strata refers to buildings that have been subdivided into portions (which include parcels and accessory parcels), while all of the other elements of the buildings are considered common property (e.g., corridors, lifts, external walls, open spaces, and water tanks). These types of construction are becoming increasingly popular around the world [3]. The number of high-rise buildings is increasing – especially in densely populated metropolitan cities (where most of these buildings are used as residential properties) [4]. The increases in urbanization in densely populated areas have required the use of high-rise buildings to tackle land shortages. Cities in developing countries whose populations are increasing are often more than twice as dense as cities in Europe and five-times as dense as cities in the United States and Australia [5, 6]. The trend of more people coming to cities from rural areas is known as urbanization [7]. Similarly, Malaysia has rapidly urbanized in the last 90 years; Malaysia's urbanization rate was 34.2% in 1980; this increased to 62% in 2000 and reached 70.9% in 2010. Metropolitan areas were expected to house 75% of the country's population by 2020 [8]. In 2020, however, 75.1% of Malaysians resided in the urban areas of the country [9, 10]. In the twelfth Malaysia plan (for 2021 through 2025), the Department of Statistics Malaysia and Economic Planning Unit forecasted that the urban population will be 79.1% in the year 2025 [11].

The expansion of the population and the trend of urbanization immediately increase the demand for high-rise residential buildings [12]. The rise in strata developments in Malaysia has sprung from the desire of people to reside in costly metropolitan regions. This trend has since spread among the country's urban demographic [13]. In this situation when the world's population is increasing and land is becoming scarce and expensive, developers have no other choice but to build high-rise residential projects; these constitute a form of settlement that ensures locations to reside [14]. In major cities, the proliferation of multi-story apartments and elevated structures highlights the growing demand for above-ground living spaces. The trend of residing in high-rise buildings is expected to continue to increase in the future [15].

Maintenance is a set of actions that keep the structures and services in good operating order throughout their existence. Building maintenance is considered to be an important task within the context of the evolving discipline of facility management. These activities have an influence on the safety of thousands of strata-titled residents [16]. The parcel owner is responsible for all of the management and maintenance of his parcel. On the other hand, it is the shared responsibility of all of the owners to manage and maintain the common properties. In order to aid the developers or management in the suitable control and upkeep of the defined common properties, a medium is required; this has led to the establishment of management corporations (MCs). In Malaysia, a developer oversees all of the strata plans for a particular property for the first year. At the end of the first year, the first annual general meeting is held in which a joint management body (JMB) is established. A developer will then transfer the responsibility to the JMB within one month. When 25% of the aggregate units have been handed over to the owners and strata titles have been granted, an MC can be formed; the strata schemes will then be self-regulated by the MC [17]. Financial issues, title transfers, and maintenance and management issues must be resolved before the MC starts to perform its responsibilities [18]. The management life cycle for a high-rise strata is represented in Figure 1.

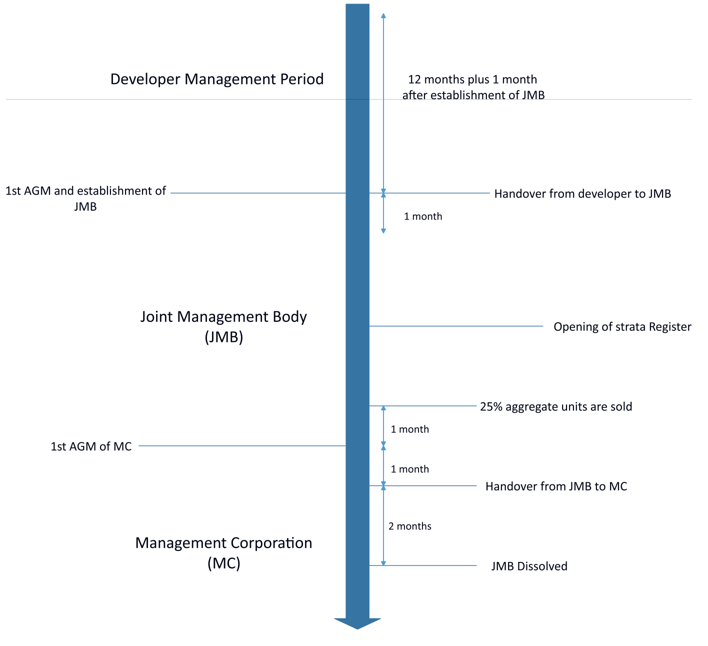


Fig. 1. Management life cycle of high-rise strata

High-rise buildings consist of privately owned and common spaces that can be represented as 3D parcels that are related within the buildings. The objects in a 3D space possess spatial attributes that describe locations, shapes, and metric measurements. The interactions, adjacency, and connectivity among the objects are also spatial attributes that are represented as spatial relationships. 3D spatial queries and analysis require 3D spatial relationships in order to obtain accurate results. The results of any spatial query using only 2D spatial relationships will inadvertently limit the dimensionality of the results to 2D. The 3D spatial relationships among 3D parcels can be described as extrinsic spatial relationships such as "overlaps," "touches," and "disjoints" [19]. The shared or common parts of 3D objects can be determined using 3D spatial queries that use 3D spatial-relationship information [20]. For example, a 3D query can be retrieved from the other 3D parcels that are related to the wall of a specific parcel that is undergoing repairs; thus, early warnings can be given to the owners of the affected 3D parcels (and to the neighbors of the affected parcels depending upon the nature of the maintenance work). Apart from this, 3D parcels can have different ownerships and uses (such as residential or commercial). Therefore, the rights, restrictions, and responsibilities (RRRs) of each subunit may differ according to ownership or use. Segmentation through the 3D mapping of multiple 3D parcels with different owners and the respective RRRs also uses 3D spatial relationships [21]. Consequently, a high-rise building can be modeled as individual 3D parcels that are segmented by ownership instead of a single 3D solid object. Therefore, the 3D representation of 3D parcels within a high-rise building can facilitate the efficient management and understanding of ownerships, locations, and 3D spatial relationships [22].

