INCORPORATING 3D SPATIAL OPERATOR WITH BUILDING INFORMATION MODELS IN CONSTRUCTION MANAGEMENT USING GEO-DBMS

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ABSTRACT:

With the advances in the field of information technologies, construction industry has started taking advantages some of these developments. GIS is the tool used to manage construction projects and can improve the construction planning and design efficiency by integrating locational and thematic information in a single environment. This paper discusses the potentials of using 3D-GIS spatial operator tools, e.g. 3D intersection & 3D difference in managing construction project activities. It applies the polygonal edge-clipping method for simple object intersection in Geo-DBMS environment. This method extends the problem of point-in-3D polygon in solving spatial operation that has been commonly used in GIS. It has been recognized that 3D union and 3D intersections are among important spatial operators in 3D-GIS. The developed analytical operations have been tested using UTM 3D building model. SQL query has been coded into the program to update automatically building information model (BIM) semantics into Geo-DBMS. Finally, the paper provides outlook to the proposed work towards the development of advanced analytical solutions in 3D-GIS domain.

1. INTRODUCTION

Geographic Information Systems (GIS) is an appropriate technology for managing construction projects and can improve the construction planning and design efficiency by integrating locational and thematic information in a single environment. It provides capabilities to solve problems, involving creation and management of data, integration of information, visualization and cost estimation to which most of the construction management software is lacking. In construction management, GIS leads to the improvement in collective decision-making among planners, designers and contractors (Bansal and Pal, 2005). The complexity and the huge amount of the information in the building design and construction project require an efficient system that may help in integrating various types of data and provide the required information and data timely that will finally support various decision and construction operations. The information required for planning and design are stored in different form, such as drawing, specifications, and bar charts. In planning process, the planner has to continually interpret and structured the information collected from various resources which is tedious and prone to errors (Cheng and Yang 2001). High level of efficiency in construction management is crucial in construction industry. A large number of data involve in planning and design phases of construction projects are usually stored in various forms such as drawings, tables, and charts. These data need to be sorted out properly to ensure it can be retrieved and manipulated by related parties when needed.

Database in GIS environment can provide a wide range of information to construction industry with a mechanism for rapid retrieval and manipulation capabilities. Integration of schedule and design information makes it easier for the project manager to monitor and control the construction progress. Several tools for construction industry using GIS as suggested in many literatures and their applicability has been demonstrated with suitable case study (see Section 2). However, the practical usefulness of these developed tools in construction industry is still doubtful and the implementation on real world project in the industry is rare. Further, most of the reported works uses different software in combination with GIS software. Although, CAD technologies provide visualization capabilities, but three dimensional (3D) GIS technologies could not only provide advance visualization techniques (e.g. fly-through with query-on-demand and way-finding) but also stores geometry's topological information and being able to perform true 3D analysis, which is not yet possible in CAD technologies.

This paper discusses the potentials of using 3D-GIS spatial operator tools, e.g. 3D intersection & 3D difference in managing construction project activities (for cost estimation calculation). Therefore the following questions arise: Are there any new changes (such as missing structure or overlaps or unintended protrusions) in building structural design between approved drawing and actual constructed building? What are their quantity and volume takeoffs? In cut-and-fill situation, where can this volume of land excavation works being filled? Furthermore, by using SQL queries, it also capable of supporting the necessary semantic queries related to the spatial hierarchies of the building elements, e.g. a query to find the windows within a specific wall. And be used as an import and export tool for providing and storing BIM information in semantic building model, e.g. info on building's storey: column part, beam part, slab part, wall part, floor plan part, building name, year of construction, and etc. These data is important in describing the building structural design and material used and can be useful for city planners and building designers which helps in the decision making process.

The paper is organized in the following order: first, an overview of construction management using GIS in general. Section 2 discussed on the needs of 3D-GIS for construction management and highlights some contribution of what 3D-GIS can be useful in managing construction. In section 3 we present the methodology used to acquire, store and reconstruct the 3D model of construction building (before and after) and introduction to 3D polygonal edge-clipping function that will be used to create new 3D intersection and 3D difference for 3D spatial operator. Then, the implementation of geo-DBMS approach for the 3D analytical analysis in managing construction and automatic updating BIM's information into the database will be discussed in Section 4. The experiment and discussions are presented in Section 5 and the research is concluded with some future work and remarks in Section 6.

