Proposing Spatial - Temporal - Semantic Data Model Managing Genealogy and Space Evolution History of Objects in 3D Geographical Space

Dang Van Pham(✉)

Faculty of Information Technology, Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam
pvdang@ntt.edu.vn, pvdang.tps@gmail.com

Abstract. Managing construction projects in new urban areas is an essential work for construction contractors as well as authorities at all levels. In this management, managing the spatial evolutionary history of two-dimensional (2D), two-point-five-dimensional (2.5D) and three-dimensional (3D) spatial objects over time and semantics in 3D geographical space is an urgent and extremely important work. This paper proposes a spatial - temporal - semantic data model (STSDM), spatial queries over time and semantics, and algorithms finding the ancestors and descendants of space objects (ASA and DSA). The paper presents some empirical results about the spatial evolutionary history of spatial objects over time and semantics. The experimental results show that it can completely be used to trace the space evolution history of bridges, houses and apartments at a given time or in a given period in new urban management applications.

Keywords: Spatial - temporal - semantic data model · STSDM · Spatial evolutionary history · Spatial queries · Space objects

1 Introduction

In urban management, especially the management of traces of spatial evolution history of 2D, 2.5D and 3D space objects of constructions in new urban areas is an important and necessary work. In aspects of construction techniques performed by humans, we can sometimes meet with risks as when they were being constructed, they collapsed. In aspects of nature, we can sometimes meet with risks caused by natural disasters such as earthquakes, tsunamis or storms causing space objects to disappear. Therefore, in aspects of managing risks and tracing the spatial evolution history of 2D, 2.5D and 3D spatial objects in new urban areas that is an essential work not only for the construction contractors but also authorities at all levels in managing new urban areas of smart.

When constructing bridges spanning rivers, buildings, smart houses, etc., keeping traces of the current history at different times of construction is an important work for building contractors. This work is aimed at helping construction contractors the opportunity to trace the spatial evolution history of 2D, 2.5D, 3D space objects as

P. C. Vinh and A. Rakib (Eds.): ICCASA 2020/ICTCC 2020, LNICST 343, pp. 148–168, 2021.
https://doi.org/10.1007/978-3-030-67101-3_13

evidence to support the calculation of labors, construction materials as well as time to complete construction items. The management of spatial and genealogy variations of spatial features in construction items is essential for contractors. They can observe in detail the construction items change over time. From there they will make timely adjustments when a project goes into operation. Therefore, people can avoid shortcomings and risks during construction.

Currently, the situation of urbanization is happening quickly and complicatedly. Therefore, an information system that manages the development in the field of construction becomes even more urgent and necessary. This system not only helps construction contractors to closely monitor their construction progress but also assists policymakers to develop new urban in the future. The management focus on methods of storing spatial data, searching and enumerating of construction items according to construction history is very important. Semantics is an essential element of a management information system. The semantic class plays an important role in saving the meaning of each attribute in the space object. Based on this factor, users can understand the types of objects in space. What is the name of the space object? What are its attributes? What properties does it reflect in space objects? Who managed, who owned and who maintained?

Time is essential factor embedded in management information systems. In life, humans always have different relationships (Fig. 1) such as blood relationships, social relationships, previous conviction relationships, previous offence relationships, born/death relationships, etc. These relationships lead to the importance of the spatial and temporal classes and have formed object – space - time relationships [1–3]. The time class plays an important role in saving the spatial change history of object – space - time relationships. Based on the element of time, we can extract history of these relationships to serve different fields of careers. The time element in a paper can represent the history of spatial change occurring at a specified time point or interval.

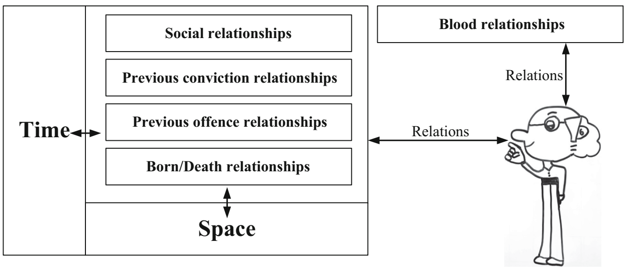

Fig. 1. Expressions of non - temporal relationships, relationships with time and space elements

The objective of this paper is to propose three classes such as spatial, temporal, and semantic classes to construct spatial - temporal - semantic data model (STSDM) for managing spatial evolution history and genealogy of 2D, 2.5D and 3D spatial objects in the new urban area. This new model has the ability to manage and potentially query space over time and semantics, and algorithms finding the ancestors and descendants of space objects. Experimental results simulating the history of spatial evolution and genealogy of spatial objects show that they can be applied to specific applications in the management of construction works in the future.

The remainder of this paper is presented as follows: Part 2 briefly presents the relevant research works, makes comments and encloses new proposals for the application of construction works in new urban areas. Part 3 proposes the STSDM and proceeds to build spatial class, time class, semantic class, algorithms to find genealogy of 3D space objects, and construct spatial and temporal queries. Part 4 presents empirical results simulating the history of space evolution and genealogy of space objects. Part 5 is the conclusion section and suggestion development for future paper. Finally, that is the material reference section.

2 Related Works

Building spatial - temporal - semantic data models plays an important role in tracking the spatial change history of houses, apartments, bridges as well as tracing the length of development history of urban architectures is the key to supporting GIS applications 2-2.5-3-4D time. This paper systematizes data models by type and makes some comments as a premise for a new proposal.

2.1 Overview of Data Model Types

For good representation of 2D, 2.5D and 3D spatial objects with boundaries, the boundary representation method (B-REP) is the most suitable choice. This method represents 3D objects based on predefined elements, including: point, line, surface, solid and this method is suitable for representing 2-2.5-3D objects have regular and scalar shapes. The data models were proposed by the authors from the past to the present that have applied the B-REP method include: The UDM spatial data model was proposed by Coors in 2003 [4]; 3D Cadastral model was proposed by Yuan Ding authors group and his colleagues in 2017 [5]; TUDM model proposed by Anh N.G.T authors group and his colleagues in 2012 [6]; VRO-DLOD3D model was proposed by Dang P.V authors group and his colleagues in 2017 [7]; CityGML model was proposed by Groger authors group and his colleagues in 2007 [8]; Kolbe authors group and his colleagues expanded CityGML model in 2009 [9]; Biljecki authors group and his colleagues improved CityGML model in 2016 [10]; Dang P.V authors group and his colleagues proposed ELUDM model for 2.5D objects in 2011 [11]; Anh N.G.T authors group and his colleagues proposed ELUDM model for 2.5D objects in 2011 [12]; Löwner authors group and his colleagues proposed a new LoD and multi-representational concept for CityGML model in 2016 [13]; CityGML-TRKBIS.BI model Aydar authors group and his colleagues to meet the need to establish 2-2.5-3D objects at the national level in 2016 [14]; TLODs model was proposed by Dang P.V authors group and his colleagues [15].

To represent 3D objects with voxel elements such as pixels in 2D GIS, the voxel method is the most suitable choice. This method represents a 3D object based on the idea of splitting an object into child elements, each of which is called a voxel [16].

