

# BUILDING SPACE ANALYSIS FOR INTEGRATING DESIGN AND CONSTRUCTION

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*ABSTRACT: One of the important analyses for a building is the space analysis. It can provide details information of the space, i.e. room that has been analysed, including the space boundaries, space separator (including wall, ceiling or floor), total area and volume. Such information are very important where it can be used for other applications such as calculating the heat-loss, designing a lighting system, ventilation system, air-conditioning system, etc. Although, such analysis has been provided by several commercial packages (with some constraints), it still not yet being fully utilised for integrating with other downstream applications such as estimating, planning and site layout planning for further analysis. A study has been done at the University of Salford, UK for integrating design and construction where the building space analysis has also been accommodated in the study, as part of the overall building analysis. All the parameters required for the integration with other applications such as space boundaries, space separator and space functionality have been captured during design application. This paper outlined the study on developing the building space data model and how such concepts have been implemented and developed within the design application (CAD) and the object-oriented environment.*

*KEYWORDS: Building Space, Space Analysis, Integrated Design and Construction*

## 1. INTRODUCTION

The research of integrated environments in the construction industry has been the focus of many researchers around the Globe since early 1980's. Until now, the suitable "antidote" for the problems related to the implementation of such integrated environment have not been found yet. Due to this fact, this research has been motivated to find an approach where the problems, which contributed to the fragmentation in the construction industry, can be reduced/minimised. Although previous studies have aimed towards producing a single integrated model to provide a common environment for all construction applications to interact with each other, some attempts have been directed towards the implementation issue, e.g. OSCON and WISPER. Moreover, the issue of management of information within the integrated environment has not yet been fully addressed. One of the issues in which has been lacked or overlooked by some researchers is the analysis of the building space. Although several models have been developed such as RATAS, COMBINE and IFCs for the building space, most of the models have been developed towards the theoretical issues only without taking into account the implementation issues. This will definitely create a lot of problems especially when trying to integrate with other downstream applications. Therefore, the aim of this paper is to highlight the implementation of the building space theoretical model within the SPACE project model.

Several data models have been developed within the SPACE project model at the University of Salford which aims to integrate the "industry standard" software through one object-oriented knowledge-based system [Faraj & Alshawi, 2000]. CAPE is part of them, which is a



design application, designed to serve all the application modules in the project model. It is divided into two main parts (Figure 1). The first part represents a building element data module and the second part is the Object Interpreter Engine (OIE). The primary aim of the CAPE data module is to facilitate the flow of information from CAD packages to an object-oriented environment where it can be accessed, in a structured manner, by other applications such as construction planning, estimating, site-layout planning and VR. Therefore, in order for such aims to be achieved, the CAPE system architecture has been divided into three main parts; the Graphical Interface for the input, the CAD System and the Object-Oriented Environment. Each of them provides the various important functions for the development of CAPE. The schematic diagram of CAPE system architecture is shown in Figure 1.

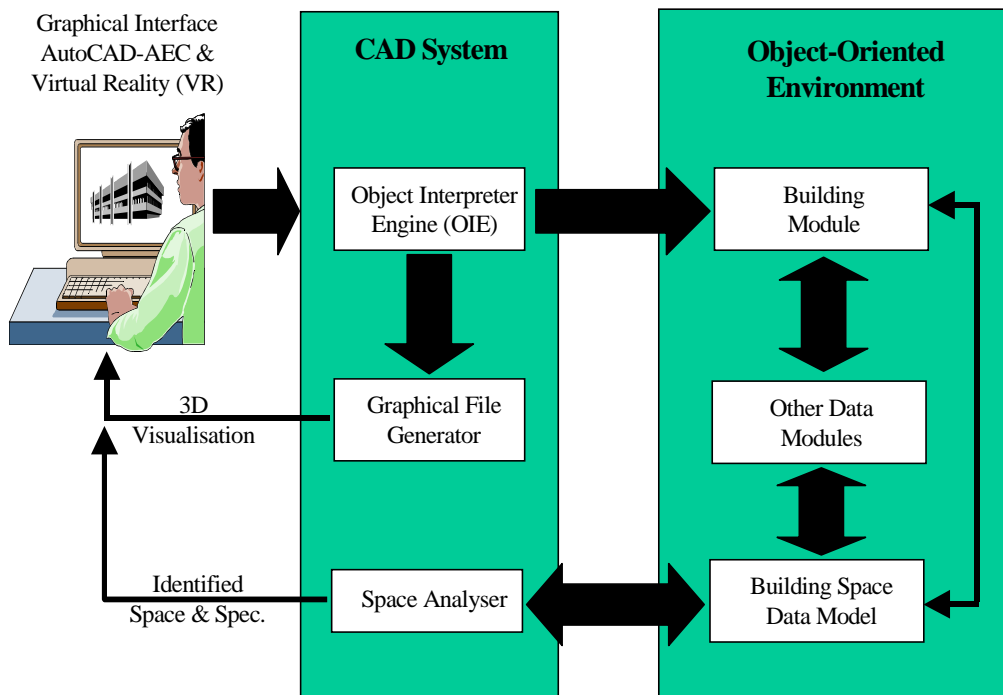


Figure 1. CAPE system's architecture

## 2. BUILDING SPACE DATA MODEL

The main entity of the CAPE data module is the "Buildings" entity. The central entity in the end user's and the architect's view of the building is the space. A space is a volume bounded on all sides by enclosing structures, which forms the physical boundaries of the space [Björk, 1992]. The "Building Space" entity is an important entity for space layout planning which is one of the most interesting and difficult design problems. It also plays an important role in the data model because of its relationship with most of the design systems such as architectural, structural and services. This entity contains two entities (Figure 2). It contains one or many "Floor Space" which in turn occupy the "Building Space" and provide "Building Space Area" which is needed as one of the parameter of the building. A "Floor Space" is a space of each floor/level within a building. A "Building Space" is a space where the building been occupied whereas a "Building Space Area" is the space area of the building. The "Floor Space" contains three types of entities. It contains one or many "Room Space" which built-up or partition-up the "Floor Space". The "Floor Space" could also contain the "Circulation Space" whereby it includes the horizontal (lobby, fire exits, corridor, etc.) and the vertical (lift) type of circulation. The "Floor Space" could also contain "Services Space" which is

used by one or many “Services Elements”. For example, a ducting system occupies the top level of each “Floor Space”.

The “Room Space” separates the “Floor Space” into partitions. It contains one or many “Room Type”; “Bedroom”, “Kitchen”, “Dining”, “Toilet” or “Others” which represent the functionality of the “Room Space”. This information is very useful as it associates a function to a space. This relationship could be significant in defining the properties of some spaces. For example, specific type of finishing can be associated with toilets, special ventilation systems with conference rooms, etc. It also provides “Space Area” which can be calculated from three or more “Space Boundary”. “Space Boundary” is an abstract concept, which represents a part of the infinitesimal thin skin, which surrounds a space or enclosing structures that bound it [Björk, 1992]. The “Space Boundary” can contain “Services Elements”, for example, a radiator which is placed along the boundary. It could also have one or more surface texture or finishes which are referenced, i.e. “Floor Finish Reference”, “Ceiling Finish Reference” and “Wall Finish Reference”. The “Space Boundary” also has two attributes of “Boundary Location” which can be used to calculate the “Boundary Area”. A “Space Boundary” on the other hand, is viewed to create “Space Separator” which enclosed the “Room Space”. The “Room Space” is normally enclosed by three or more “Space Separator” and it may or may not contain an “Opening”.