2. WHY 3D-GIS IN CONSTRUCTION MANAGEMENT

To-date, two dimensional (2D) GIS is still being utilized in various engineering projects especially in managing construction industry (Bansal and Pal, 2005) but its complete potential to expand into another dimension, the 3D-GIS for better data manipulation, analysis and visualization using 3D data sets has not been realized yet. 3D-GIS, known as an ideal tool for representing 3D geometry, semantic as well as topology, has been gradually utilized in many disciplines. 3D-GIS provide several benefits to the construction industry, in which most of the construction management software are lacking. It may improve the construction planning and design efficiency by the integration of 3D spatial and attribute information in single environment.

Several researches had been carried out on utilizing GIS in construction management. Bansal (2005) carried out a research to investigate the usability of GIS in construction industry where the author combined the construction schedule of different construction activities (in bar chart form) with the 2.5D visualization of the building using ArcView 3.2. This is to overcome some limitations in conventional construction management tools where no tools have the capabilities to represent information in the simulated construction process despite their capabilities in optimizing construction sequences and establishing project plans. This enables project managers to retrieve the construction schedule as well as visualizing the design information in 3D in order to effectively monitor and control the construction progress.

In a more elaborate research, Bansal and Pal (2006a) extend their development of previous information system (Bansal, 2005) in ArcView to investigate the possibility of using GIS functionality to replace the manual methods to extract the information from the database for data manipulation in rate analysis. Their research focused on the GIS database development to overcome the limitation in construction management where most of the data required in construction projects are stored in a stand-alone system thus, integrating all data in one system will enable the data from various sources to be manipulated for analysis and increase the efficiency in managing the construction project. Again, Bansal and Pal (2007) introduced a method for calculating building cost estimation to various tasks related to construction materials, labours, and equipments. The implemented method stores descriptive data of different task and relates these data to the corresponding spatial feature in different themes using ArcView 3.2. It then uses the ESRI's 3D analyst tool for visualization of the buildings. These few mentioned researches are still implemented in 2D GIS where current GIS applications, which use true 3D functionalities other than 3D visualizations, do hardly exist. Despite the less difficulty in database development (in 2D GIS) for construction management, the current 2D GIS data structure itself has a limitation, due to how it is organized in a dual architecture structure.

Traditional 2D GIS store its data in a dual architecture structure in which a GIS consists of separated data management for attributes on the one hand and spatial data on the other hand (Stoter and Zlatanova, 2003). Even though the authors suggested to implement an extensible DBMS with spatial to support the use of Geo-DBMS for 3D application, the GIS and DBMS vendors are still not matured towards full support for 3D.

As far as construction management and 3D-GIS aspect is concerned, few researches related with it have been done. Simulation process has proved to be an effective tool for planning and improving the performance of a construction process in many successful case studies Zhong, Li, Zhu, and Song (2004). However, these tools lack the capability to represent explicit information involved in the simulated construction process. To overcome these limitations, the authors suggested that 3D spatial data need to be used to represent elements that have physical dimensions in 3D-GIS. By considering time as an attribute of the 3D spatial model, it can depict the simulated operations dynamically in a 3D environment as being carried out in the same way as they would be in the real world. This process of visualization can help to detect performance inconsistencies and obtain insight into the simulated construction operations. Isikdag et.al (2008) investigated that BIM is capable of re-storing both geometric and semantic information in the building-design field for geospatial environment and proposed an automation of data management tasks in site selection and fire response management processes. Recent studies demonstrated that it is possible to transfer 3D geometric and semantic information from BIM into a 3D-GIS environment (Isikdag, 2006). BIM is an emerging technology to manage the essential building design and project data in digital format throughout the building life-cycle. Later in 2009, Ivin et.al has developed and implemented two 3D spatial analysis tools; 3D navigation and 3D buffering within Geo-DBMS environment for disaster management. Although this research is not related to construction management, but the method of applying such 3D spatial operator in Geo-DBMS is possible and looks promising. Bansal (2010), has addressed the integration of 3D models and BIM to create the simulation of construction process by linking execution schedule with the 3D model in support of construction safety planning. It was executed by developing a safety database from which safety information are retrieved and linked with the activities of the schedule and the components of a building model.

In general, managing construction is quite demanding and needs rapid spatial information on the spot even using the conventional 2D GIS. It would be great if a construction project is managed by decision makers using 3D-GIS where the required information is in the form of 3D display of a dynamic 3D spatial query and analysis. Therefore in this paper, two 3D spatial operator tools; 3D intersection and 3D difference are focused and carried out to assess the applicability of implementing it in construction management context and also to investigate whether it can benefit from such an implementation.

3. THE METHODOLOGY

In this paper, the following management task will be solved using the proposed 3D spatial operator: Are there any new changes (such as missing structure or overlaps or unintended protrusions) in building structural design between approved drawing and actual constructed building? What are their quantity and volume takeoffs? To answer this question, a spatial comparison will be made between a complete constructed building (as-built) object with a 3D model regenerated from architecture plan of a construction building using Geo-DBMS environment. The returned results are the quantities and volumes of each intersected objects. In this section, the methodology of each steps and the algorithm used for 3D spatial operator are described.