An element is referred to as a 3D geospatial and is assigned by an integer [17]. Models proposed by the authors in the past that have applied the voxel method include the 3D Array model proposed by Rahman [18, 19]. The model has the simplest data structure used to represent 3D objects. Elements in 3D Array have one of two values 0 and 1. In which 0 describes the base value, 1 describes the value that each element in the 3D Array is occupied by the 3D object.

If a 3D object is scanned in a 3D array that the elements of the array are initially initialized with a value of 0. After scanning the 3D object, the elements with a value of 1 represent the information for the 3D object. Octree model was proposed by Gorger authors group and his colleagues in 2004 [20]. Octree is an extension of a tetrahedral tree to an octal. Octree is a 3D representation model based on a block platform. The octal tree gives us an image, which is a method represented by a tree data structure. In general, an octal tree is defined based on the smallest cube containing the 3D object to be represented. The original cube will be divided into 8 sub cubes. An octal tree is based on decomposition according to the recursive algorithm. In a tree, each node either leaves or has 8 seedlings. Each seedling will be tested before being divided into 8 other seedlings.

To represent 3D objects in 3D geographical space, we use the combination of basic 3D blocks proposed by Rahman in 2008 is the best choice [18]. CSG model represents 3D objects by combining predefined 3D elements. Basic 3D blocks are often used as cube, cylinder and sphere. The relationships between these figures include: transformations and logical operands. The transformations include translations, rotations, and degrees. Logical operands include union, intersection, and difference. CSG is often used in CAD and CSG is very convenient in calculating the volume of objects, CSG is not suitable for representing objects with irregular geometric shapes.

2.2 Comment and Recommendation Data Models

Through analysis of the above data model types, it is given us a clear view of the developmental history process of data models proposed by the authors groups. We found that these models mainly use the B-REP method, which represents 2-2.5-3D objects based on predefined elements including: point, line, surface, solid. Therefore, this method is suitable for representing 2-2.5-3D objects of regular and scalar shapes.

To represent spatial objects including bridges, residential houses, villas, etc. in 3D geographical space, the application of modeling is the key to success. The criteria to consider models are models that must be able to represent spatial objects in 3D geographical space include the criteria representing outside surface, the criteria representing inside surface, the criteria representing the level of detail but must also be able to store spatial data, time data, and semantic data. In 2013, T.A.N.Gia authors group and his colleagues [21] presented a summary of GIS 3-4D data models, in which this authors group has proposed a presentation that summarizes the criteria that each GIS 3-4D data model must satisfy. Those criteria include surface representation of objects, inside surface representation of objects, representation of main elements, representation of data size applying to applications, spatial data structure, spatial attribute queries, spatial object location queries, semantic queries. After that in 2017, T.A.Nguyen-Gia authors group and his colleagues [22] gave a brief survey of the current popular 3-4D

GIS data models with comparison tables by typical criteria such as representation of surface types, inside surface representation of objects, triangulation capability, triangulation incapability, model platforms, data storage dimensions, and applicability to existing applications now.

Through the systematization and classification of data models and based on the criteria proposed by the authors mentioned above as a premise for this paper to propose the construction of the STSDM to manage spatial evolutionary history, we found that the above models mainly applied B-REP method. In general, these models focus on managing and exploiting spatial, time and relationships objects. However, a major challenge now is how to represent residential houses in urban areas in more detail in the spatial evolutionary history of 2D, 2.5D and 3D space objects, from there the managers have the opportunity to manage spatial objects according to spatial evolutionary history to serve in the planning of future urban development policies. From these challenges, we propose constructing a STSDM to manage spatial evolutionary history and find the genealogy of bridges and residential buildings in new urban areas in 3D geographical space.

3 Spatial – Temporal – Semantic Data Model

3.1 Time Class

Time is an essential element of an information system that manages construction items. The time class plays an important role in tracking the spatial variation of objects in space. Based on the time element, people can intervene in time to resolve urgent issues and recognize the situation more clearly. The time element in the paper can represent spatial changes that occur at a time point or a given time segment. In order to manage spatial objects according to time and semantics which had studies suggesting three types of time data as shown in Table 1 [15, 23]. The time element is attached to spatial data, which makes the stored data more abundant and more meaningful to use. Happened events are causes of the spatial changes of objects that also presented in this

Table 1. Detailed description of time data types

No	Time data type	Meaning describes the time data types
1	Event time (ET_s)	Event time is the time that begins to occur and ends in the real world. There is day – month – year - hour: minute: second beginning to occur and day – month – year - hour: minute: second ending in the real world
2	Legal time (LT_s)	Legal time is the effective time on legal documents. There is day – month – year - hour: minute: second beginning to occur and day – month – year - hour: minute: second ending in documents
3	Database time (DT_s)	Database time is the time to write to the database. There is day – month – year - hour: minute: second beginning to occur and day – month – year - hour: minute: second ending in database

paper. Time is used to trace the beginning and ending history of an object in space. Time is divided into three specific time data types (see Table 1) having nine-time data units located on the time axis (see Fig. 2) with the convention in Table 2. In the nine-time data units described in Table 2, people are mainly interested in the four-time data units as T_1, T_3, T_5 and T_8. From the nine-time data units we form the time topology relations in Tables 3, 4 and 5 as follows (Figs. 3, 4, 5 and 6).

Table 2. The table describes nine - time data units

No	Convention	Meaning describes the time data types
1	T_1	The start time of the object in the real world
2	T_2	The end time of the object in the real world
3	T_3	The time people start the owner or manager of the object
4	T_4	The time people end the owner or manager of the object
5	T_5	The time people start to maintain the object according to regulations
6	T_6	The time people end to maintain the object according to regulations
7	T_7	Time people maintain the object periodically
8	T_8	The time people start to write objects to the database
9	T_9	The time people end to write objects to the database

Table 3. The table classifies time data units into time data types

No	Convention	Meaning describes the time data types
The event time type consists of two - time data units:		
1	T_1	The start time of the object in the real world
2	T_2	The end time of the object in the real world
The legal time type consists of five - time data units:		
3	T_3	The time people start the owner or manager of the object
4	T_4	The time people end the owner or manager of the object
5	T_5	The time people start to maintain the object according to regulations
6	T_6	The time people end to maintain the object according to regulations
7	T_7	Time people maintain the object periodically
The database time type consists of two - time data units:		
8	T_8	The time people start to write objects to the database
9	T_9	The time people end to write objects to the database

Table 4. The table describes the relationship before and after between time data units