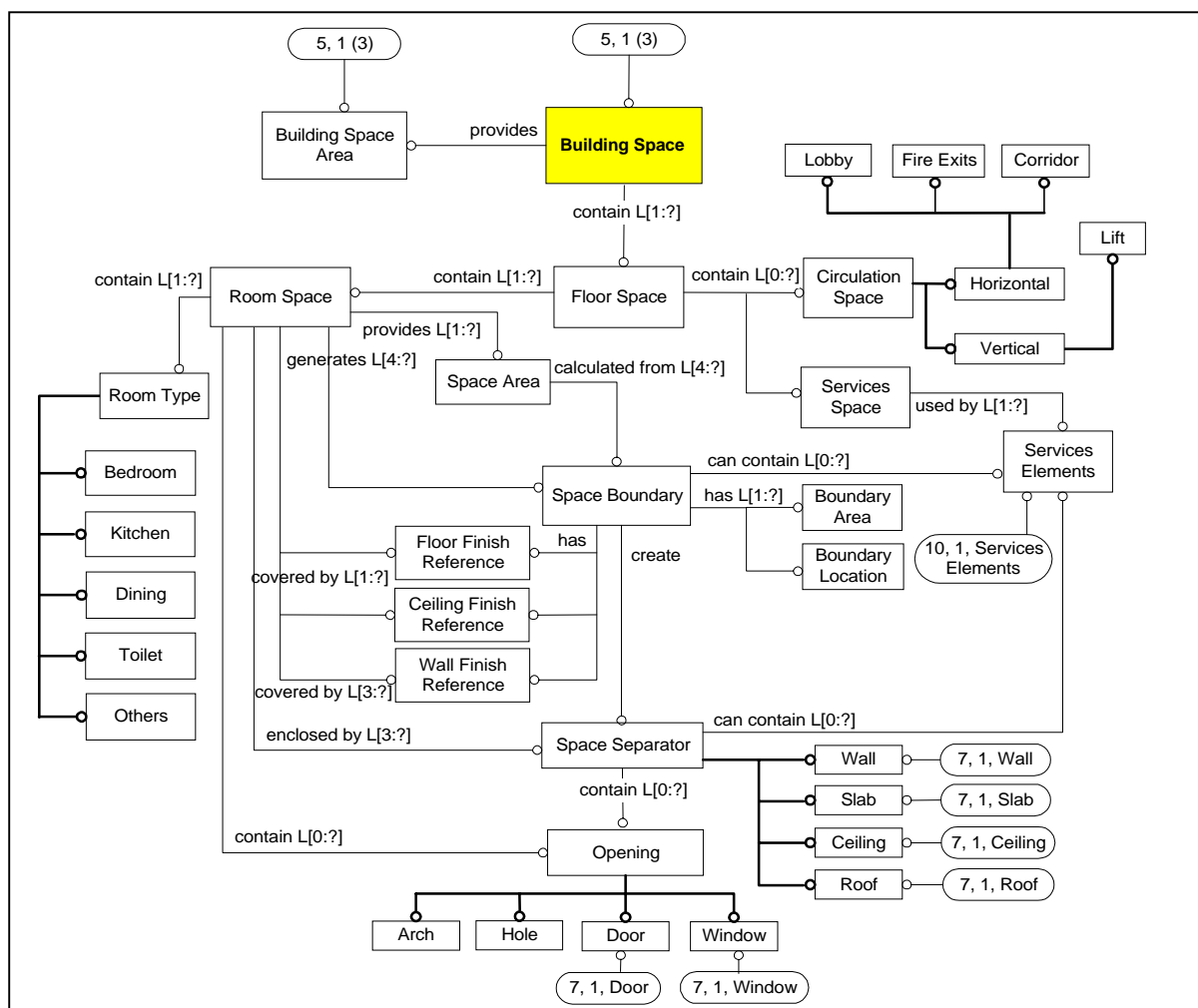


Figure 2. Building Space Data Model

The “Space Separator” or enclosing structure is an aggregation of objects which forms the space boundaries of two or more individual spaces (or between spaces and the outside of the building) [Björk, 1992]. It is viewed as a shell which consists of “Wall”, “Slab”, “Ceiling” and “Roof” and sometimes with a number of “Opening”, which is an abstract generalisation and usually filled with “Window”, “Door”, “Arch” or left as a “Hole” [Björk, 1992]. An “Opening” allows the movement of people, light, air fluids, etc. It sometimes contains “Services Elements” such as ducting systems along or in between the “Space Separator”, i.e. between ceiling and roof. Thus, it is important in this model to incorporate all the elements together, for example, to calculate the heat lost of a “Room Space”, in which the parameter of the “Space Separator” together with the “Opening” are used.

### 3. THE IMPLEMENTATION OF CAPE BUILDING SPACE DATA MODEL

The implementation of the CAPE building space data model has been divided into two main parts; the space analyser within the design package (AutoCAD-AEC™) and the space analysis of the building space within the object-oriented environment.

#### 3.1 Space Analyser

The main objective of this application is to analyse the spaces that are created within the building. Although AutoCAD-AEC™ provides a function to define a space, it can only be used to define a specific space function (e.g. a living room, kitchen, etc.) and does not analyse the space to give specific information such as boundaries, elements which creates the space, etc. In this study, a special function has been developed and added to the AutoCAD-AEC™ for analysing spaces. The steps, which are followed for analysing spaces, their associated elements and the space boundaries, are:

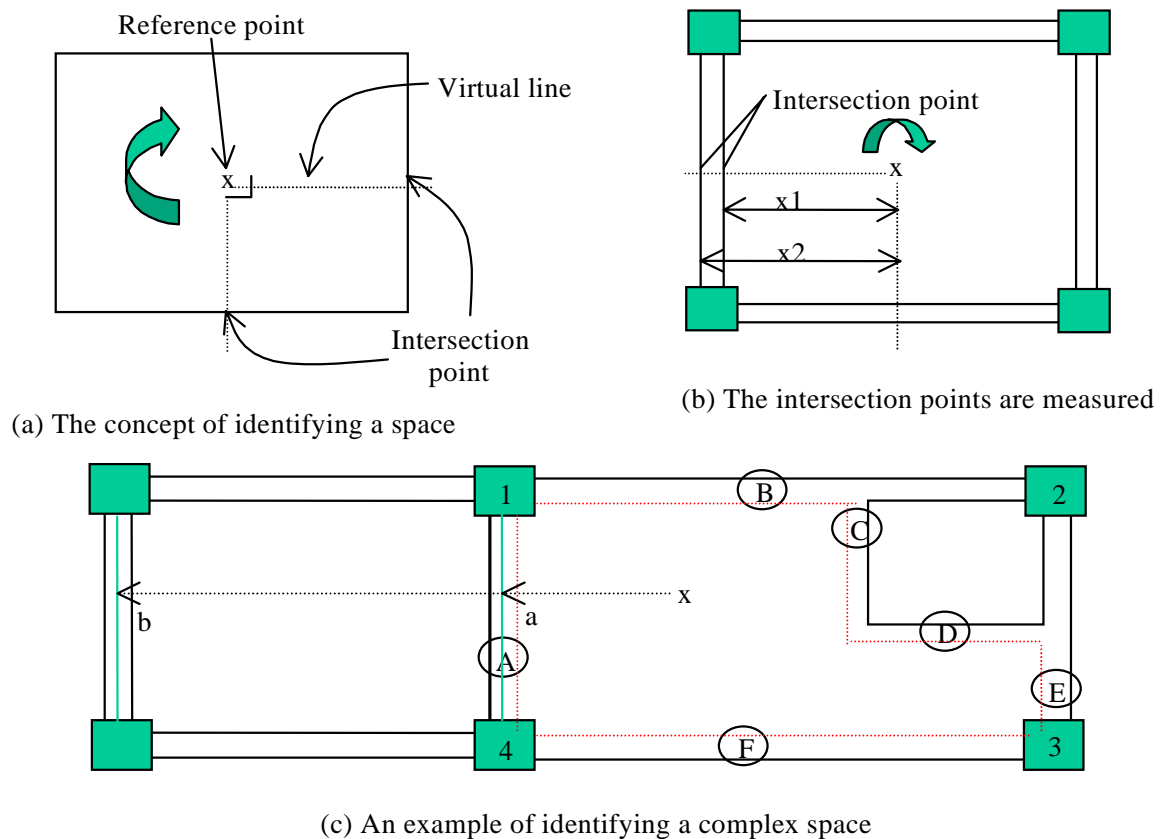


Figure 3. Analysing a space

1. Define a space function (e.g. living room) within a building space where a space-reference point can be captured as shown as 'x' in Figure 3(a).
2. Capture all previously created walls and sort the walls according to the level of the space-reference point. For example, walls, which are the same level (level 1), will only be analysed if the analysis of a space (e.g. living room) in level 1 is required. This procedure will minimise the analysis time.
3. Draw a 'virtual line' from the space-reference point to the left-hand side of the reference point where an intersection point can be captured. This concept is shown in Figure 3(b).
4. Get the distance from the intersection point to the spaces-reference point. In Figure 3(b),  $x_1$  and  $x_2$  can be determined where  $x_1$  and  $x_2$  is the distance from the 'virtual line' (created perpendicular with the referenced wall) to the inner and outer face of the referenced wall respectively. The minimum distance, i.e.  $x_1$  will be selected.
5. The same procedure is continued using a 'virtual line' which is drawn at the top left-hand side of the space-reference point following a clockwise direction.

To illustrate the concept in more detail, consider an example of a complex space as shown in Figure 3(c). In this example, more than four walls have been drawn to create a space. The following steps show how the concept works.