3.1 Data Acquisition and Processing

In the study, one of the new student's residential building (building name: XA2) in the university campus was used. The data consist of the building's 2D floor and elevation plan in AutoCAD format (*.dwg) and obtained from the Asset Management Office, UTM. It provide all the details of the building, such as the width, location of the windows, height information and etc. from level 1 to level 8 and the roof top (see Figure 1 and 2).
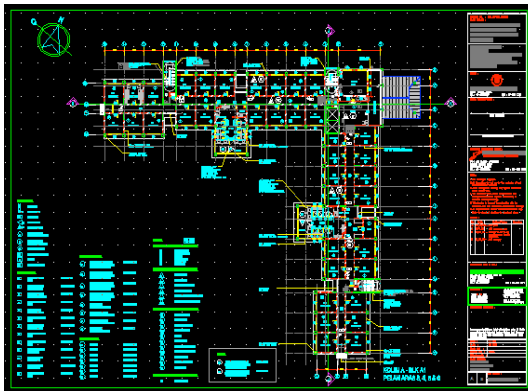

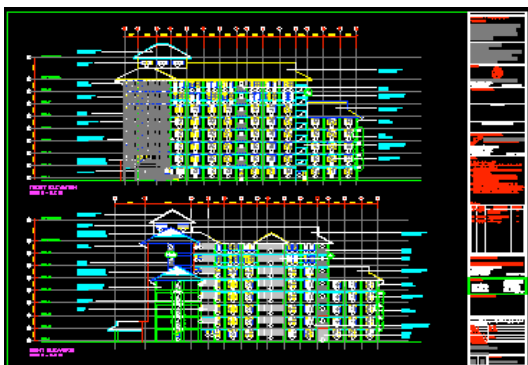Fig. 1. Detail for each floor plan of XA2 building.

Fig. 2. The building elevation plan (front and left side view).

Since the existing 2D drawing provides much information, an editing work has to be carried out to eliminate the unwanted information (see Figure 3). In order to regenerate 3D building model based on architecture drawings, coordinates and other information related to each and every building objects such as beams, windows, doors, stairs, and foot-print (corners of the floor plan) are stored in Geo-DBMS. Whilst another 3D model

(of the same building) is reconstructed using as-built drawings from survey works after construction has finished. A program is developed using Visual Basic 6 to read these coordinates and output them as a VRML file (in *.wrl format) for visualization of the 3D building model (see Figure 4).
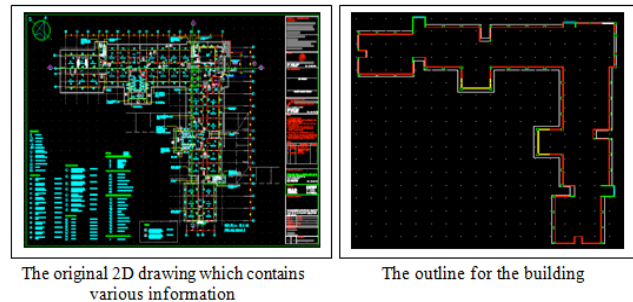
The original 2D drawing which contains various information

The outline for the building

Fig. 3. Editing work in AutoCAD. (Left) Shows the original 2D drawing which contains various information. (Right) After editing, it only shows the foot print of the floor plan.
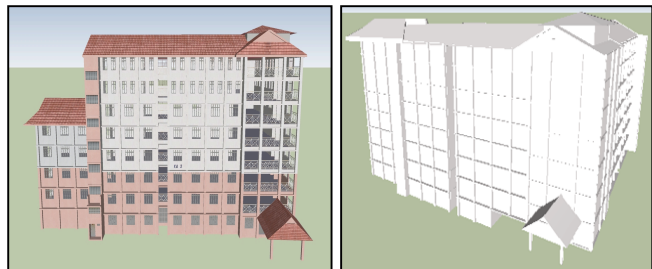
(a)   (b)

Fig. 4. (a) 3D model for building XA2 regenerated from architecture drawings. (b) 3D building reconstructed based on as-built drawing from survey works.

3.2 Polygonal Edge-Clipping Function

In this paper, we concentrated on simple but complete strategy in extending the point-in-polygon method for 3D Euclidean space using polygonal edge-clipping function by Chen et. al (2009) in Geo-DBMS environment. It is an improved method by Chen & Abdul-Rahman (2006) and again by Chen et. al (2007b). The algorithm will fully cover the third dimension in order to apply in 3D situation.