No	Relationship	Meaning describes the relationship before and after
1	$T_1 < T_2$	T_1 is a unit of time beginning to occur with space objects in real world earlier than the end time unit of the space objects in real world (T_2)
2	$T_1 < T_3$	T_1 is a unit of time beginning to occur with space objects in real world earlier than the time when people start the owner or manager of the space objects according to regulations (T_3)
3	$T_1 < T_4$	T_1 is a unit of time beginning to occur with space objects in real world earlier than the time when people end the owner or manager of the space objects according to regulations (T_4)
4	$T_1 < T_5$	T_1 is a unit of time occurring in the real world earlier than the start time maintaining of space objects according to regulations (T_5)
5	$T_1 < T_6$	T_1 is a unit of time occurring in the real world earlier than the start time maintaining of space objects according to regulations (T_6)
6	$T_1 < T_7$	T_1 is a unit of time occurring in the real world earlier than the time maintaining of spatial objects periodically (T_7)
7	$T_1 < T_8$	T_1 is a unit of time occurring in the real world earlier than the start time recording the change of spatial objects into database (T_8)
8	$T_1 < T_9$	T_1 is a unit of time occurring in the real world earlier than the end time recording the change of spatial objects into database (T_9)
9	$T_5 < T_6$	T_5 is a unit of start time maintaining space objects according to regulations earlier than the unit of time maintaining space objects to regulations (T_6)
10	$T_6 < T_7$	T_7 is a unit time maintaining space objects periodically later than the end time unit maintaining space objects to regulations (T_6)
11	$T_8 < T_5$	T_8 is a unit of time recording the database earlier than the time unit maintaining on legal documents (T_5)
12	$T_8 < T_9$	T_9 is a unit of end time recording the changes of space objects into the database later than the start time recording the changes of space objects into the database (T_8)

Table 5. Table describes the overlapping relationship between time data units

No	Relationship	Meaning describes the overlapping relationship
1	$T_1 = T_8$	T_1 is a unit of time occurring in real world overlapping with the time recording into database (T_8)
2	$T_1 = T_5$	T_1 is a unit of time occurring in real world overlapping with the time maintaining on legal documents (T_5)
3	$T_8 = T_5$	T_8 is a unit of time recording into database overlapping the time maintaining on legal documents (T_5)

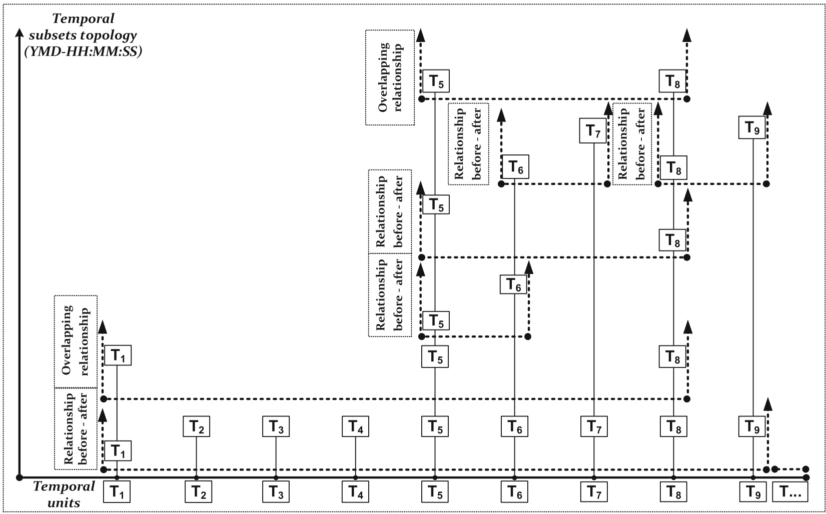

Fig. 2. Topology relational diagram of nine - time units

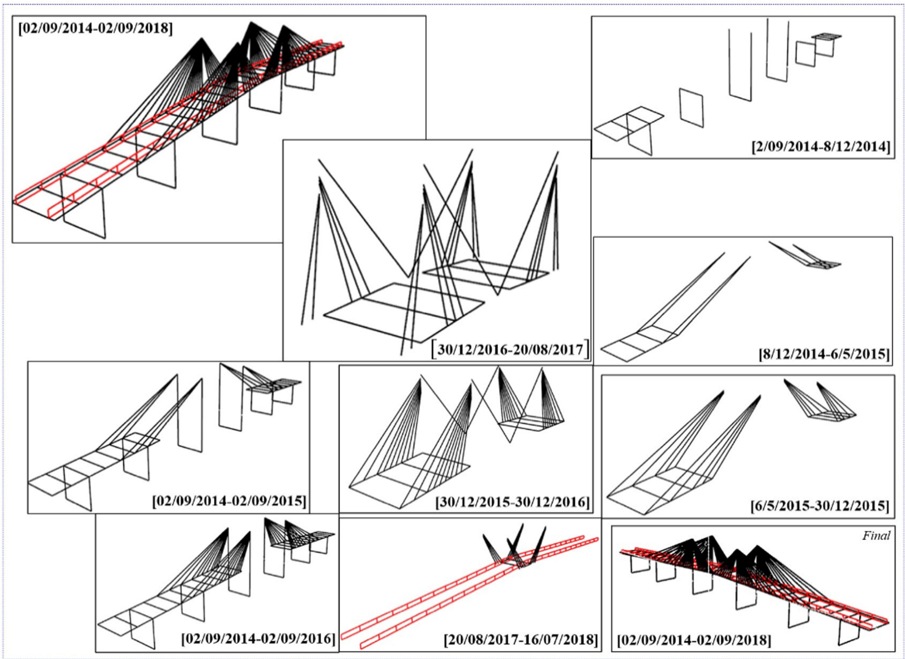

Fig. 3. Illustrating the spatial transformation history of a bridge in specified interval

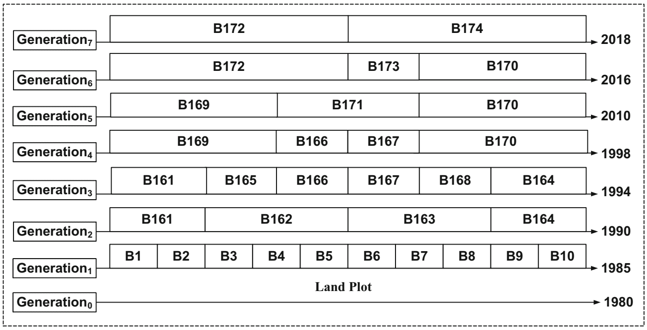

Fig. 4. Illustrating the history of using the land plot

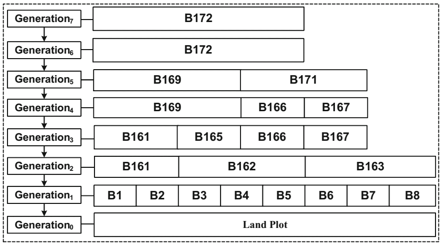

Fig. 5. Ancestor of a house with code "B172"

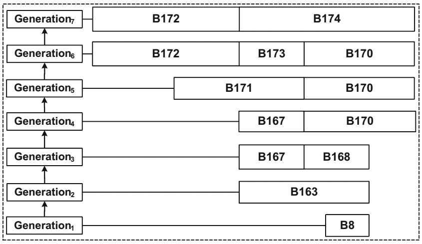

Fig. 6. Descendants of a house with code "B8"

3.2 Semantic Class

Semantic data is integrated into spatial and temporal objects to express the meaning of using objects. Semantics are attributes that contain phrases used to explain a phenomenon, a thing, an event, a happening occurred on space and time objects. For example, when we say the type of time is the type of event time, so must be accompanied by semantic attributes to explain the type of event time is like? When we say the object, we have to explain what kind of object it is? What is this object's name? What geographical region does this object belong to? Who is the owner, who is the manager or the maintainer? The semantic attribute is also used to explain what causes an object to change in space. What makes objects lose in the real world as well as in database.