This paper attempts to implement temporal-management and 3D spatial relationships in a spatial database for a high-rise building. As a building complex can consist of different uses and ownerships, 3D space segmentation was carried out to visualize and calculate the volumetric composition of 3D space according to commercial, residential, and common property units. In addition, a case study of temporal data management was demonstrated for maintenance activities that facilitate proactive maintenance by MCs. This can be further supported by 3D spatial analysis using topological relationships that describe the adjacency and connectivity among the 3D objects. Therefore, proactive management for maintenance activities can benefit from 3D spatial analysis to determine any affected 3D units and assist MC in providing early and targeted warnings for the tenants. The paper is presented in the following sections: Section 2 provides a brief overview of related studies on the spatial distribution of ownership in high-rise buildings as well as maintenance issues and challenges. The methodology of developing a temporal management strata database, the segmentation of 3D space, and 3D spatial analysis is discussed in Section 3. The results and discussions are presented in Section 4. Finally, the conclusions of this study are presented in Section 5.

2. Related Studies

2.1. Spatial Distribution of Ownership

There is a complex spatial distribution of space based on ownership that is present in high-rise residential strata schemes. A master lot (ground parcel) can be divided into four types on the basis of ownership: a parcel, an accessory unit, a common property, and a limited common property. A parcel (apartment or condominium) is one of the constituent units of a strata building that is owned by a separate strata title [23]. The parcel owner is solely responsible for all management and maintenance of his/her parcel. An accessory unit is a space or unit that exists on a strata plan to be exclusively used by a parcel [24]; e.g., a designated parking space that is associated with a single parcel. This parcel and the accessory unit may not be spatially adjacent but have the same ownership; however, everything else (such as hallways, swimming pools, lifts, external walls, parking, open areas, mosques, and water tanks) is considered to be common property.

According to the Building and Common Property (Maintenance and Management) Act 2007 (BCPA), 'common property' is all development areas that are not included in an ownership parcel, which include structural elements of the building such as stairs, fire exits, entrances/exits, fittings, corridors, lobbies, lifts, refuse chutes/bins, drains, water tanks, sewers, pipes, wires, cables/conduits that serve more than one parcel, playing fields/recreational areas, roadways, car parking spots, open spaces, landscaped areas, walls/fences, and all other amenities and installations. Any part of the property that is used or capable of being used or enjoyed in common by all building occupants also falls under this category [3]. According to the Strata Management Act of 2013 (Act 757), any property that is not specifically named in the strata title is regarded as a part of the common assets. The areas or facilities in a strata building that only selected parcel owners can use is termed a limited common property [25]. Limited common properties are particularly required in integrated developments or mixed-use development lands [26]. As all parcel owners do not have access to these facilities, defining a limited common property helps in the equitable division of management funds [18].

Within a single floor of any high-rise residential building, ownership distributions like parcels, common properties, accessory units, and (in some cases) limited common properties can be observed. This ownership distribution can be mapped spatially by using existing 3D modeling techniques, which can further be analyzed in a better way.

2.2. 3D Space Segmentation

In terms of 3D modeling and graphical representation, buildings or 3D parcels are represented as 3D volumetric solids. This describes the geometric properties and shapes of the 3D objects. Although 3D objects may be similarly represented geometrically, meaningful information that describes the different object types may differ. This can be represented by semantic information that describes the key characteristics of an object that cannot be represented graphically or geometrically. 3D space segmentation is often supported by semantic information, whereby a space is subdivided based on the type of 3D space or other characteristics. For example, a 3D indoor space can be segmented into navigable and unnavigable spaces from which indoor navigation paths can be determined [27]. Apart from this, land-administration models also utilize semantic information to segment 3D building complexes according to use (such as private, residential, and public uses) [21].

2.3. Maintenance Issues

Due to the lack of a proactive maintenance strategy, poor planning, and the poor execution of maintenance work, high-rise residential buildings suffer. As a result, many complaints are filed about the poor conditions of residential properties and assets [28, 29]. Building maintenance must be carried out effectively and correctly, as these beautiful structures signify that nations are moving into a new era; thus, each government must preserve its best possible image. In order to save on maintenance costs and prevent the threat of rising maintenance costs due to neglect over time, the Malaysian government has also instructed all of its agencies to perform maintenance on all of their buildings at extremely early stages. Building maintenance is a relatively recent topic in Malaysia. Some conducted studies have focused on the types and components of the maintenance of buildings. Parallel to this, studies on maintenance spending, funding, and financial budgets for maintenance work are incredibly rare, and the budgets for building maintenance have received very little attention [30]. After the occupancy of apartments by owners, there are huge demands for maintenance. The developed world has recently faced overwhelming total expenses for the management of buildings [31, 32]. The Malaysian government has lost billions of ringgit (RM) annually due to rising building-maintenance costs [33, 34]. Similarly, complex divisions of facilities and different maintenance-responsible bodies in high-rise buildings also indicate that a digital preventive maintenance system is needed; this would be helpful in cutting maintenance costs and avoiding the failures of building assets.

2.4. 3D Spatial Analysis in High-rise Buildings

Spatial analyses within high-rise buildings often require information regarding the relatedness of 3D units (such as connectivity and adjacency). In a 3D space, objects can have adjacent or connecting neighbors in both the horizontal and vertical directions. Various methods can be implemented to determine the adjacency or connectivity of 3D objects; for example, a 3D proximity-analysis method creates a buffer for each of a 3D object's edges to find adjacent buffer-intersecting 3D objects [35]. Similarly, a ray-casting method can also be used to determine the adjacent objects within a high-rise building [36]. However, a simple representation of adjacency and connectivity using the spatial relationships that define the interactions among 3D objects can also facilitate a 3D spatial analysis.

3. Methodology

In this study, a high-rise building is modeled and stored within a spatial database. The temporal attributes of a maintenance schedule are also stored within the database and accompanied by ownership attributes. 3D space segmentation was also carried out to further visualize the 3D parcels according to ownership. Finally, 3D spatial queries were executed based on the identification of adjacent 3D parcels that are affected by the maintenance. Figure 2 describes the overall methodology that is executed in this study.