The polygonal edge-clipping function is to provide a simple method for object intersection within the 3D space (see Figure 5). Thus, the geometrical modeling is focused on the polygonal edge-clipping function as follows:

(a) Intersection between two spatial objects (preliminary intersection before splitting the primitives into lower dimensions);

(b) Intersection between line (base object) and polygon (target object);

(c) Point-in-polygon test (in 3D space);

(d) Re-structuring intersection points;

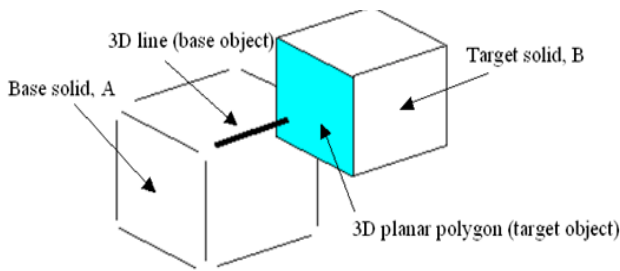(e) Integration of the internal and external segments.

Fig. 5. Intersection between two simple objects.

This entire objects manipulation directly solved multiple spatial operations. They are, 3D Intersection, 3D Difference, 3D Union and 3D XOR which are some popular spatial operations in 3D-GIS, and edge-solid intersection analysis, which is the basic initial classes among these problems. Due to a polyhedron is constructed by polygons, the intersection between 3D line and 3D planar polygon is important in developing the 3D spatial analytical solutions. From this intersection it will divided into two types of objects. There are base and target objects. The base solid implements 3D line as a base object, whereas target solid implements 3D planar polygon as target object. The possible intersection between 3D line and 3D polygon is given in see Figure 6). Detail concept of the function can refer to Chen et. al (2009).
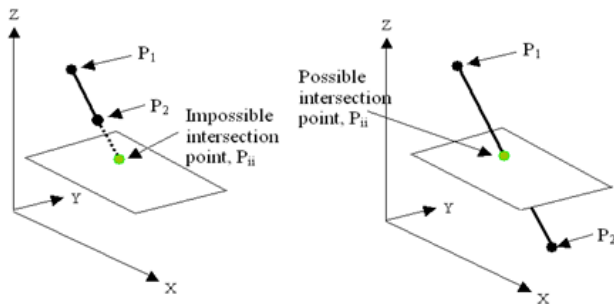

Fig. 6. Intersection between 3D line and 3D planar polygon.

In polygonal edge-clipping function, two solid objects intersect each other as shown in Figure 5. Since a solid object is constructed by a set of faces, and a face is constructed by a series of lines, the intersection that involves 3D line and 3D face is discussed. This is because the intersection result will be used to define internal and external of base object, so as to target object. Each line from base object will be examined for all possible intersections toward the 3D planar polygon from the target object. For most of the cases, each base line may be intersected by many target faces (see Figure 7). Thus, the intersection would produce many intersection points and need to be arranged. The data structure for these intersection points requires special treatment because each intersection point will be linked in a proper manner in order to produce a correct trimmed link. A sorting algorithm will be implemented to arrange this set of intersection points for each base line (see Figure 8).
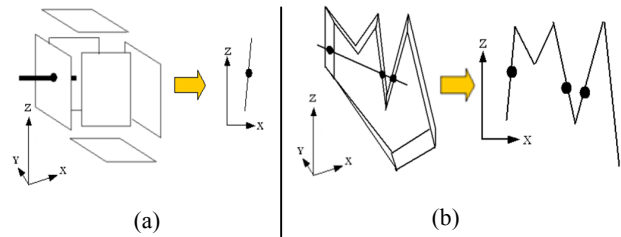

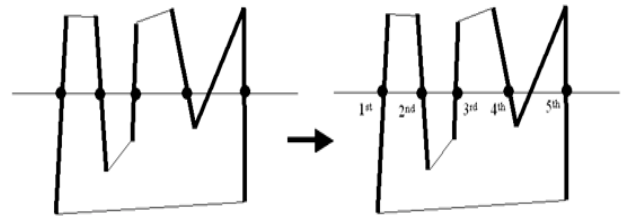Fig. 7. (a) Single intersection point, and (b) Multiple intersection points.

Fig. 8. Arrangement for multiple intersection points.