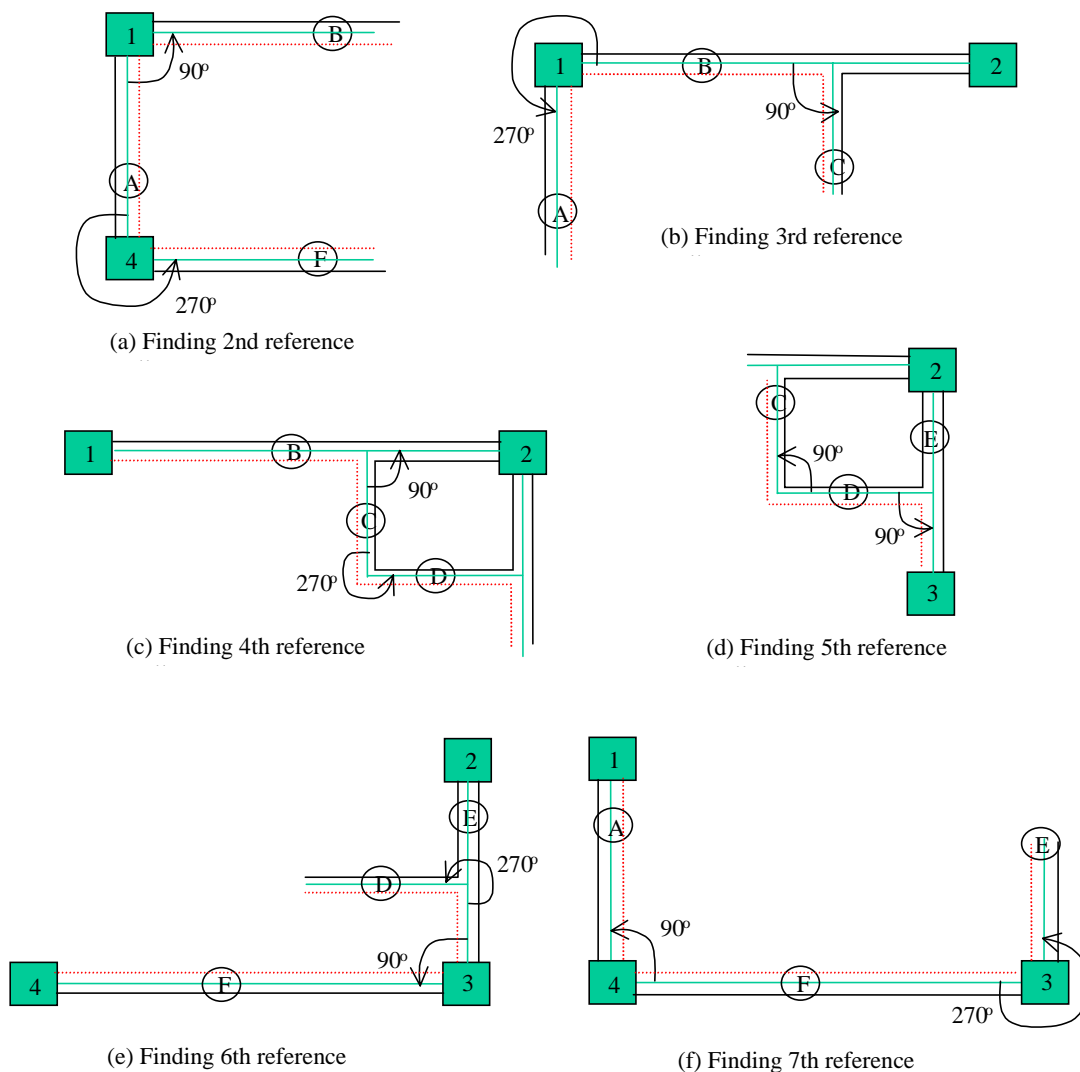


Figure 4. An example of identifying a complex space

1. Using the earlier algorithm for analysing the space, check all the captured walls, which are closest to the space-reference point. In this case, wall 'A' will be selected since distance 'a' is closer than distance 'b' (Figure 3(c)). The same procedure is done to the top of the space-reference point where wall 'B' will be selected. At the right-hand side, wall 'C' will be selected if the 'virtual line' intersect with wall 'C' or wall 'E' will be selected since the intersection between the 'virtual line' at the right-hand side of reference point might intersect with either wall 'C' or 'E'. Finally at the bottom, wall 'F' will be selected. Using this procedure, only four walls can be captured.
2. In order to check other walls, all wall(s) associated with all the captured walls (captured walls are the walls, which have been captured while analysing the space) will be analysed. If there are any, include all the associated walls into the previous captured walls. In this case, wall 'D' and 'E' will be included since wall 'D' is associated with wall 'C' and wall 'E' is associated with wall 'D'.
3. Take the first wall from the captured walls as the reference wall. Find other walls, which are closest with the reference wall. This is done by checking the walls, which are associated with the same column associated with the reference wall. In this case column 1 & 4 will be used where wall 'B' and 'F' will be checked.
4. The second reference wall is identified using the angle method whereby the smallest angle will be used. This is to ensure that the space will be analysed in a clockwise direction. In Figure 4(a), wall 'B' will be selected since it provides an angle of  $90^\circ$  compare to wall 'F' which provides an angle of  $270^\circ$ . The measurement of an angle is automatically done by AutoCAD™ functions which measured the angle in counter-clockwise.
5. The same step 3 and 4 are followed until the final reference wall is the same with the first reference wall as shown in Figure 4(b) – 4(f). In a case where the same reference wall (which has been considered earlier) given smaller angle than the second wall, the second wall will be selected. This is shown in Figure 4(c) where wall 'D' is measured to have an angle of  $270^\circ$ , while wall 'C' has  $90^\circ$ . Since wall 'C' has been selected earlier, wall 'D' will be selected as the new reference wall.
6. Finally, after all the walls have been captured to define a space, all the captured reference walls will be stored. The next step is to define the space boundaries.

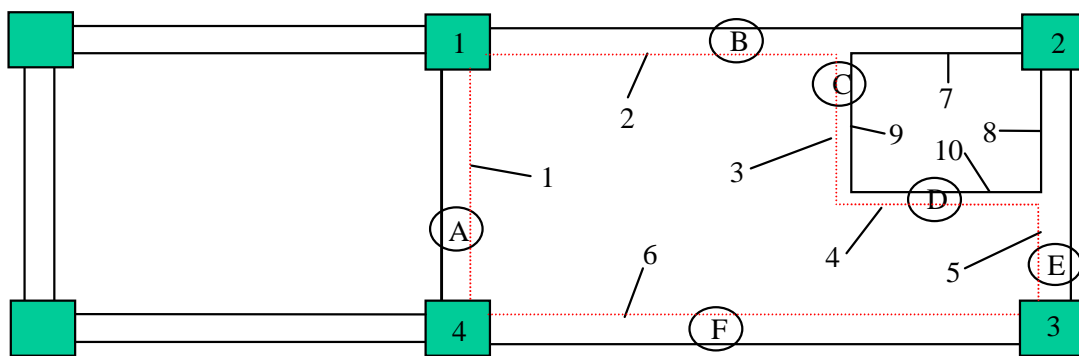


Figure 5. An example for analysing the space boundaries

Using the example shown in Figure 5, the steps involved in analysing the space boundaries can be explained as follows:-

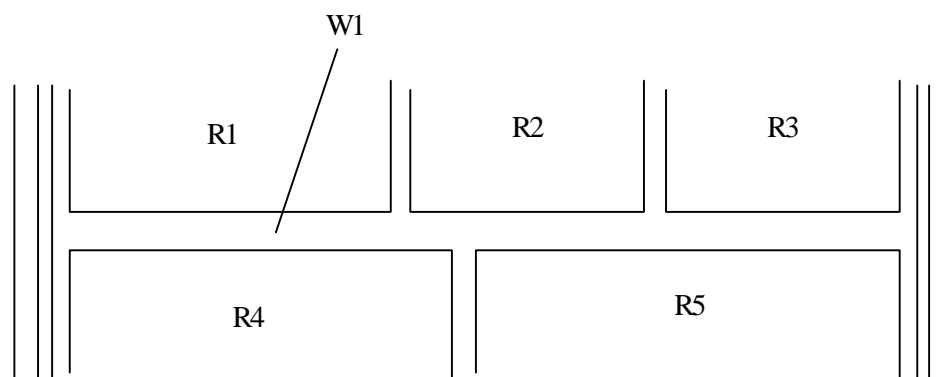
1. For the first boundary, get the first wall from the wall reference list, i.e. wall 'A'. If the reference wall is a cavity wall, get a list of entities, which belongs to cavity wall. Select

- the entity with the layer name which represents the internal wall. In this case, entity '1' will be selected.
2. If the reference wall is a solid wall, get all the entities which belong to the solid wall. In this case, two entities will be selected. The entity, which is closest to the space reference point, will be selected.
  3. For the second boundary, get the second reference wall, i.e. wall 'B'. Check the wall as in the step 1 and 2. In this case, two entities will be captured, i.e. entity '2' and '7'.
  4. Check which entity has their co-ordinates closest to the previous reference wall. In this case, entity '2' will be selected.
  5. For the third boundary, since the third wall is a solid wall, two entities have to be compared, i.e. entity '3' and '9'. Following the same method used in step 4, entity 3 will be selected.
  6. For the fourth boundary, since the fourth wall is also a solid wall, two entities have to be compared, i.e. entity '4' and '10'. Following the same method used in step 4, entity '4' will be selected.
  7. For the fifth boundary, two entities have been selected, i.e. entity '5' and '8'. Following the same method in step 4, entity '5' will be selected.
  8. For the sixth boundary, only one entity has been selected, i.e. entity '6'.
  9. Store the selected entities which represent the space boundaries of a defined space as dotted lines (Figure 5).

The above steps for analysing a space, which includes analysing the space boundaries and space separator (wall, slab, etc.), provide information such as:-

- ❑ Space boundaries in which the surface finish area can be determined.
- ❑ Space boundaries in which the total space area can be determined.
- ❑ Space boundaries will define the relationship between spaces, i.e. adjacent to or far from.
- ❑ Space separator (e.g. walls) which have the associated elements (e.g. windows/doors) will provide the information for determining the total heat lost.
- ❑ Space separator which is associated with many spaces.

The following steps will show how the information provided above can be utilised using an example in Figure 6.



*Figure 6. The relationship between space*

1. Using the space boundary of space R4, the adjacent spaces such as R1 and R2 can be determined by finding the closest/nearest distance between the space boundary of space



- R4. If the distance is measured between the space boundaries of R4, R1, R2 and R3, it will be found that R1 and R2 are adjacent to R4 comparing with R3.
- The number of spaces separated by wall W1 (R1, R2, R3, R4 and R5) can be determined by sorting the associated elements and spaces in the wall W1 representative object.

### 3.2 The Object-oriented Environment

In the object-oriented environment, the building data module and other data modules are implemented. The building data module includes building elements data module, building space data module, building design data module, etc. Figure 7 shows the object hierarchy, which has been mapped in KAPPA-PC™. Figure 7(a) shows the object hierarchy of the project model (SPACE) including the building module and other modules such as construction and site information. Figure 7(b) shows the object hierarchy of the building module including building elements data module, building space module, building design module, etc. Two types of analysis have to be performed, i.e. the object analysis and the space analysis. In this paper only the space analysis will be discussed in detail.