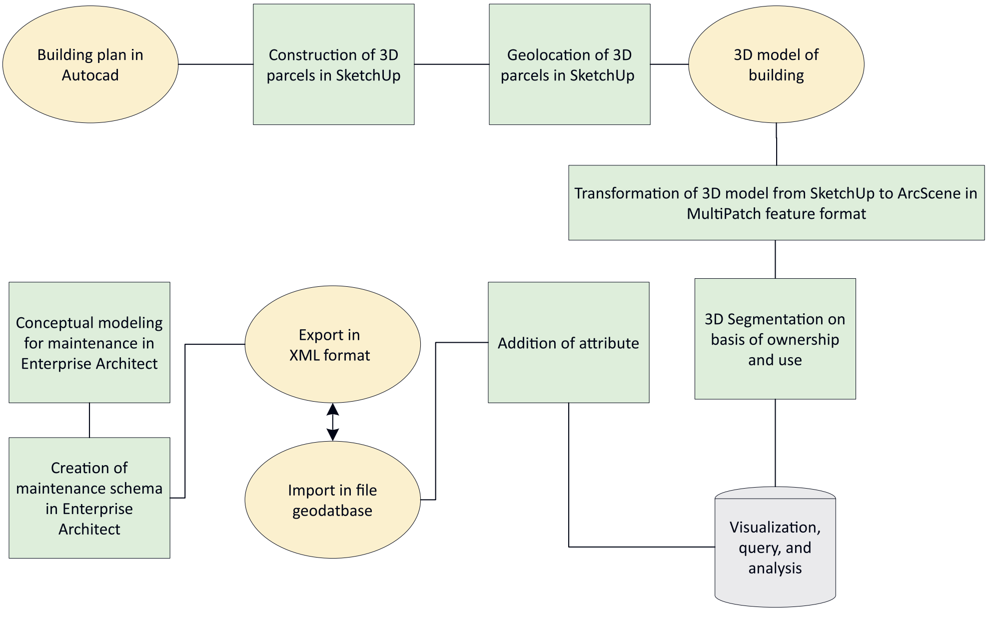


Fig. 2. Overall methodology

3.1. 3D Modeling

A 3D model of a high-rise building is constructed to represent the building and its subunits as 3D objects. The study area is a condominium complex that is located in Selangor, Malaysia, that consists of residential and commercial units. Currently, the building is still under construction; therefore, only building floor plans were available as data. The 3D model was constructed using SketchUp software. Satellite imagery and an illustration of the building are shown in Figure 3.

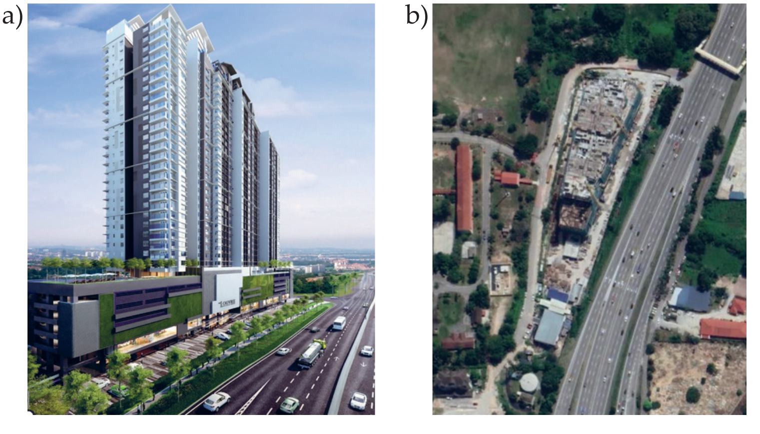


Fig. 3. High-rise building illustration (a) and satellite imagery (b)
Source: https://www.iproperty.com.my/building/the-louvre-country-heights-pty_64625/ (a), Google Earth (b)

The high-rise building consists of 37 floors whose subunits can belong to commercial and residential owners as well as common property spaces. The building is made up of 2 basement floors that are designated for public parking, 2 levels for commercial mall units, 4 floors for residential parking, 1 floor for residential amenities, 26 floors for residential units, and 2 floors for utilities. The 3D model was constructed using AutoCAD drawings of the building plans (as depicted in Figure 4). The building plans describe the dimensions of the parcels along with the floor heights and common spaces (such as corridors, elevator shafts, stairs, and utilities); however, the building plans do not include wall thicknesses, floor thicknesses, or any exterior facades of the building. Thus, only the interior parcels and common properties were modeled in 3D, whereas the surfaces were modeled as 2D polygon surfaces (which do not require thicknesses). The 2D surfaces will be modeled together as a 3D closed solid instead of individual surfaces.

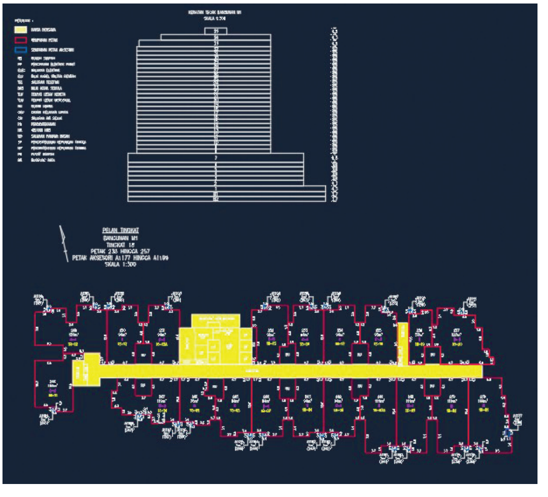


Fig. 4. AutoCAD drawing of building plan

The parcels on each floor were drawn as polygons and walls according to the floor heights that were specified in the building plan. Each unit's walls, floor, and ceiling surfaces were grouped together to form a 3D closed volume or solid; therefore, each 3D unit will have its own polygon surfaces. Neighboring units that appeared to share the same walls inherently had individual walls assigned to individual units. Instead of sharing common surfaces, neighboring 3D parcels had intersecting boundary surfaces. An example of the 3D parcels on a floor is shown in Figure 5.

After each floor was drawn, the floors were put together on the shared stairwells and elevator shafts. The floors were then geo-located using the Geolocation tool in SketchUp (as shown in Figure 6).