3.3 Combine Spatial, Temporal and Semantic Class into STSDM

After combining three spatial - temporal - semantic class and then becoming a spatial - temporal - semantic data model and called spatial - temporal - semantic data model (STSDM). STSDM has the ability to store and manage 2D, 2.5D and 3D spatial objects in time and semantics and is illustrated by the spatial, temporal and semantic data sets shown in the section of experimental result. In addition, STSDM also has the ability to query space over time, has the ability to query space by semantics, has the ability to query space by time and semantics, and can find ancestors and children grandchildren of space objects and especially the history of space evolution is applied to specific spatial objects such as bridges that are 2-2.5D objects and apartments are 3D objects located on new urban areas.

Entity group belongs to space class. To answer which space object is located on? We have the following entities: there are 6 main entities Point, Line, Surface, Surfacetype, Body, Bodytype and there are 2 sub entities Node, Face. Entity group belongs to time class. To answer what kind of time those space objects born and lost belong to? At what time or period that object was it born and lost? We have the following entities: Stypetime, Timeunits, Tymdhms, Times. Entity group belongs to semantic class. To answer what is the type of object? And what is the name of object? We have the following entities: Objectstype and SObjects. To answer how is that object? Which geographical region does that object belong to? Who is the owner of that object? Who is the manager or maintainer? What event causes the object to change? We have the following entities: Owners, RegionaS, RegionbS, RegioncS, Eventstype, Events. To answer what is the semantics of each attribute in that space object? We have entities attributes. Below, this is a summary of the relations for the STSDM model and shows the size of a record for each relation that we have decomposed the STSDM model (see Fig. 7) into relations in Table 6.

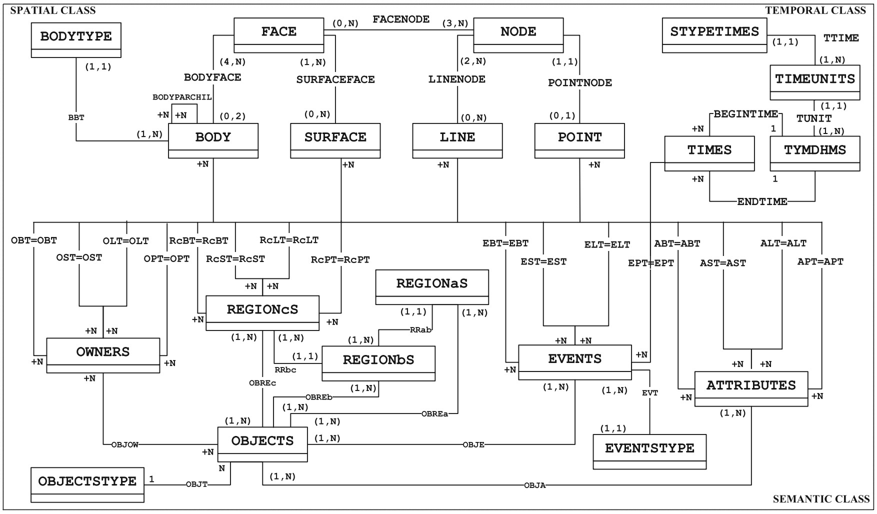

Fig. 7. Spatial – Temporal – Semantic Data Model (STSDM) managing spatial objects of 2D, 2.5D and 3D

Table 6. Decomposing the STSDM into the relations

No	Relations name	Bytes	No	Relations name	Bytes	No	Relations name	Bytes
1	Stypetimes	70	18	Surparchil	40	35	Rcbt	68
2	Timeunits	60	19	Lineparchil	60	36	Rcst	58
3	Tymdhms	80	20	Pointparchil	48	37	Rclt	35
4	Times	30	21	Objectstype	48	38	Rcpt	40
5	Node	30	22	Objects	86	39	Ebt	50
6	Point	30	23	Owners	76	40	Est	20
7	Line	34	24	Objow	66	41	Elt	69
8	Linenode	20	25	Obja	50	42	Ept	64
9	Face	28	26	Obje	40	43	Attributes	62
10	Facenode	28	27	Obt	50	44	Regionas	69
11	Surfacetype	28	28	Ost	58	45	Regionbs	67
12	Surface	20	29	Olt	60	46	Regioncs	75
13	Surfaceface	58	30	Opt	48	47	Obrea	48
14	Bodytype	54	31	Abt	38	48	Obreb	34
15	Body	78	32	Ast	58	49	Obrec	57
16	Bodyface	92	33	Alt	64	50	Eventstype	50
17	Bodyparchil	69	34	Apt	50	51	Events	48
Sum of bytes:		**809**	**Sum of bytes:**		**940**	**Sum of bytes:**		**914**

3.4 Building Some Spatial Queries Over Time and Semantics

Through the analysis and combinations of the above classes, STSDM has query abilities, has ability to find ancestors and ability find descendants with a variety of criteria to help construction contractors as well as government levels seize opportunities, promptly handle incidents occurring during the construction process, carry out completion plans and carry out traces of spatial evolutionary history of 2D, 2.5D and 3D objects. These capabilities are expressed through queries and two algorithms for finding ancestors and finding descendants that we described and implemented by experiments on Oracle 11G database management system and the C# programming language [24–26], the empirical results show that they are completely practical and can be applied to 3D GIS systems to manage construction works in new urban areas for practical implementation.

Query 1: Find and display the spatial evolutionary history of the construction process of the bridge "Phu My" over time and semantics. The periods of construction of the "Phu My" bridge are as follows: [Sep 02, 2005 $\in T_1$ - Dec 08, 2005 $\in T_2$] (Fig. 8); [Dec 30, 2006 $\in T_1$ - May 01, 2008 $\in T_2$] (Fig. 9); [Dec 30, 2007 $\in T_1$ - Feb 2, 2009 $\in T_2$] (Fig. 10); [Sep 02, 2005 $\in T_1$ – Sep 02, 2009 $\in T_2$] (Fig. 11) and is the type of ET_s

Query 2: Find and display houses owned by Ms. Pham Thao Nguyen during the period [Sep 8, 1998 $\in T_3$ - Jun 12, 2008 $\in T_4$] and is the type of LT_s.

Query 3: Find and display the space of houses according to each event and time period: (Planning, [Sep 8, 1998 $\in T_8$ - June 12, 2012 $\in T_9$]); (Storms, [Sep 8, 1998 $\in T_8$ - June 12, 2012 $\in T_9$]); (Landslide, [Sep 8, 1998 $\in T_8$ – June 12, 2016 $\in T_9$]) and is the type of DT_s.

Query 4: Find and display houses by time points, houses built during the years: 1985 $\in T_8$; 1990 $\in T_8$; 1994 $\in T_8$; 1998 $\in T_8$; 2010 $\in T_8$; 2016 $\in T_8$; 2018 $\in T_8$ and is the type of DT_s.

Query 5: Find and display the bridge space "Can Tho" before Sep 26, 2007 $\in T_1$ had an accident and is the type of ET_s.

Query 6: Find and display the bridge space "Can Tho" after the period of time [Sep 26, 2007 $\in T_1$- Aug 25, 2008 $\in T_2$] had an accident and is the type of ET_s.