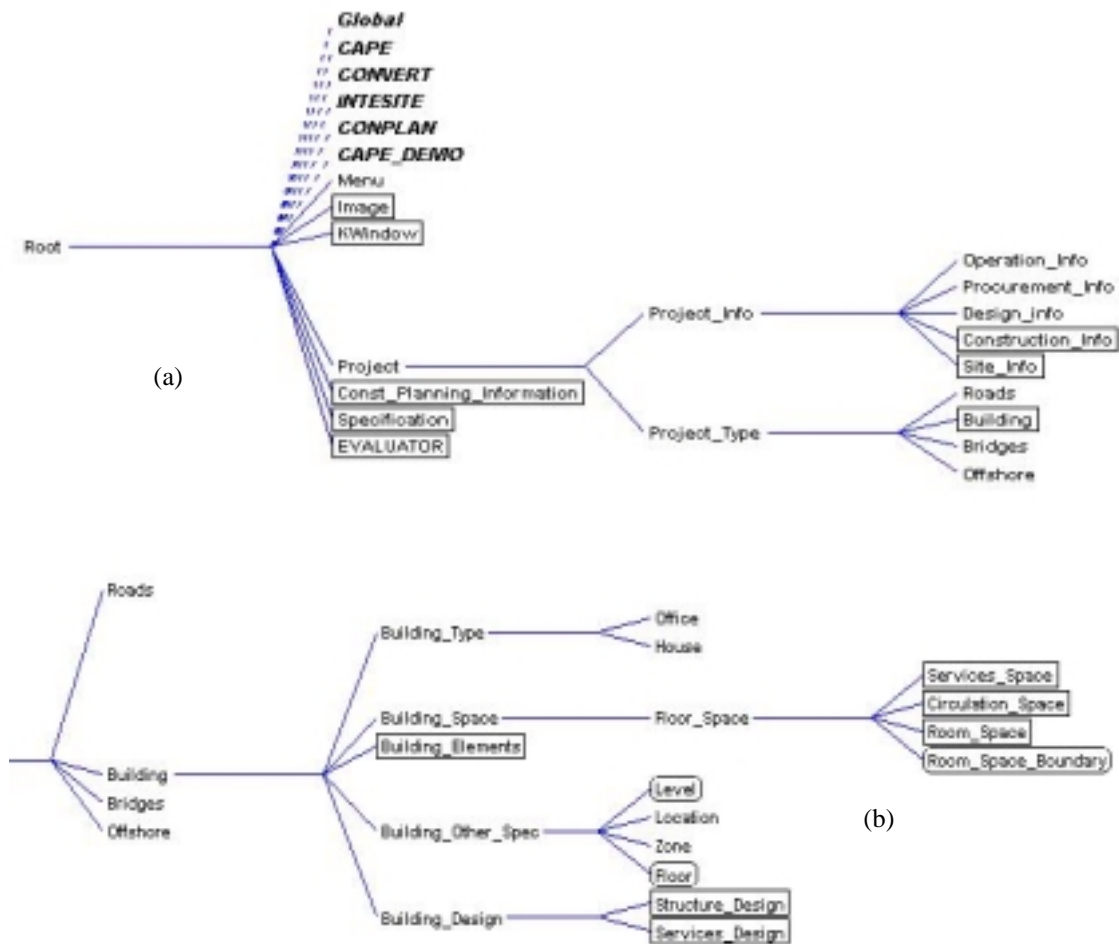


Figure 7. Object hierarchy in KAPPA-PC™

#### 3.2.1 The Space Analysis

The space objects, which have been created in the CAD system, cannot be populated with vast information such as material specifications, etc. This is due to the limitations of CAD database and the complexity of storing further information. Therefore, objects are created in



the object space hierarchy to overcome this problem. The space information and the space boundaries are stored in separate objects where the space object holds the information such as space area, floor finishes, etc., while, the space boundary object holds information such as space boundary, wall surface finishes, etc. Figure 8 shows a 'space boundary object', which has the wall surface finishes and Figure 9 shows a 'space object' which has the floor finishes. Details of both surface finishes specification are stored in the specification module.

The functions required for analysing the space have been itemised as follows:-

- a. Create space object
- b. Define space associated elements
- c. Define space boundaries

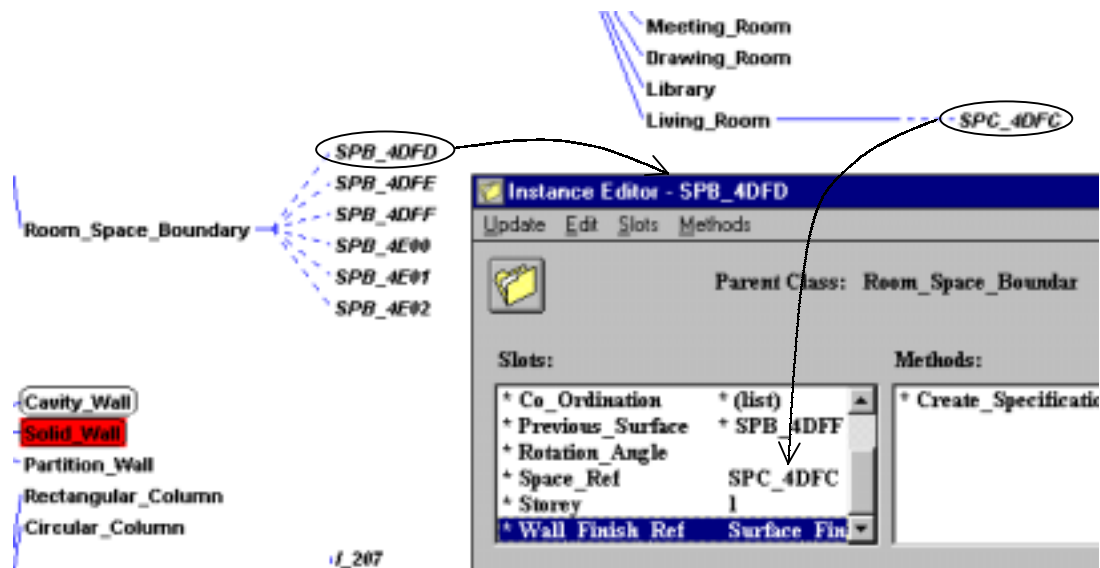


Figure 8. Space boundary with wall surface finishes specification

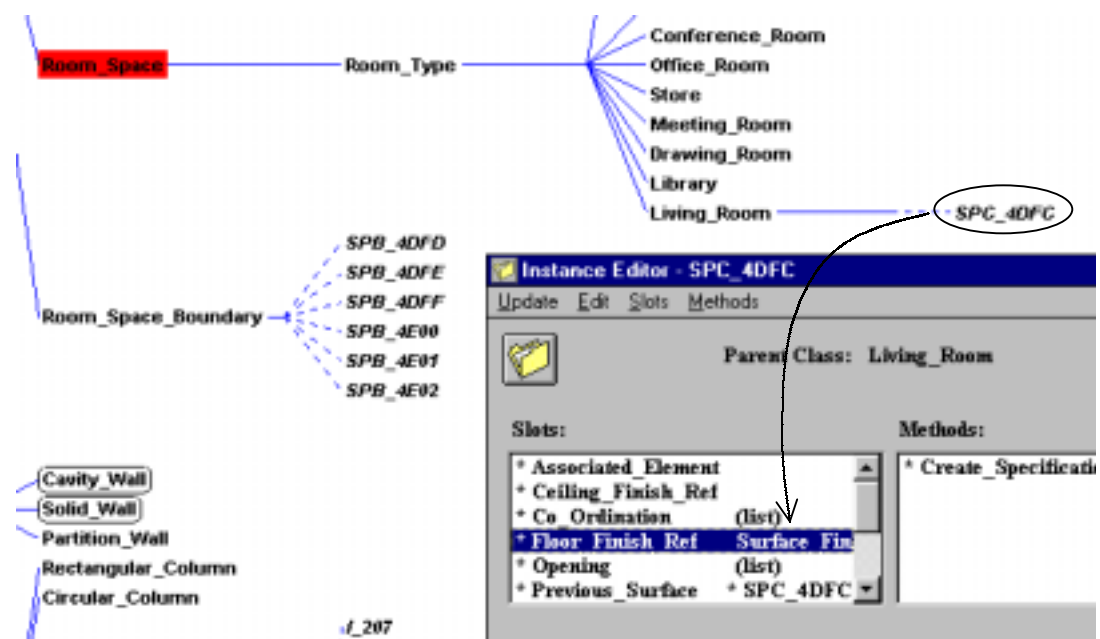


Figure 9. Space object with floor finishes specification

### 3.2.1.1 Create space object

After the process of defining and analysing the space in the CAD systems, the defined spaces are transferred and created as space objects in the object-oriented environment. The process of creating the space objects is similar to that of the building element object. The space object name is the handle name which is retrieved from the space entity in the CAD systems. Since KAPPA cannot handle instance name starting with a number an extension of “SPC\_” is used.