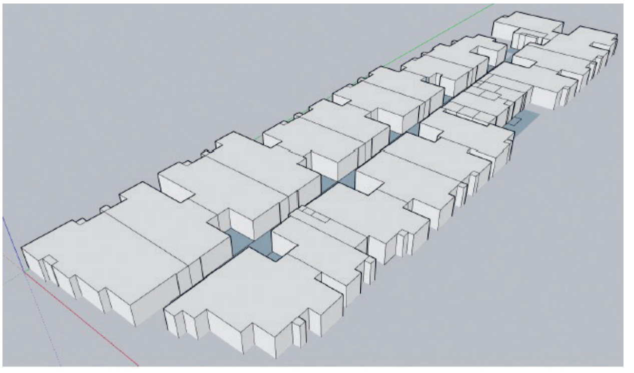


Fig. 5. 3D model of parcels on one floor within high-rise building

Fig. 6. Geolocated 3D model of subunits within building

3.2. 3D Space Segmentation

A 3D space that consists of different components or elements can be segmented into smaller parts. This 3D segmentation procedure allows 3D space segments to be analyzed separately or as a whole depending on the analysis requirements. A segmented space can be identified based on the use of a 3D unit such as a residential, commercial, facilities, and utilities as well as on the basis of ownership (such as parcel, accessory unit, and common property). The 3D model of the building subunits and ownership attributes were stored in an ArcGIS geodatabase. The subunits were imported from SketchUp and stored as multi-patch features. The selection of subunits was carried using “Select by Attribute.” The selection was exported as a 3D segmented space according to its use. The 3D space segmentation will facilitate further analysis that is related to the uses of 3D subunits within high-rise buildings.

3.3. Temporal Strata Database Management

As described above, a high-rise building is divided into four categories on the basis of the ownership rights. The involvement of 3D space, the complex division of the facilities, and the multiple management bodies that are present in high-rise buildings all lead to the need for a digital system to monitor the maintenance processes. In this study, the ArcGIS multi-patch feature was used to present the 3D space of the building. As a use case, the conceptual model was created in Enterprise Architect software (as shown in Figure 7). This model included two elements of the building: air conditioning, and electrical wiring. If a single air conditioner needs maintenance within a parcel, it will not affect the adjacent/neighboring parcels. However, management body of strata scheme can more effectively assess and visualize which actions will support in carrying out proactive management with the aid of the associated database management and 3D model of building. This is further described in the Results and Discussion section. In the next step, the schema for an air-conditioning maintenance schedule is created (as shown in Figure 8).

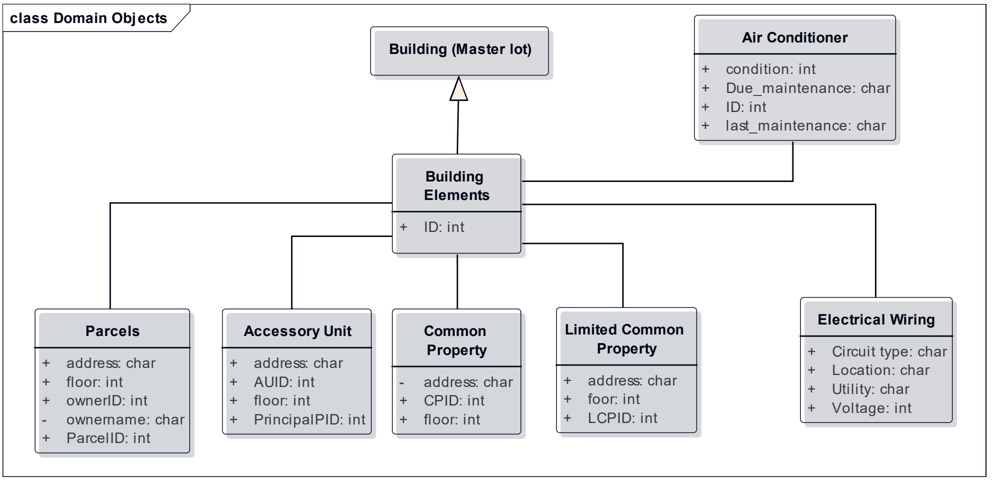


Fig. 7. Air-conditioner maintenance – conceptual model

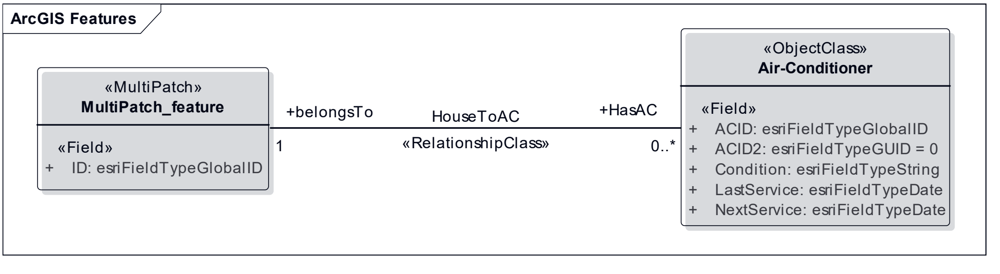


Fig. 8. Schema for air-conditioner maintenance schedule

The 'last serviced' and 'next serviced' dates are added as fields. This schema was exported in the XML format and then imported into the file geodatabase using the ArcGIS Catalog. The addition of the date record, query for analysis, and visualization was done in ArcScene.

3.4. 3D Spatial Relationships in Determining Adjacent 3D Subunits

In the management of high-rise buildings, scheduled maintenance required information regarding any adjacent 3D units based on 3D spatial relationships such as "Touches" and "Intersects." The "Select by Location" tool within ArcGIS (shown in Figure 9) was used to determine the adjacent 3D subunits. Several spatial selection methods were used for the "Touches" spatial relationship, which included the "Share a line segment with" and "Touch the boundary of." The features are considered to "touch" if the line segments or boundaries touch, but no interiors of the features overlap. Apart from this, the "Intersect" spatial relationship is determined using the "Intersect (3D) with Source Layer" spatial-selection method that determines any features that overlap.