Query 7: Find and display the bridge space "Phu My" was built in the period from Sep 2, 2005 $\in T_8$ to Sep 2, 2009 $\in T_9$ and according to the event "Planning" and is the type of DT_s.

Query 8: Find the ancestor of the house with the code "B172". Applying the ASA and DSA algorithms to find the ancestors below, the found result is the order of generations for each generation of house "B172" in Table 7.

Query 9: Find descendants of the house with code "B8" (Fig. 15 and 16). Applying the ASA and DSA algorithms to find descendants below, the found result is the order of genealogy for each generation of house "B8" in Table 8.

Table 7. List the orders of the generations of the house "B172"

Input Data	**Output Data** *(The found result is the ancestral house of the house having the code "B172".)*	
"B172" *(In generation 6)*	Ancestral generation $5_{(5th\ generation)}$	B171
	Ancestral generation $4_{(4th\ generation)}$	B169
	Ancestral generation $3_{(3rd\ generation)}$	B165, B166, B167
	Ancestral generation $2_{(2nd\ generation)}$	B161, B162, B163
	Ancestral generation $1_{(1st\ generation)}$	B1, B2, B3, B4, B5, B6, B7, B8

Table 8. List the orders of the generations of the house "B8"

Input Data	**Output Data** *(The found result is the descendant house of the house having the code "B8")*	
"B8" *(In generation 1)*	Descendants of generation $2_{(2nd\ generation)}$	B163
	Descendants of generation $3_{(3rd\ generation)}$	B167, B168
	Descendants of generation $4_{(4th\ generation)}$	B170
	Descendants of generation $5_{(5th\ generation)}$	B171
	Descendants of generation $6_{(6th\ generation)}$	B172, B173, B170
	Descendants of generation $7_{(7th\ generation)}$	B174

3.5 Designing Algorithms Find Ancestors and Descendants (ASA and DSA)

- **ASA (Ancestors Search Algorithm)**

Create the tblAncestors table to contain ancestors

Global declaration: i=0, j=0, gcount=0, arrAncestors, arrParDirect, arrParAll

Input : bodychild

Output : arrAncestors

```
Function AncestorsSearch (bodychild) return arrAncestors
Is
        cstop Exception;
        Cursor nCur(parameters are bodychild) is query ancestorbody;
Begin
        Open nCur(bodychild);
        Get the ancestral body of some generation from nCur;
        While nCur data discovery
        Loop
              arrParAll(i):= bodyparent;
              arrParDirect(j):= bodyparent;
              Increase the index i of the arrParAll array to one unit;
              Increase the index j of the arrParDirect array to one unit;
              Get the ancestral body of some generation from nCur;
        End loop;
        Count the gcount generation to one unit;
        If discovered out of data arrParDirect Then
              raise cstop;
        End if;
        for direct in 1..arrParDirect
        Loop
              tblAncestors ⇦ arrParDirect(direct);
              return AncestorsSearch(bodychild);
        End loop;
        return arrParDirect;
        Exception when cstop then
              return arrParAll;
End function;
```

- **DSA (Descendants Search Algorithm)**

Create the tblDescendants table to contain descendants

Global declaration: i=0, j=0, gcount=0, arrDescendants, arrChildDirect, arrChildAll

Input : bodyparent

Output : arrDescendants

```
Function DescendantsSearch(bodyparent) return arrDescendants
Is
    cstop Exception;
    Cursor nCur(parameters are body parents) Is query descendantsbody;
Begin
    Open nCur(bodyparent);
    Get the the descendant of some generation from nCur;
    While nCur data discovery
    Loop
            arrChildAll(i):= bodychild;
            arrChildDirect(j):= bodychild;
            Increase the index i of the arrChildAll array to one unit;
            Increase the index j of the arrChildDirect array to one unit;
            Get the descendant body of some generation from nCur;
    End loop;
    Count the gcount generation to one unit;
    If discovered out of data arrChildDirect Then
                    Raise cstop;
    End if;
    For direct In 1..arrChildDirect
    Loop
                    tblDescendants ⇦ arrChildDirect(direct);
                    return DescendantsSearch(bodyparent);
    End loop;
    return arrChildDirect;
        Exception when cstop then
                    return arrChildAll;
End function;
```

4 Experiment

In this section, we perform installation the STSDM in Oracle 11G and combine with C# programming language [24–26] to represent the spatial change history of the 2D, 2.5D and 3D spatial objects in 3D geographical space through the use of queries and the two ancestral and descendant search algorithms presented above (ASA and DSA). Empirical results show this STSDM is capable of answering questions related to the topic of managing the evolutionary history of spatial objects in 3D geographical space. The queries require the user to provide input parameters, output parameters are the results of the spatial evolutionary history and the semantics of spatial objects. Here are some empirical results obtained from the execution of queries and two algorithms for finding ancestors and descendants.

4.1 Query Spatial Evolutionary History Over Time and Semantics of Object 2-2.5D

Experiment 1: Apply to query 1 above to find and display the spatial evolution history of the bridge construction process "Phu My" at given intervals and semantics. We get the result shown in Fig. 8, 9, 10 and 11.

- **Input:** The bridge "Phu My" and the periods [Sep 2, 2005 $\in T_1$ – Dec 08, 2005 $\in T_2$]; [Dec 30, 2006 $\in T_1$ - May 01, 2008 $\in T_2$]; [Dec 30, 2007 $\in T_1$ - Feb 2, 2009 $\in T_2$]; [Sep 02, 2005 $\in T_1$- Sep 02, 2009 $\in T_2$] and is the type of $\in ET_s$.
- **Output:** Image of bridge and semantic description of the bridge.

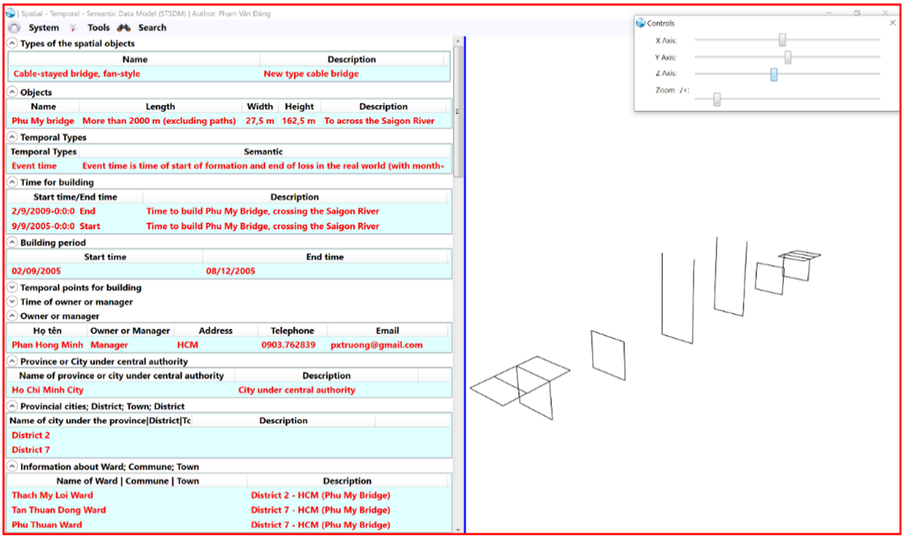

Fig. 8. Display semantics and image of bridge with construction time [Sep 2, 2005 $\in T_1$ – Dec 8, 2005 $\in T_2$] $\in ET_s$.