After all intersection points were computed, the related intersection points will be connected as bridge to form a link and stored temporarily in DBMS. This link denotes as the clipping result between face (from base object) and polygon (from target object). The intersection points shown in Figure 9 are useless if they are not connected in an appropriate manner. The sequence of each link needs special treatment in order to produce a correct bridge for further applications.
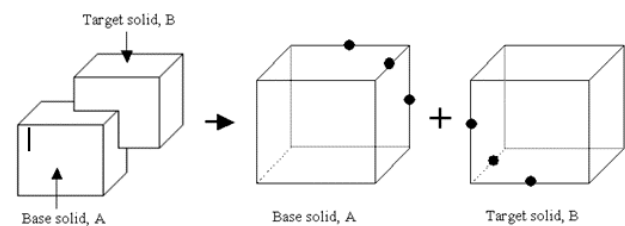

Fig. 9. All intersection points for base and target solid.

The cross-connected faces from the target object will form each link for base object. Figure 10 denotes the target faces intercept the base face. The internal link needs to be defined as a bridge.
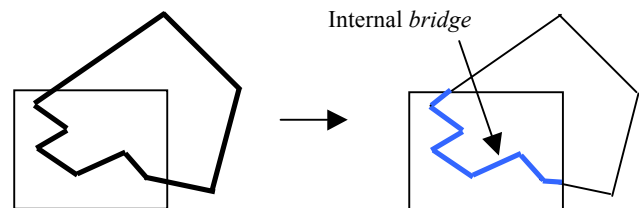

Fig. 10. Cross-connected link (view from top).

The algorithm in performing the link creation begins with the initial intersection point from each base object's line (see Figure 11a). The intersection point will be used to examine the successive intersection point. The initial intersection point will store the information about which face of target solid that intersects base face (see Figure 11b).
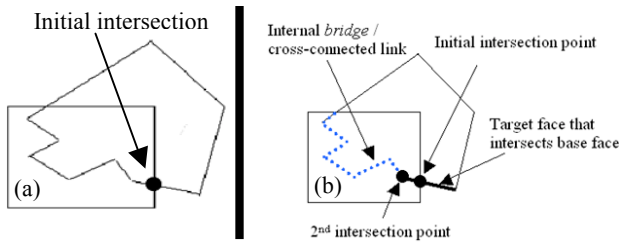
Fig. 11. Initial intersection point (view from top).

The search for next intersection point will be done if the second intersection point still intersects at the internal of base solid the second intersection point, the coordinate values (x_2, y_2, z_2) will be used to search the second target face that intersects at the same location and same base face. After the second target face was found, it will be used to extract the point that intersects base face. The third intersection point will be stored and used to connect to the internal bridge. The processes will be repeated until the search for successive intersection point(s) reaches to the border of base face.

After creating the cross-connected link, it will be used to develop two separated segments, i.e. internal and external for both base and target solid. Therefore, the total of four segments will be produced. Each base polyhedron is constructed by a set of faces. The base faces are used to construct the external segment of base solid, whereas the other internal segment (from the same base faces) will be used for target solid. As the base solid is completely modeled, the target object will be dealt as a base solid, and vice-versa. In certain cases, the base face will be divided into more than two segments. To determine the total external segments from base object, all intersection points must be implemented. The determination starts from the first intersection point of the base face, where its successive point is not the interval point of cross-connected link. As a result, the last points to be connected together with the intersection points are the points from cross-connected link.

After the external segments are defined, the next task is to determine the internal segment(s) of base object. The determination begins with the line that exists inside the target object. This line will be connected to the cross-connected link that is opposite direction with the previous determination of external segments. As a result, the sequence of internal segment is 1, 2, a, b, 3, 4, c, 5, 6, d, e, 7, 8, f, 9, 10, 1 (see Figure 12). The same implementation continues to determine other internal and external segments of each target object (building's objects such as beams, etc.) which are stored in Geo-DBMS.
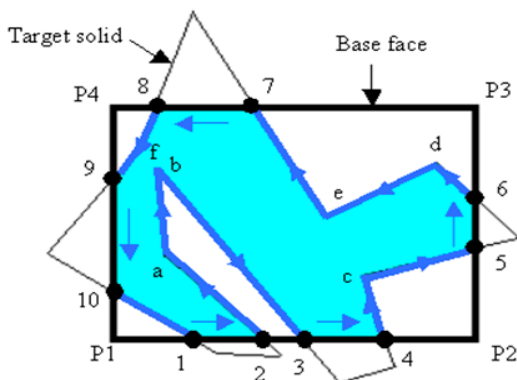

Fig. 12. Internal segment (view from top).

4. THE IMPLEMENTATION

Existing DBMS provides a SQL schema and functions that facilitate the storage, retrieval, update, and query of collections of spatial features. Most of the existing spatial databases support the object-oriented model for representing geometries. The benefits of this model are that it supports for many geometry types, including arcs, circles, and different kinds of compound objects. Therefore, geometries could be modeled in a single row and single column. The model also able to create and maintain indexes, and later on, perform spatial queries efficiently. In the next section, some commercial spatial database will be discussed, in term of their characteristics, capabilities and limitations in handling multi-dimensional datasets.