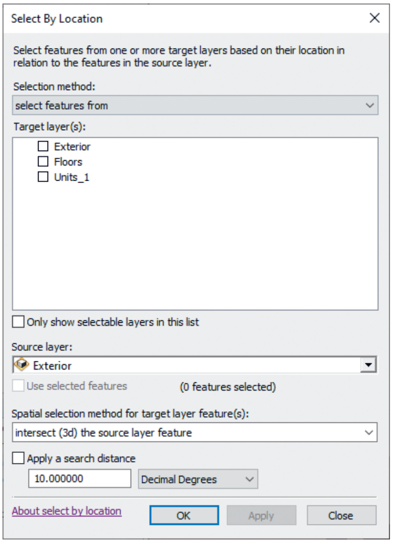


Fig. 9. "Select by Location" tool in ArcGIS

4. Results and Discussion

4.1. 3D Space Segmentation

The space in a given high-rise building can be categorized on the basis of use and ownership. On the basis of use, building space is segmented into four categories: residential, commercial, utilities, and facilities. Those parcels that are used for residential areas and are owned by strata title holders are characterized as residential. Besides this, the accessory parcels, lifts, stairs, corridors, and lobbies are referenced as facilities. Meanwhile, the water tanks, control rooms, pump rooms, and others are referred to as utilities. Similarly, those parcels that are used for commercial activities are referred to as commercial. Figure 10 depicts a high-rise building segmented according to the use of 3D units that are represented by color, where the residential parcels are yellow, the commercial parcels are brown, the utilities are blue, and the facilities are yellow. The surface (ground) area for each space use is calculated to analyze the distribution of space (as shown in Table 1).

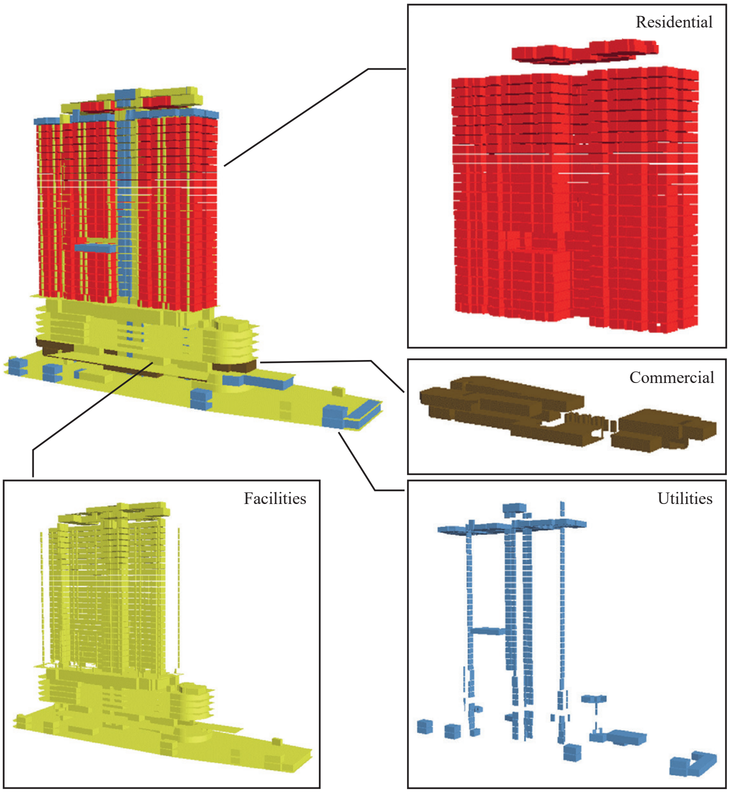


Fig. 10. 3D space segmentation based on parcel use

Table 1. Surface (ground) area of high-rise building parcels based on use

Type	Area [m²]	Percentage of area (area/total area) [%]
Residential	52,050.81	35.7
Commercial	4,154.21	2.8
Utilities	4,478.46	3.1
Facilities	85,063.69	58.4

As discussed in the previous sections, a building space can be divided into four categories of ownership: a parcel, an accessory parcel, a common property, and a limited common property. A parcel is described as a unit that is owned by a strata title holder. Additionally, an accessory parcel is a space that is associated with a specific strata title holder. In addition to this, the common property is jointly owned by all of the owners in the strata. On the other hand, a limited common property is space that is owned by selected strata title holders in a strata scheme. Figure 11 describes the segmentation of space based on the ownership categories that are represented by color, where the parcels are red, the common properties are yellow, the limited common properties are purple, and the accessory parcels are gray. Table 2 shows the area distributions of the mentioned divisions.