.

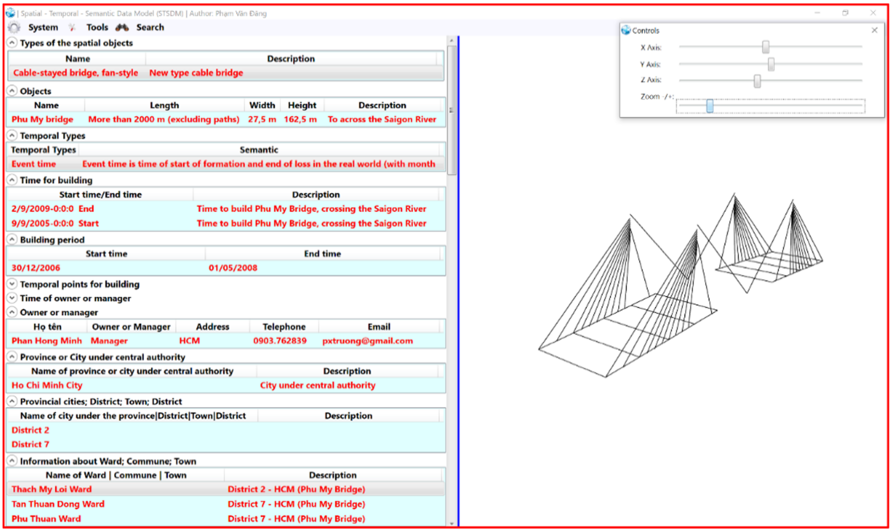

Fig. 9. Display semantics and image of bridge with construction time [Dec 30, 2006 $\in T_1$ - May 01, 2008 $\in T_2$] $\in ET_s$.

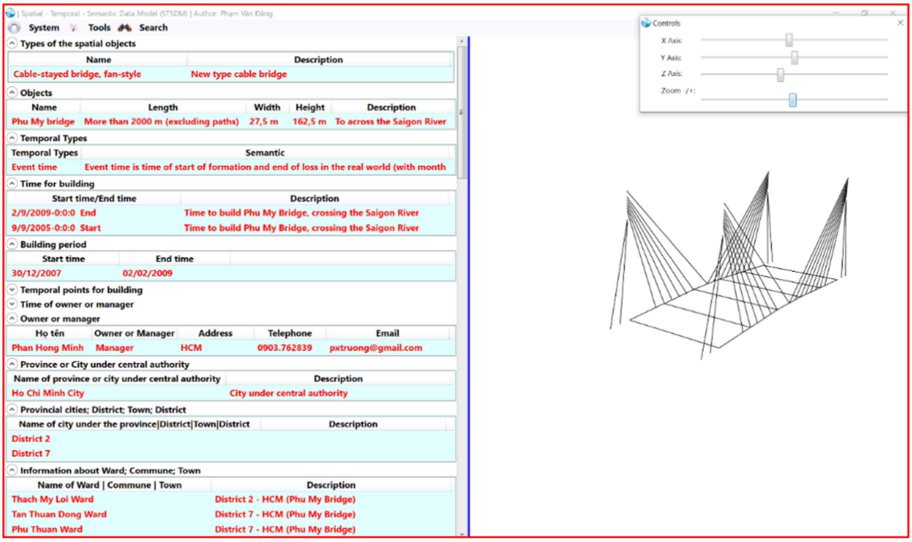

Fig. 10. Display semantics and image of bridge with construction time [Dec 30, 2007 $\in T_1$ – Feb 2, 2009 $\in T_2$] $\in ET_s$.

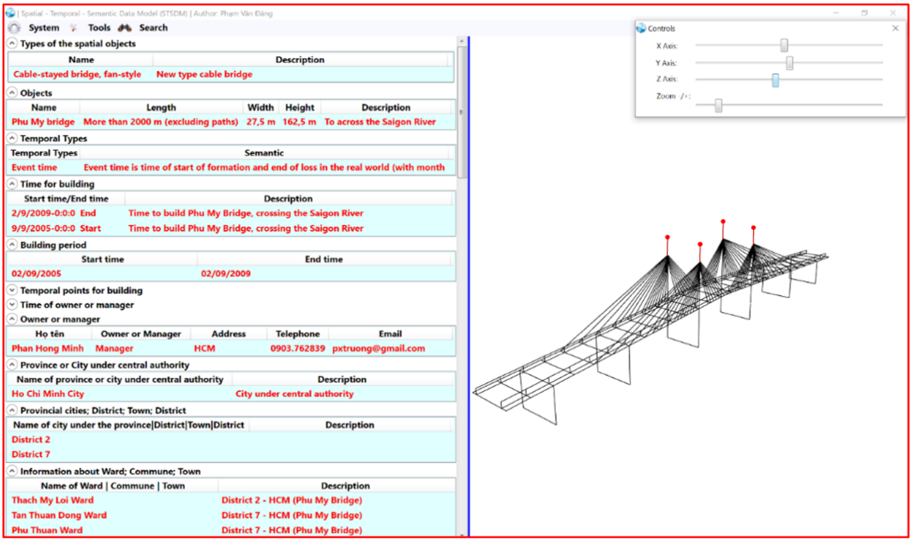

Fig. 11. Display semantics and image of bridge with construction time [Sep 2, 2005 ∈ T_1 – Sep 2, 2009 ∈ T_2] ∈ ET_s.

4.2 Query Space Over Time and Semantics of 3D Objects

Experiment 2: Apply to query 2 above to find and display houses owned by Ms. Pham Thao Nguyen in the period of time and is the type of given legal time. We get the result shown in Fig. 12.

- **Input:** Ms. Pham Thao Nguyen and the period of time [Sep 08, 1998 ∈ T_3 – June 12, 2012 ∈ T_4] and is the type of LT_s.
- **Output:** Images of houses and semantics describing houses owned by Ms. Pham Thao Nguyen.

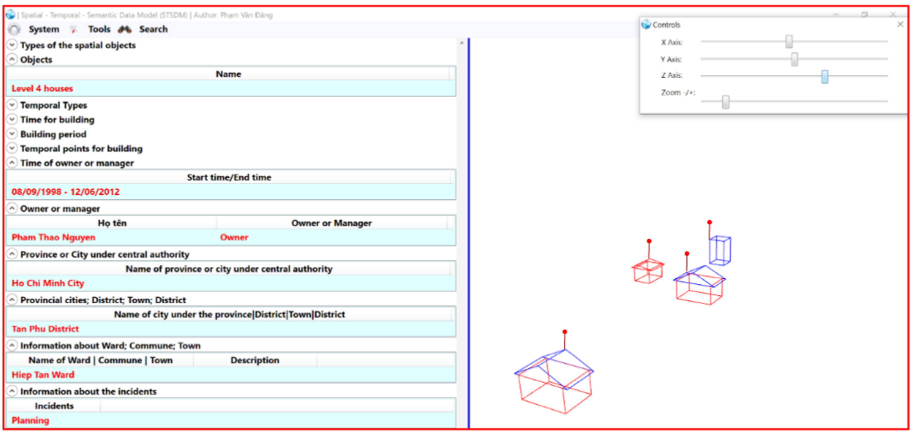

Fig. 12. The houses were owned by Ms. Pham Thao Nguyen in the period of time [Sep 08, 1998 ∈ T_3 - June 12, 2012 ∈ T_4]. ∈ LT_s

Experiment 3: Apply to query 3 above to find and display the space of houses by event, period of time and is the type of database time. We get the result shown in Fig. 13 and 14.