4.1 Modeling 3D Object using Multipolygon

In the Oracle Spatial object-relational model, a 3D solid object from 3D primitive is possible, e.g. polyhedron. However, the study selected multipolygon to construct a 3D spatial object within geo-DBMS environment. This is due to two reasons: (i) the implementation of polyhedron from Oracle Spatial 11g could yield additional data structure for spatial object. The data structure of polyhedron define 3D object as a macro in the first place, e.g. POLYHEDRON {}. Then, each of the faces will be defined within the macro of polyhedron, e.g. POLYHEDRON {(Face1), (Face2), (Face3)…}. Finally, the vertices that construct each of the faces will be inserted within the data structure of faces. Comparing the multipolygon, the data structure that involves macro and micro will not be used. The implementation of multipolygon could yield a simple data structure that defines a 3D spatial object. (ii) Taking the advantage of 3D visualization, the study integrates with 3D display tool that support up-to multipolygon for 3D spatial objects. It could be done by implementing the multipolygon that bound a solid. The geometric description of a spatial object is stored in a single row and in a single column of object type SDO_GEOMETRY in a user-defined table. Any tables that have a column of type SDO_GEOMETRY must have another column, or set of columns, that defines a unique primary key for that table.

An example implementing 3D Multipolygon (where the geometry can have multiple, disjoint polygons in 3D) is given as below:

```
CREATE TABLE Solid3D (
    ID number(11) not null,
    shape mdsys.sdo_geometry not null);

    INSERT INTO Solid3D (ID, shape) VALUES (
    1 SDO_GEOMETRY(3007,
    NULL,
    NULL,
    SDO_ELEM_INFO_ARRAY (
        1, 1003, 1,
        16, 1003, 1,
        31, 1003, 1,
        46, 1003, 1,
        61, 1003, 1,
        76, 1003, 1),
    SDO_ORDINATE_ARRAY (
        4,4,0, 4,0,0, 0,0,0, 0,4,0, 4,4,0,
        4,0,0, 4,4,0, 4,4,4, 4,0,4, 4,0,0,
        4,4,0, 0,4,0, 0,4,4, 4,4,4, 4,4,0,
        0,4,0, 0,0,0, 0,0,4, 0,4,4, 0,4,0,
        0,0,0, 4,0,0, 4,0,4, 0,0,4, 0,0,0,
        0,0,4, 4,0,4, 4,4,4, 0,4,4, 0,0,4
)));
```

The advantage of implementing the multipolygon in DBMS is that the integration between CAD and GIS is possible for 3D visualization, i.e. Oracle (or called Spatial) spatial schema is supported by Bentley MicroStation (2008) and Autodesk Map 3D (2009). This is due to the geometry column provided by Spatial is directly access to the 3D coordinates of the object, which allow the display tools retrieve spatial information from the geometry column. The overall process in managing construction information using Geo-DBMS can be described as shown in Figure 13.
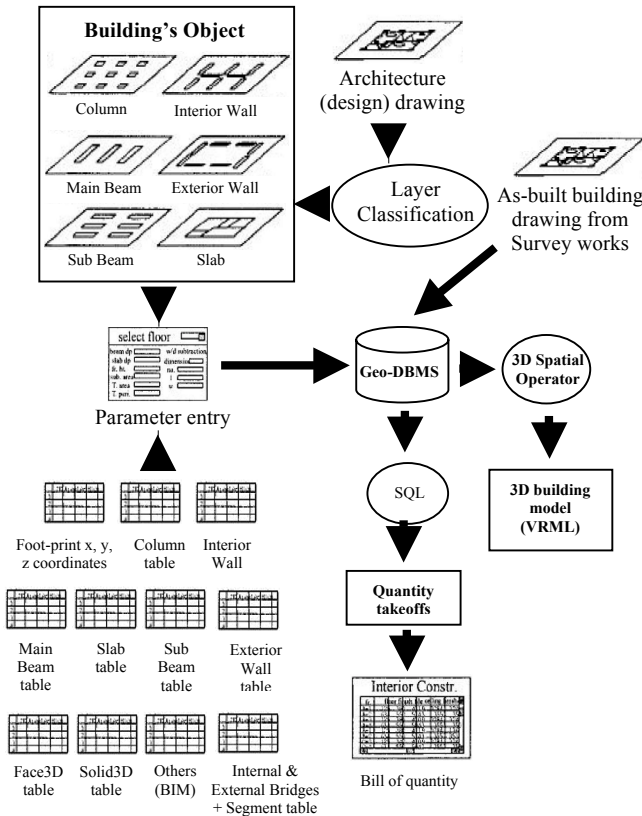

Fig. 13. Process of managing construction information using Geo-DBMS.