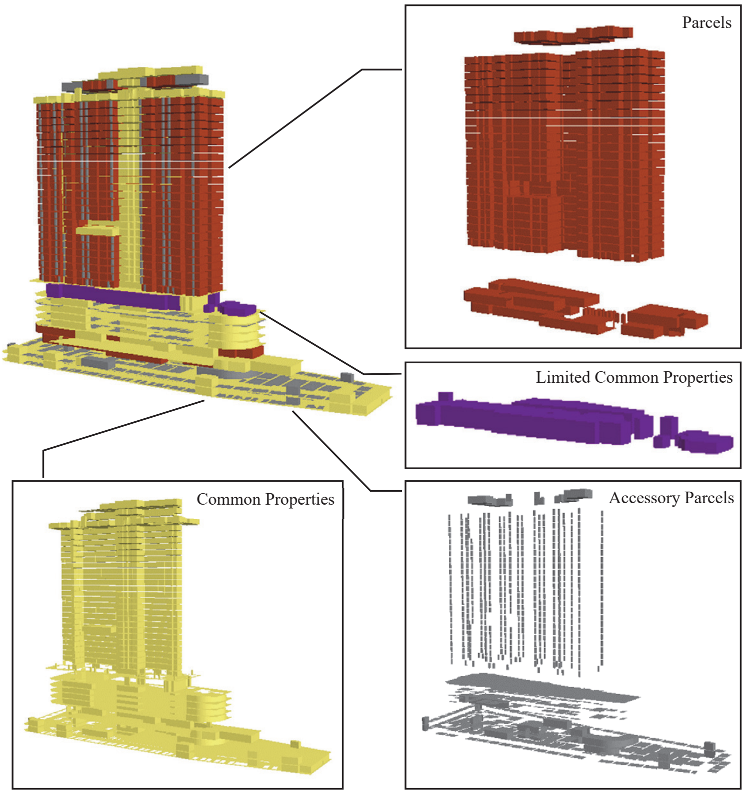


Fig. 11. 3D space segmentation based on ownership of parcels

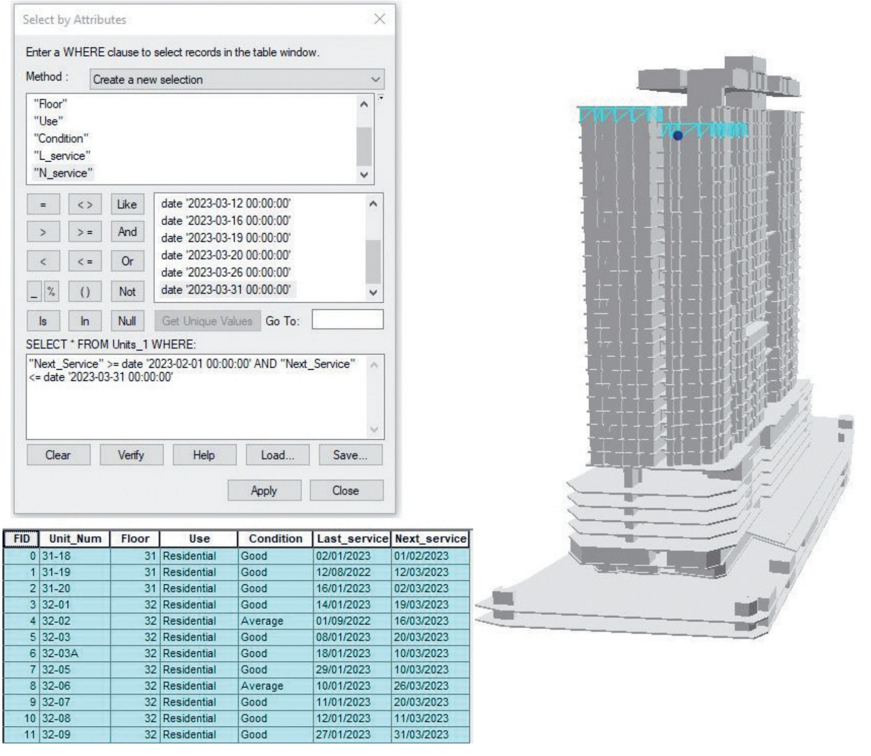
Based on the results, it can be observed that the percentage of common property takes up the highest percentage of the space within the high-rise building. As mentioned in the previous sections, the common property also consists of parcels with facilities and utility purposes; this includes car parks, ramps, landscaped areas, swimming pools, elevators, stairs, and others. Parallel to this, facilities and utilities also contributed the highest percentage of space based on parcel use. The maintenance responsibilities of the MC to each parcel differ according to the ownership (as outlined in the preceding sections). Therefore, the 3D segmentation of space allows for an accurate representation of those spaces to which maintenance is due and to what extent.

Table 2. Surface (ground) area of high-rise building parcels based on ownership

Type	Area [m²]	Percentage of area (area/total area) [%]
Parcel	56,205.03	38.6
Accessory parcel	23,372.70	16.0
Common property	64,220.88	44.0
Limited common property	1,948.56	1.4

4.2. Temporal Strata Database Management

A proposed schedule for air conditioning maintenance and service is presented. After importing the modeled schema in ArcScene, the "LastService" and "NextService" fields are filled in manually with records in the date format as attributes of the residential parcels on Floors 31, 32, and 33. An attribute table that presents the unit number, floor, and last and next service dates is presented in Figure 12.



FID	Unit_Num	Floor	Use	Condition	Last_service	Next_service
0	31-18	31	Residential	Good	02/01/2023	01/02/2023
1	31-19	31	Residential	Good	12/08/2022	12/03/2023
2	31-20	31	Residential	Good	16/01/2023	02/03/2023
3	32-01	32	Residential	Good	14/01/2023	19/03/2023
4	32-02	32	Residential	Average	01/09/2022	16/03/2023
5	32-03	32	Residential	Good	08/01/2023	20/03/2023
6	32-03A	32	Residential	Good	18/01/2023	10/03/2023
7	32-05	32	Residential	Good	29/01/2023	10/03/2023
8	32-06	32	Residential	Average	10/01/2023	26/03/2023
9	32-07	32	Residential	Good	11/01/2023	20/03/2023
10	32-08	32	Residential	Good	12/01/2023	11/03/2023
11	32-09	32	Residential	Good	27/01/2023	31/03/2023

Fig. 12. Query of parcels that require maintenance based on schedule

In order to extract the air conditioning maintenance that is planned for the months of February and March 2023, a query was applied to the planned "Next-Service" column of the data. The query and selection of the parcels are shown in Figure 12.

4.3. Adjacent Units Affected by Maintenance

In the event that a parcel undergoes maintenance and that the maintenance work must be done in such a way that it makes noise, 3D topological relationships can be used to determine the adjacent units that will be affected by the noise; these units may be neighboring units that surround the parcel in the horizontal and vertical directions. An example query was carried out using the Select-by-Location tool in ArcGIS to determine those adjacent units that were affected by maintenance in a commercial parcel. The affected parcel was Commercial Parcel Number 31 located on Level 2 (as shown in Figure 13). As a result, seven adjacent parcels were identified (as depicted in Figure 14).