Once an object is classified as a space object, a space object is created as an instance in the space data module under the defined class. For example, when a user defines a space name as a “living room”, an instance is created at the “living room” class as shown in Figure 8. The process of defining the space name is controlled by the building space data module whereby only the classes, which are defined in the “Room\_Type” object are selected. This is to ensure no error occurs when creating a space object in the project model.

### 3.2.1.2 Define space associated elements

During the analysis of the space in the CAD system, the building elements, which are associated with the defined space, are captured and associated with the space entity. These associated elements are then passed to the project model after the space instance is created whereby each associated element is separated either as a space separator or a space opening. Space separator includes wall and flat slab, while space opening includes windows and doors. Figure 10 shows an example of a list of space separators and space openings for a space object.

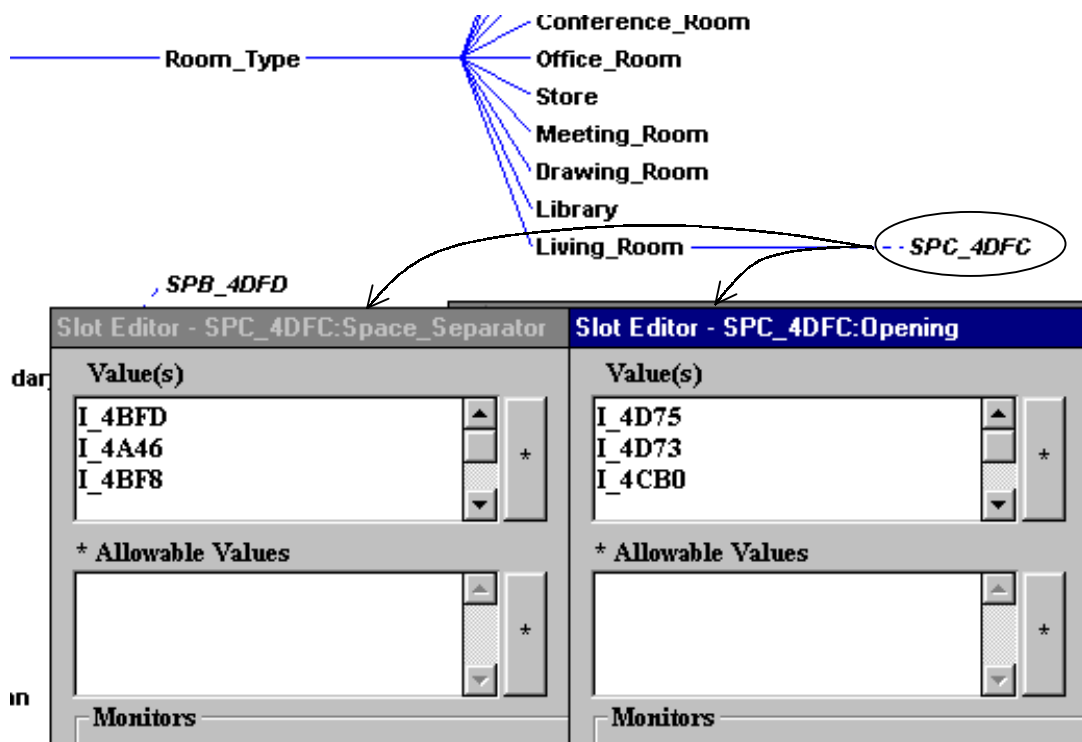


Figure 10. Space object with space separator and space opening

Since the associated elements captured for the space separator include walls, windows and doors, excluding slabs, they have to be sorted in order to include slabs in the space separator list, while the window and door in the ‘space opening’ list. This function is developed using

an algorithm below and Figure 11 shows an example of a sorted space separator which includes cavity wall and flat slab.

- Get the associated elements from CAD
- Check each element
  - If the element is a “Door” OR a “Window” Then set as “Space Opening”
  - If the element is a “Cavity Wall” OR a “Solid Wall” Then set as “Space Separator”
- Get the associated elements
- If the associated element is a “Flat Slab” Then include this element in the “Space Separator” list
- End of checking

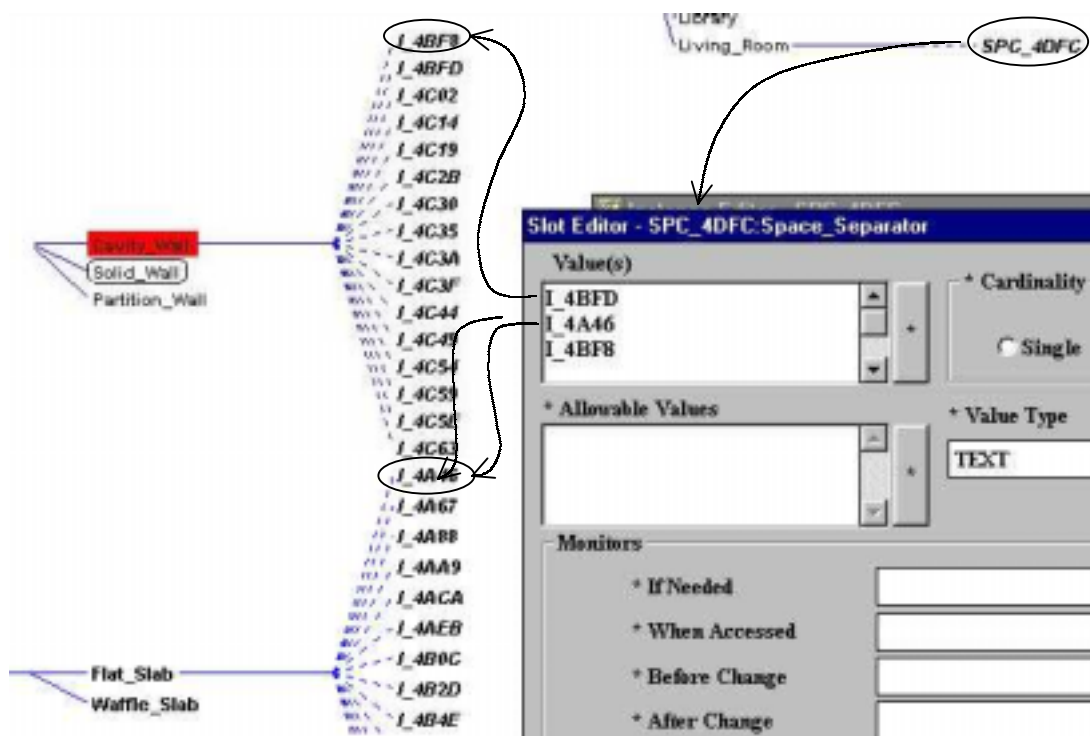


Figure 11. Space separator including cavity wall and flat slab

### 3.2.1.3 Define space boundaries

The space boundary's objects of a defined space also need to be created in the project model. As mentioned earlier, such objects are required for defining other related information with the space boundaries such as surface finishes, surface area, space separator, etc. In order to create the space boundary's objects, each space boundary which is captured while defining a space in the CAD systems will be created at the 'Room\_Space\_Boundary' object/class. Like the 'space object', the space boundary's objects will be created with an extension of "SPB\_" plus the space boundary handle name. All the space boundary's objects will be cross-referenced with the 'space object' as shown in Figure 12.