- **Input:** Types of events such as (Storm, [Sep 08, 1998 $\in T_8$ - June 12, 2012 $\in T_9$]) or ([Landslide, Sep 08, 1998 $\in T_8$ - June 12, 2012 $\in T_9$]) $\in DT_s$.
- **Output:** Houses images and semantics describing houses after events occurred.

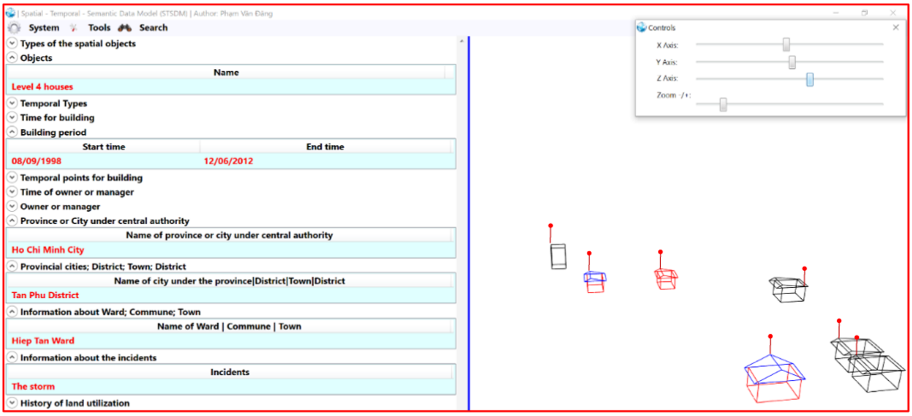

Fig. 13. Incident due to the storm and the period of time [Sep 08, 1998 $\in T_8$ – June 12, 2012 $\in T_9$] $\in DT_s$

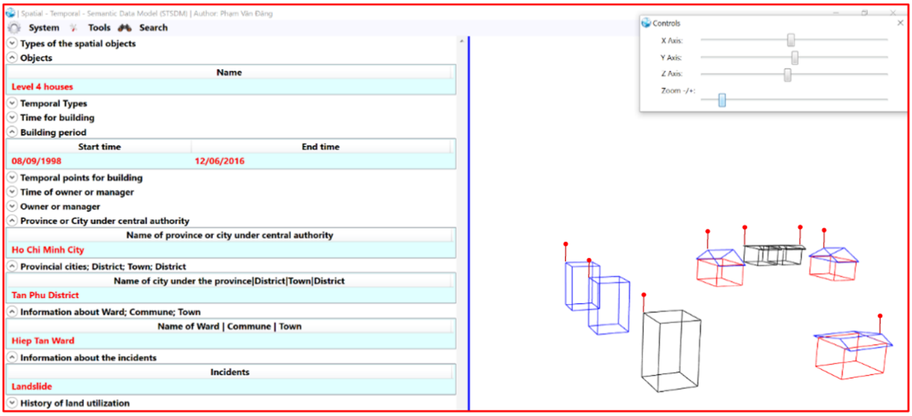

Fig. 14. Incident due to the Landslide and the period of time [Sep 08, 1998 $\in T_8$ – June 12, 2012 $\in T_9$] $\in DT_s$

4.3 Query Each Generation of Descendant Houses of a Father House

Experiment 4: Apply to query 9 above to find each generation of descendant houses of father house with code "B8". We have the results of finding generations of descendant houses of father house in Fig. 15 and Fig. 16.

- **Input:** the house with code "B8"
- **Output:** Images of descendant houses of a father house with code "B8"

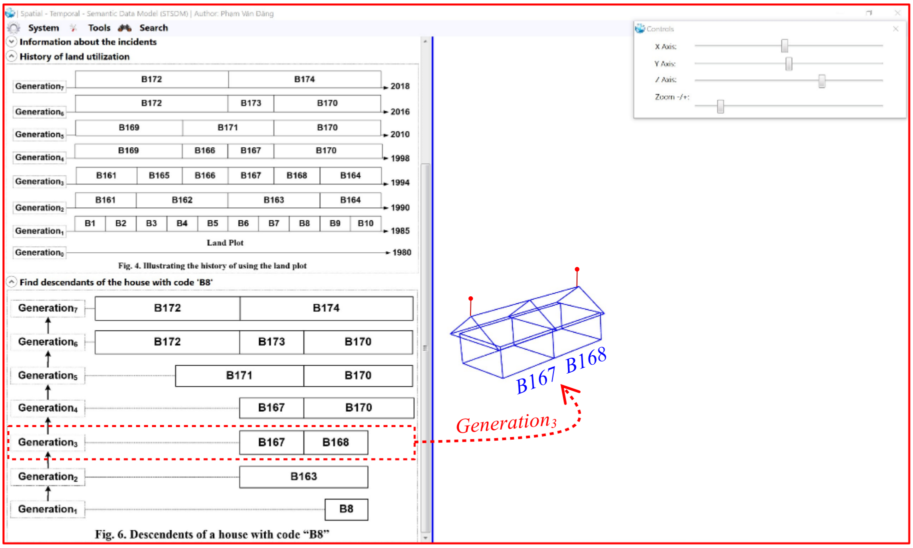

Fig. 15. There are two houses B167 and B168 just found in generation 3.

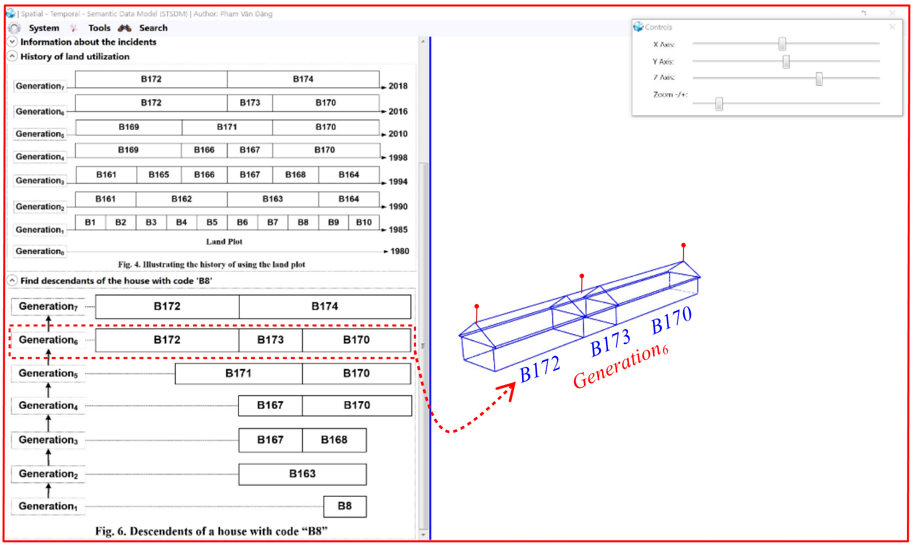

Fig. 16. There are three houses B172, B173 and B170 just found in generation 6.