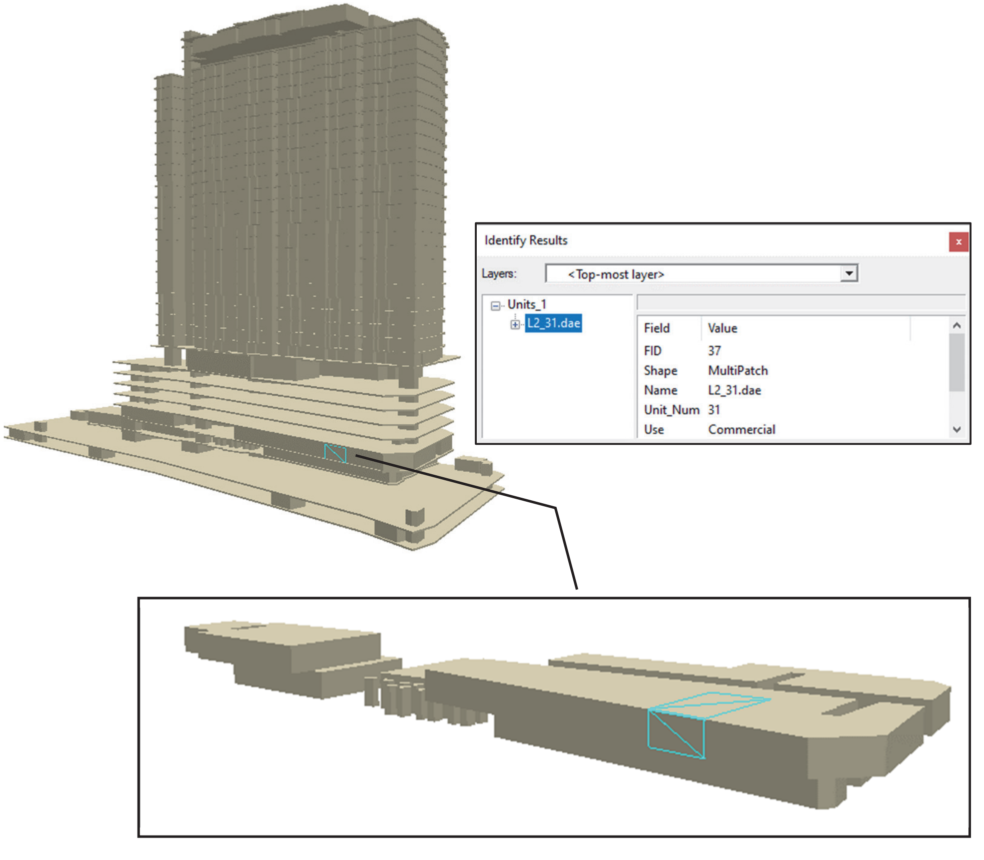


Fig. 13. Commercial parcel undergoing maintenance

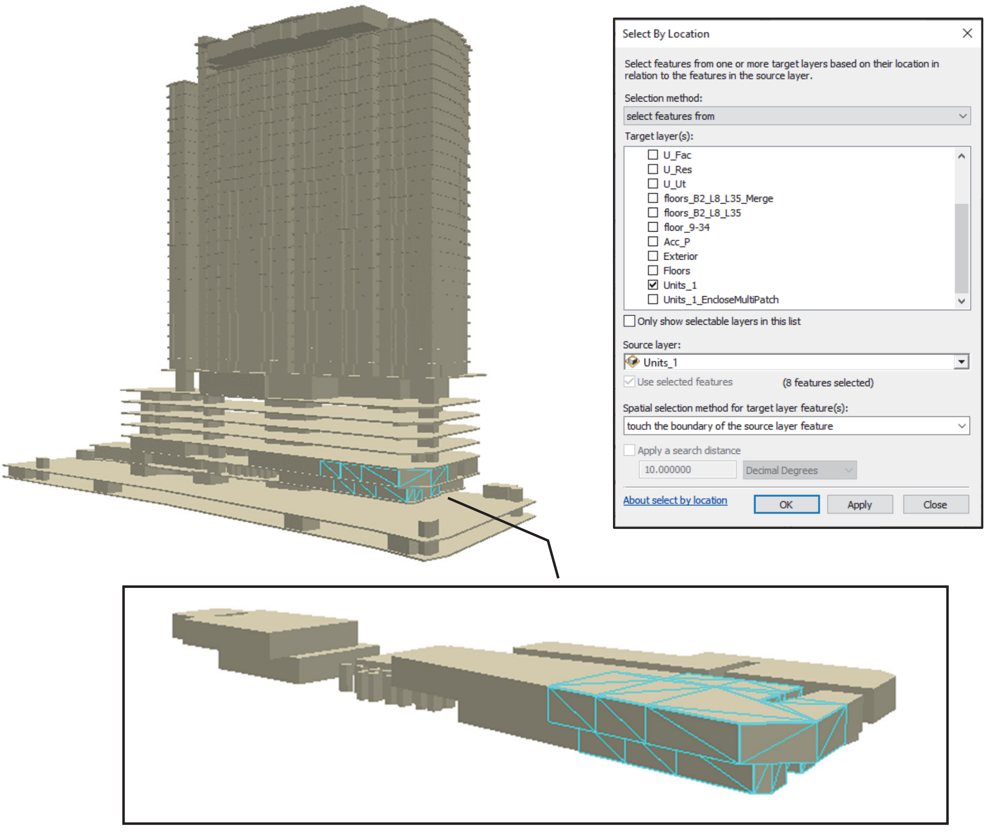


Fig. 14. Adjacent units affected by parcel undergoing maintenance

In the case of electrical wiring, this may similarly affect adjacent/neighboring parcels if a fault occurs in any location. Here, 3D spatial analysis will be used to identify the adjacent/neighboring parcels. Figure 15 shows the view of a single floor in the subject building; the walking corridor that is selected in the figure is common property and is connected to residential parcels. If an electrical fault occurs within the common property of any floor of the building, it may have an effect on the parcels on that floor (depending on the design of the electrical wiring). In this case, 3D spatial analysis can be helpful in order to identify any affected parcels. Figure 16 shows the selection of all of the parcels with the affected problems that were adjacent to the walking corridor using the same "Select by Location" query that is represented in Figure 14.

The use of multi-patch features for a visualization and a simple spatial analysis of the 3D models was found to be sufficient. However, the spatial operators that were used to determine the topological relationships among the objects treated each object like a 2D object. For example, a 3D parcel is represented as a series of patches or 2D triangulated surfaces (as shown in Figure 17). As a result, this limited but practical geometric representation of 3D objects was able to determine any adjacent objects in both the horizontal and vertical directions. However, the topological relationships among the 3D objects were also limited to 2D relationships, whereby the intersections between the objects were decomposed into 2D or lower-dimensional intersections.