Space boundary is also associated with space separator and space opening where the total surface area can be determined. Figure 13 shows an example of a space boundary 'SPB\_4DFD' which is associated with space separator (cavity wall) 'I\_4BFD' and space opening (window) 'I\_4D75'. If the dimensions of both a cavity wall and a window are used then the surface finishes area can be determined.

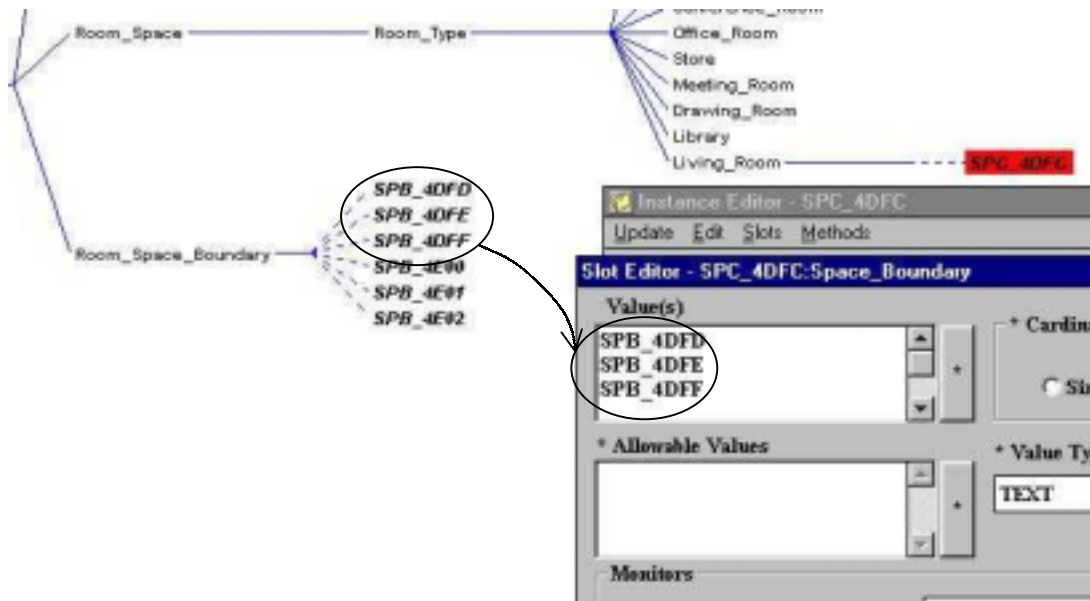


Figure 12. Space object which is associated with space boundaries objects

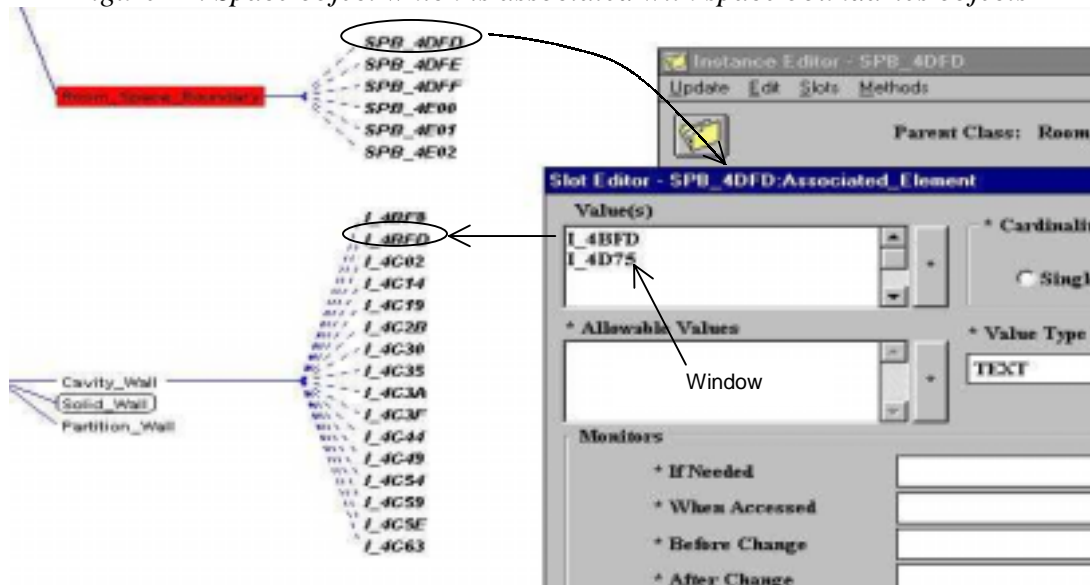


Figure 13. Space boundary which is associated with space separator (cavity wall)

#### 4. DEMONSTRATING AND EXPERIMENTING THE BUILDING SPACE PROTOTYPE

As part of CAPE development, a prototype has been developed for analysing the building space in the CAD system and also in the Object-oriented environment as shown in Figure 1. This prototype has been developed using the building space data model and also the Object Interpreter Engine (OIE) as described in the earlier sections.