4.2 Integration of the Internal and External Segments

The integration of the internal and external of base and target object can be done in solving multiple 3D spatial analytical solutions. The experiment implements new classes within the Geo-DBMS (Oracle) environment to test the approach mentioned in section 3. Figure 14 denotes a sample of intersection objects. The input datasets denote simple polyhedron a, b, and c. The intersections are between (b) and (a), together with (b) and (c).
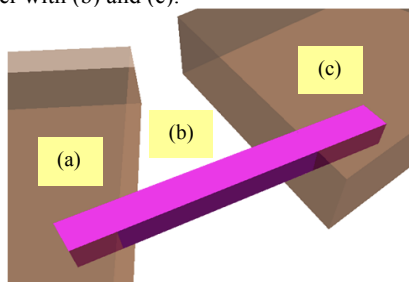

Fig. 14. 3D Intersection between (b) and [(a) & (c)].

The intersection results are given in Figure 15a (Difference), 15b (Intersection), 16a (Union), and 16b (XOR).
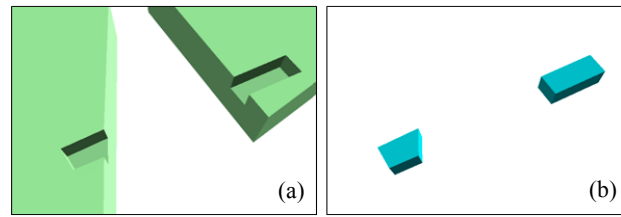

Fig. 15. Intersection result: (a) Difference, and (b) Intersection
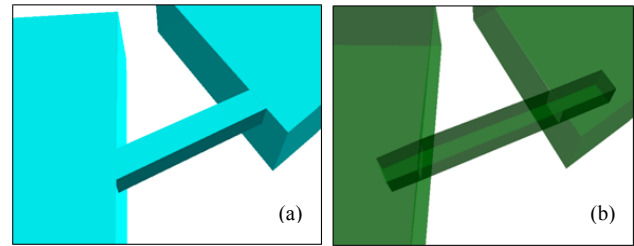

Fig. 16. Intersection result: (a) Union, and (b) XOR

4.3 Updating BIM Information

The most important aspect in construction management is the ability to add/get semantic data to/from the database. Since the implementation was in Geo-DBMS environment, SQL queries can be used as import/export tools based on the completed date of a certain schedule. This can be done automatically by adding the UPDATE SQL statement into the interface program. Once the end user click the update button, the program will execute automatically the SQL statement. Semantic data such as owners, names, year of construction, building function types, wall type, door type, and etc. could be added to the database content. These data can be useful for instance, for city planners and building designers.

```
UPDATE   Building3D_Table   SET  DateCompletion=
Now(),  WallType='A1056' where PID=3215;
```

The result:

```
 PID      DateCompletion            WallType

----------------------------------------

 3215     10/7/2008 11:25:02 AM        A1056
```

5. EXPERIMENT AND DISCUSSIONS

In order to provide a practical solution for the proposed new approach as discussed at previous sections, this section will discuss the current geo-DBMS implementation. The approach started with validation of input data into spatial DBMS. Although the 3D spatial object created for the study implements multipolygon that construct a solid object, some characteristics of 3D object need to be defined in order to create a valid object within geo-DBMS environment. The characteristics of valid object could be found in Aguilera & Ayala (1997); Aguilera (1998). The implementation of such validation within geo-DBMS environment could be found in Chen et al. (2007a); Chen et al. (2007b).

3D visualization is an important phase that helps in presenting the output data. In the study, the building was regenerated in Level-of-Details (LoD) 3 (see Figure 17a) which also stores every detail of the buildings' objects i.e. beams, walls, windows, doors, etc. (see Figure 18). Another 3D model of the same building (XA2) also has been reconstructed using as-built drawing in LoD2 (see Figure 17b).