5 Conclusion

This paper has systematized and analyzed in detail the spatial and temporal data models proposed by the authors over the years and the paper made new comments and proposals. The paper presents the necessity of three spatial, temporal and semantic classes to cater to construction works management in new urban areas and describe in detail how to incorporate these three new classes into construction works management to implement the construction of spatial - temporal - semantic spatial data model and this new model is called STSDM. STSDM is capable of managing spatial evolutionary history of 2D, 2.5D and 3D spatial objects, capable of spatial queries over time and semantics, capable of spatial queries over time, capable of semantic queries, and capable of finding ancestors and descendants of space objects. The above experimental results show that it is possible to apply the capabilities of the STSDM in managing the spatial evolutionary history of construction works in new urban management in the future. In addition, this STSDM is capable of managing various and rich objects in terms of colors, shapes, dimensional numbers and more diversified semantic integration.

References

1. Andrienko, N., Andrienko, G.: Spatio-temporal visual analytics: a vision for 2020s. J. Spat. Inf. Sci. **2020**(20), 87–95 (2020)
2. Ott, T., Swiaczny, F.: Time-Integrative GIS. Springer, Heidelberg (2001). https://doi.org/10.1007/978-3-642-56747-6. p. 234
3. Peuquet, D.J.: It's about time: a conceptual framework for the representation of temporal dynamics in geographic information systems. Ann. Assoc. Am. Geogr. **84**(3), 441–461 (1994)
4. Coors, V.: 3D-GIS in networking environments. Comput. Environ. Urban Syst. **27**(4), 345–357 (2003)
5. Ding, Y., Jiang, N., Yu, Z., Ma, B., Shi, G., Wu, C.: Extrusion approach based on non-overlapping footprints (EABNOF) for the construction of geometric models and topologies in 3D cadasters. ISPRS Int. J. Geo-Inf. **6**(8), 232 (2017)
6. Anh, N.G.T., Tran, V.P., Huynh, K.D.: A study on 4D GIS spatio-temporal data model. In: Proceedings of IEEE 4th Conference on Knowledge and Systems Engineering, Danang, Vietnam, IEEE Computer Society Order Number P4670 (2012)
7. Dang, P.V., Phuoc, T.V., Phuoc Tuyen, H.N.: Visual representation of geographic objects in 3D space at levels of different details. Presented at the FAIR - Fundamental and Applied Information Technology (2017)
8. Gröger, G., Kolbe, T.H., Czerwinski, A., Nagel, C.: City Geography Markup Language (CityGML) Encoding Standard. Open Geospatial Consortium Inc., Wayland (2007)
9. Kolbe, T.H.: Representing and exchanging 3D city models with CityGML. In: Lee, J., Zlatanova, S. (eds.) 3D Geo-Information Sciences. LNGC, pp. 15–31. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-540-87395-2_2
10. Biljecki, F., Ledoux, H., Stoter, J.: An improved LOD specification for 3D building models. Comput. Environ. Urban Syst. **59**, 25–37 (2016)

11. Van Pham, D., Tuan Anh, N.G., Vinh, P.T.: Levels of detail for surface in urban data model. In: International Conference on Future Information Technology – ICFIT, pp. 460–464 (2011)
12. Tuan Anh, N.G., Vinh, P.T., Vu, T.P., Van Pham, D., Sy, A.T.: Representing multiple levels for objects in three-dimensional GIS model. Presented at the The 13th International Conference on Information Integration and Web-based Applications & Service (iiWAS2011) (2011)
13. Löwner, M.O., Gröger, G., Benner, J., Biljecki, F., Nagel, C.: Proposal for a new LOD and multi-representation concept for CITYGML. ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. **IV-2/W1**, 3–12 (2016)
14. Ates Aydar, S., Stoter, J., Ledoux, H., Demir Ozbek, E., Yomralioglu, T.: Establishing a national 3D geo-data model for building data compliant to CITYGML: case of Turkey. ISPRS Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **XLI-B2**, 79–86 (2016)
15. Van Pham, D., Vinh Tran, P.: Visually analyzing evolution of geographic objects at different levels of details over time. In: Cong Vinh, P., Alagar, V. (eds.) ICCASA/ICTCC 2018. LNICSSITE, vol. 266, pp. 98–115. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-06152-4_9
16. Swanson, J.: The Three Dimensional Visualization and Analysis of Geographic Data, 24 March 2020. http://maps.unomaha.edu/Peterson/gis/Final_Projects/1996/Swanson/GIS_Paper.html
17. Lieberwirth, U.: 3D GIS voxel-based model building in archaeology. In: Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Berlin (2007)
18. Abdul-Rahman, A., Pilouk, M.: Spatial Data Modelling for 3D GIS. Springer, Heidelberg (2008). https://doi.org/10.1007/978-3-540-74167-1
19. Rahman, A.A.: Developing three-dimensional topological model for 3D GIS. Project report, UTM (2005)
20. Gröger, M.R.G., Plümer, L.: Representation of a 3D city model in spatial object-relational databases. In: XXth ISPRS Congress, Geo-Imagery Bridgeing Continents, Commission 4 (2004)
21. Gia, T.A.N., Tran, P.V., Khac, D.H.: Overview of three and four-dimensional gis data models. In: Park, J.J.(Jong Hyuk), Ng, J.K.-Y., Jeong, H.Y., Waluyo, B. (eds.) MUE 2013. LNEE, vol. 240, pp. 1013–1020. Springer, Dordrecht (2013). https://doi.org/10.1007/978-94-007-6738-6_125
22. Nguyen Gia, T.A., Dao, M.S., Mai Van, C.: A comparative survey of 3D GIS models. Presented at the 2017 4th NAFOSTED Conference on Information and Computer Science (2017)
23. Dang, P.V., Phuoc, T.V.: Developing TPS data model in 3D GIS for management the population data. Presented at the The 9th National Conference on Fundamental and Applied IT Research (2016)
24. Xuesong, W.: A Tool for Visualizing 3D Geometry Models (Part 1), 11 October 2009. https://www.codeproject.com/Articles/42992/A-Tool-for-Visualizing-3D-Geometry-Models-Part-1. Accessed Feb 2020
25. Greener, S.: SpatialDB Advisor: Elem_Info_Array Processing: An alternative to SDO_UTIL.GetNumRings and querying SDO_ELEM_INFO itself. http://www.spatialdbadvisor.com/oracle_spatial_tips_tricks/89/sdo_utilget_numrings-an-alternative. Accessed Dec 2019
26. Oracle Spatial User's Guide and Reference, Release 9, Part Number A88805-01, June 2001. https://docs.oracle.com/cd/A91202_01/901_doc/appdev.901/a88805/sdo_uglb.htm. Accessed Jan 2020