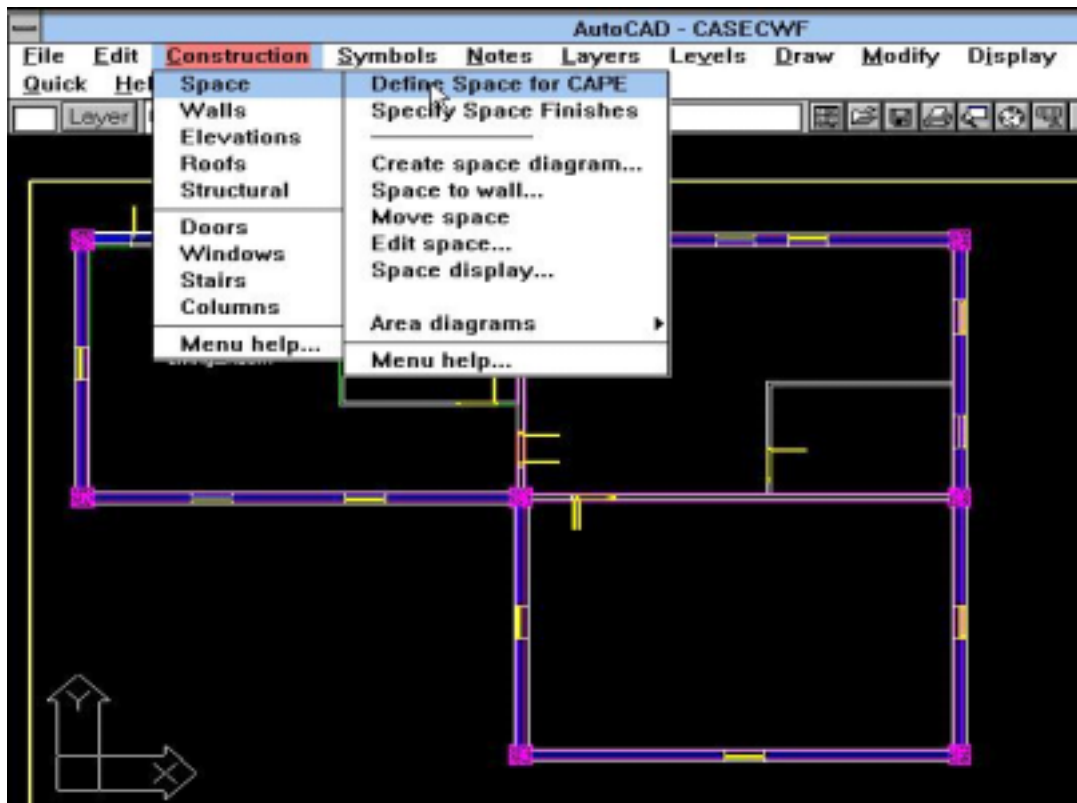


Figure 14. Main menu screen for defining a space in CAPE

#### 4.1 Space Definition

A special application has been developed to define spaces from the building's plan. This application is developed in the CAD system where additional functions have been added to the AutoCAD-AEC™ pull-down menu as shown in Figure 14. These two functions (Define Space and Specify Space Finishes) are used to define the space and space finishes where the space boundaries will be captured and later the right surface finishes will be attached to the space and the boundaries as discussed earlier.

In order to interrogate the defined spaces in the CAPE module where the space boundaries and the surface finishes are stored, the same query window of CAPE is used. Three different options have been developed, i.e. the space boundaries and the surface finishes for walls and floors as shown in Figure 15. In this demonstration, the CAPE query window is invoked from the customised AutoCAD-AEC™ side menu.

From the CAPE main query window, information associated with the defined space can be retrieved by clicking on either the space object or its relevant components. This is shown in two different demonstrations, i.e. by displaying the space boundaries and by surface finishes for the defined space. Figure 16 shows the space boundaries are highlighted for a selected space, living room, in which the textual information is also printed on the screen. Thus, this information shows that the defined space boundaries, which are stored in the CAPE module, can be visualised as and when required.



Figure 15. CAPE queries window for space demonstration

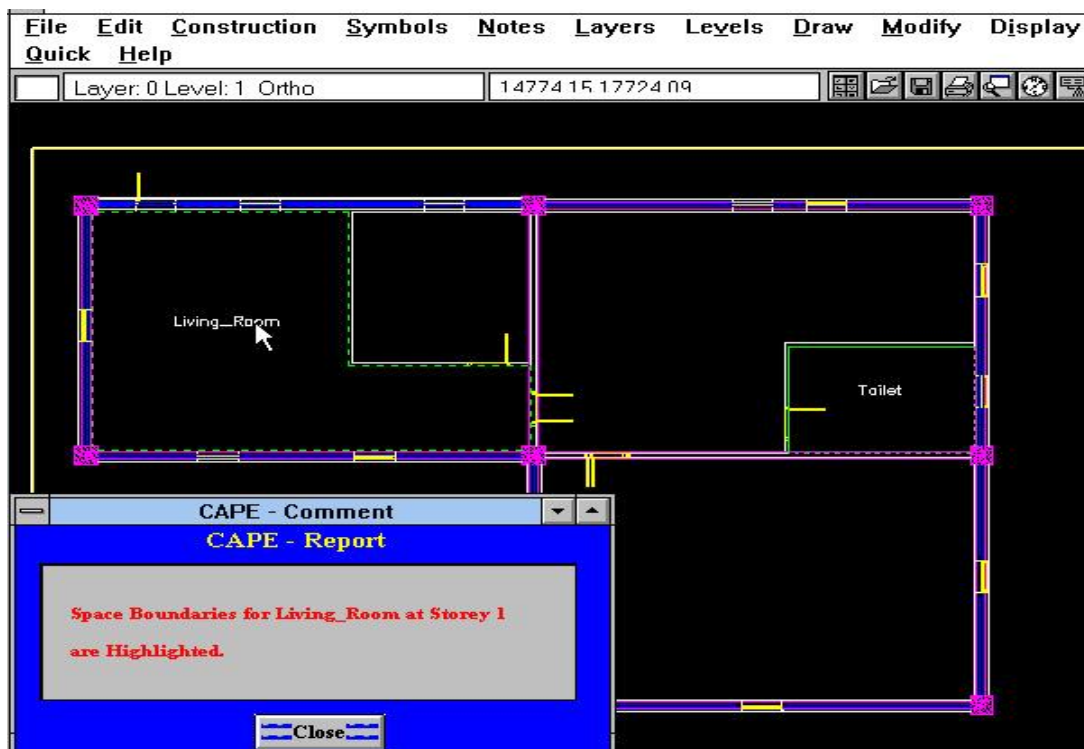


Figure 16. Highlighting the space boundaries of a living room

The surface finishes, which are attached to a defined space, can also be displayed. The floor surface finishes can be displayed by clicking on the space object or space name, while the wall surface finishes can be displayed by selecting any wall. This is shown in Figure 17. In a case where a wall is divided into two different spaces, all wall surface finishes attached to that wall will be displayed. Thus, this information enables users to associate a cost, a



construction plan, etc. to a space according to their functionality. Users can therefore change a space attributes and examine their impact on cost, current requirements, construction, etc.



*Figure 17. Displaying surface finishes for a selected space*

## 5. CONCLUSION

The building space analysis, although it is only part of the overall Integrated Construction Environment, plays an important roles for determining the overall skeleton of a building. Such space analysis provides detail relationship with most of the design systems such as architectural, structural and services. Therefore, full consideration must be taken when analysing, modelling and implementing the building space for integrating design and construction. This paper has outlined the building space data model, which is part of design data module (CAPE data module) where most of the entities and attributes that are required for integrating design and construction have been accommodated. Such data model has been implemented in the CAD system and also in the object-oriented environment. Several demonstrations to show the capabilities of the prototype have also been demonstrated.



## REFERENCES

Björk. B. C. (1992), A Conceptual Model of Space, Space Boundaries and Enclosing Structures, *Automation in Construction*, Vol.1, No.3, pp. 193-214.

Che Wan Putra, C.W.F. and Alshawi. M. (2000), CAPE: Integrating Design and Construction, *INCITE 2000*, 17-18 January 2000, Hong Kong, pp. 209-222.

Che Wan Putra, C.W.F (1998), *CAPE: Construction Application Protocol for Data Transfer: A Building Data Model*, Unpublished PhD Thesis, Department of Surveying, University of Salford, UK.

Faraj. I. And Alshawi. M. (2000), SPACE: Simultaneous Prototyping for an Integrated Construction Environment, *INCITE 2000*, 17-18 January 2000, Hong Kong, pp. 466-484.