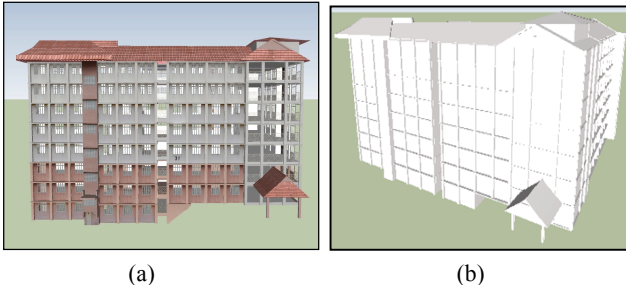(a)   (b)

Fig. 17. (a) The front view of XA2 building (LoD3) in VRML.
(b) As-built 3D model in LoD2

Fig. 18. Detail interior view (LoD4) in VRML

5.1 3D Spatial Operator: 3D Intersection & 3D Difference

Normally, there will be some differences between drawing and actual constructed building such as overlaps or unintended protrusions, because of the changes during field construction. Hence, as-built survey work should be carried out for the necessary building and update the previous drawing in DBMS. By having a 3D model, this issue can be solved, using the proposed 3D spatial operator (3D intersection and 3D difference). For example, Figure 19 shows the differences between existing floor plan (proposed 6 floors) with the actual constructed building (only 5 floors).
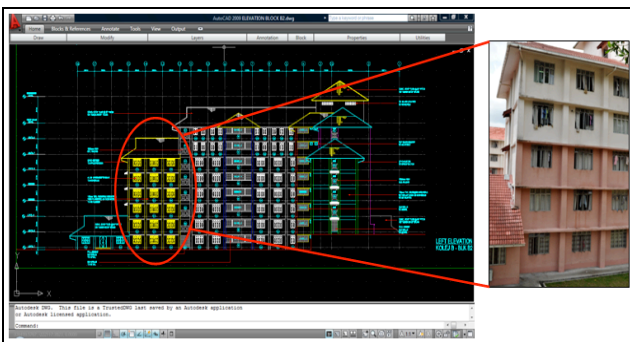

Fig. 19. The differences between architecture drawing and
actual (as-built) constructed building

The following SQL statement denotes the implemented 3D intersection and 3D difference function. For 3D intersection;

```
SELECT FunctionName (Face_1, Face_2, Face_3, Face_n,
BuildingObjectType, BuildingObjectID) FROM
SolidTableName;

SELECT 3D_INTERSECT_Face3D (F033, F034, F052,
F051, F103, F104, BuildObjTyp, BuildObjID) FROM
Building3DSolid_Table;
```

The result:

```
SID BUILDING_ID  BUILDOBJTYP BUILDOBJID AREA
-------------------------------------------------

1    XA2    INT_WALL2   IW087   0.03
2    XA2    INT_WALL2   IW088   0.01
3    XA2    INT_WALL2   IW089   0.025
4    XA2    INT_WALL2   IW090   0.01
5    XA2    INT_WALL3   IW064   0.02
6    XA2    INT_WALL3   IW063   0.02
```

For 3D difference;

```
SELECT FunctionName (Face_1, Face_2, Face_3, Face_n,
BuildingObjectType, BuildingObjectID) FROM
SolidTableName;

SELECT 3D_DIFFERENCE_Face3D (F221, F220, F219,
F218, F231, F232, F233, F240, F241, F238, F239,
BuildObjTyp, BuildObjID) FROM
Building3DSolid_Table;
```

The result:

```
SID   BUILDING_ID    BUILDOBJTYP    BUILDOBJID
---------------------------------------------

1       XA2          EXT_WALL7      EW143
2       XA2          EXT_WALL7      EW144
3       XA2          EXT_WALL7      EW145
4       XA2          EXT_WALL7      EW146
5       XA2          EXT_WALL8      EW142
6       XA2          EXT_WALL8      EW147
7       XA2          ROOF02         RF15
8       XA2          ROOF02         RF16
9       XA2          ROOF02         RF17
10      XA2          ROOF02         RF18
11      XA2          ROOF02         RF19
```

6. CONCLUDING REMARKS

We have implemented an approach for 3D analytical operations for construction management using 3D-GIS approach. The results have shown that the implementation of 3D intersection and 3D difference using 3D data type allowing 3D-GIS analysis practical for such 3D application. Our concept was tested within Oracle Spatial 11g computing environment and has provided a promising outcome with respect to the developed algorithms.

Future research will concentrate on implementing 3D union and 3D XOR for further 3D application. Since the study did not focus on geometry topological while executing the polygonal

edge-clipping function, hopefully next research will try to fill this gap by incorporating it in the algorithm or function and compare it with the results obtained form CGAL or Java 3D API which also contains similar functions (3D intersection and difference).

We believe this research effort towards realizing a fully 3D spatial analysis tools within Geo-DBMS environment would be beneficial to 3D-GIS research community. This is because major GIS task involves geo-DBMS, i.e. dataset handling, analytical operations, etc. It is our aim to move further in addressing this issue of spatial data modeling and geometrical modeling for 3D city model in GIS environment.

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