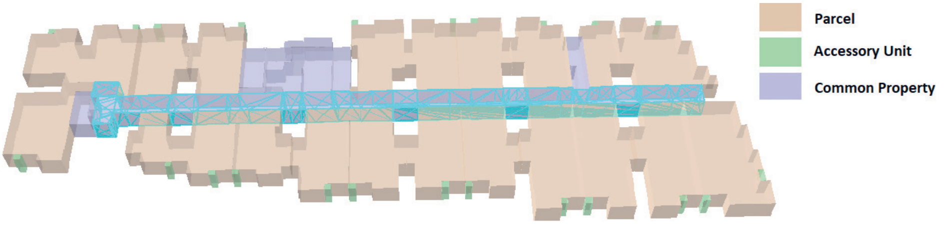


Fig. 15. View of single floor (Floor 20)

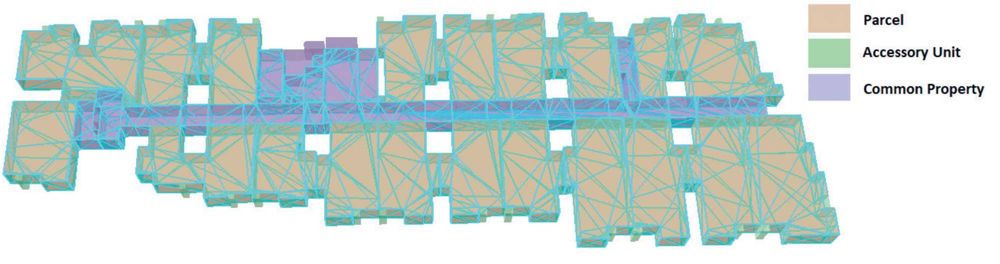


Fig. 16. Parcels affected during maintenance of electrical fault (Floor 20)

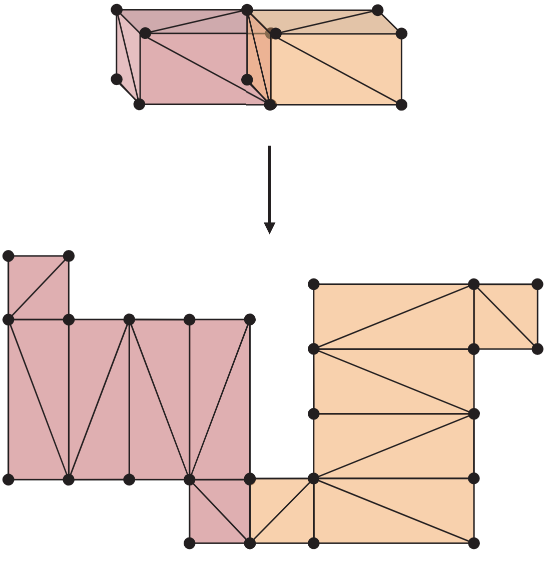


Fig. 17. Representation of connected 3D objects as multi-patch feature

5. Discussion

The management of multi-use high-rise buildings is a complex and challenging task that requires effective communication, organization, and coordination. In order to ensure the effective maintenance and management of these buildings, it is essential to have accurate and comprehensive information about a building's components, ownership, and uses.

Based on the works that were performed, one promising approach to managing multi-use high-rise buildings is the implementation of a temporal strata database-management system with accurate 3D representations of the spaces, space segmentations, and spatial analyses. These systems can provide several benefits, including the proactive maintenance and management of common property, the accurate planning of future maintenance tasks, concise and comprehensive information of parcels with respect to ownership and uses, and a reduction of maintenance costs through preventive maintenance.

The implementation of space segmentation is also helpful for a MC in monitoring building conditions, analyzing and allocating budgets, and managing temporal strata-management issues. Space segmentation provides an organized overview of a building's components, allowing the MC to make better-informed decisions regarding any maintenance and repairs. By having a clear understanding of the building's components, the MC can allocate resources more effectively and reduce the likelihood of costly and time-consuming repairs.

Moreover, the integration of spatial analysis into these systems can be used to identify adjacent parcels that will be affected by any maintenance. This enables early warnings to be given to those residents or parcel owners who will be affected by the maintenance tasks. By providing advanced notice, residents or parcel owners can take preventive measures to minimize the impact on their daily routines, leading to improved relationships among MCs and their residents.

The findings of this study have significant implications for the management of multi-use high-rise buildings. Implementing these systems can lead to cost savings, improved communication between MCs and residents, and more effective maintenance and repairs. By having accurate and comprehensive information about a building's components, ownerships, and uses, MCs can make better-informed decisions, allocate resources more effectively, and reduce the likelihood of costly and time-consuming repairs.

However, there are also potential challenges that are associated with the implementation of these systems. For instance, the implementation cost can be substantial, and there may be resistance from some residents or parcel owners who are not familiar with the technology. Additionally, the implementation process may require significant time and effort, which can delay the benefits of the system. Future research should focus on the development of more-sophisticated systems that incorporate the latest technology and innovations as well as on the identification of the best practices for implementing these systems in different contexts. Moreover, the study's findings emphasize the importance of effective communication and collaboration among MCs and residents, which is essential for the successful implementation and use of these systems.

The implementation of a temporal strata database-management system with an accurate 3D representation of the space, space segmentation, and spatial analysis can significantly aid in the proactive maintenance and management of multi-use high-rise buildings. The benefits of these systems include cost savings, improved communication among MCs and residents, and more-effective maintenance and repairs. While there are potential challenges that are associated with the implementation of these systems, the benefits are significant and justify continued research and development in this area.

6. Conclusion

In conclusion, the implementation of a temporal strata database-management system with an accurate 3D representation of space, space segmentation, and spatial analysis can provide several benefits for the maintenance and management of multi-use high-rise buildings. These benefits include the proactive maintenance and management of common property, the accurate planning of future maintenance tasks, concise and comprehensive information of parcels with respect to ownership and uses, and a reduction of maintenance costs through preventive maintenance. Space segmentation also provides an organized overview of a building's components, allowing its MC to make better-informed decisions regarding maintenance and repairs, analyze and allocate budgets, and manage temporal strata-management issues. The integration of spatial analysis into these systems enables the identification of adjacent parcels that will be affected by maintenance, and early warnings can be given to those residents or parcel owners who are affected by any maintenance tasks. Despite the potential challenges that are associated with the implementation of these systems, the benefits are significant and justify continued research and development in this area. Future research should focus on the development of more-sophisticated systems that incorporate the latest technology and innovations as well as on the identification of the best practices for implementing these systems in different contexts. Effective communication and collaboration among MCs and residents are essential for the successful implementation and use of these systems. In summary, the implementation of these systems has significant implications for the management of multi-use high-rise buildings; it can lead to cost savings, improved communication among MCs and residents, and more-effective maintenance and repairs. Therefore, it is imperative for building managers to consider implementing these systems in order to enhance their maintenance and management practices.

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