STAKEHOLDERS

Full Paper

A MULTIPLE CRITERIA DECISION MODEL FOR ACCESSIBILITY ASSESSMENT

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ABSTRACT

Accessible or inclusive building design is one that enables everyone to gain easy access to a facility, regardless of the type or degree of flexibility. Since the introduction of the Disability Discrimination Act 1995 (DDA) in the UK, the consideration of issues such as access and inclusive design has become paramount. Space analysis is one of the important aspects of current accessibility assessment. Existing space analysis techniques, such as Space Syntax, have tackled the local and global accessibility of a building layout using the graph theory. However, there are difficulties in the automatic transfer the design information from architecture drawings into a space analysis tool. With the recent development of the building information model (BIM) and IFC (Industry Foundation Classes), it is possible to automate the transfer process through IFCs. This paper demonstrates the automation process and how it can be used in accessibility analysis.

Keywords**: Accessibility, Building Information Model, Space Syntax, Graph Theory, Space Planning**

1. INTRODUCTION

Current UK legislation regarding accessibility is governed by in the Building Regulation and Disability Discrimination Act (1995). This Act encourages the creation of environments that are accessible by all persons irrespective of any disability, including people with physical, sensory and cognitive impairments. The publication of BS 8300:2001 'Design of Buildings and their Approaches to Meet the Needs of Disable People – Code of Practice,' and the subsequent revision of Part M of the Building Regulation give detailed guidance on the design of domestic and non-domestic buildings.

The level of access of an existing building or new development is assessed through access audits and access appraisals; in addition, an Access Officer from the local planning office is involved in the development of all public facilities during the planning stage. :

- Access audit: An access audit is to establish how well a particular building or environment performs in terms of access and ease of use by a wide range of potential users. The audit report should recommend access improvements, prioritise action and indicate where improvements can be made. (Sawyer and Bright, 2004)
- Access appraisal: The Access appraisal is an audit of the proposals for a new development, refurbishment or alteration. This involves making a detailed assessment of the proposed level of accessibility in a building using drawings, specifications and consultation with architect or designer. (Sawyer and Bright, 2004)

However, the process of the both access appraisal and auditing can be lengthy and cumbersome, especially when the building is large and complex. It involves numerous site visits, field surveys and the overall assessment often solely relies on the access consultant or auditor's experience. It has also been acknowledged that it is not always possible to fully cater for every one according to their individual needs, although it is possible to create an environment that encompass wide range of users (Barker et al., 1995). Therefore, can the process be automated or simplified with aid of the technology? With the recent development of the building information model (BIM), it is possible that many aspects of accessibility assessment can be conducted on a virtual building model, such as spatial arrangement of the building, individual characteristics of building elements, etc. This paper aims to demonstrate how to use the building information model to analyse the space layout and how the accessibility requirements can be integrated.

2. SPACE ANALYSIS

The spatial design of a building is usually governed by building and fire safety codes. As the concept of the inclusive design becomes ever important in architecture design, the traditional fire safety rules may not provide an efficient solution to accommodate the new demand. A method of space analysis, Space Syntax was developed by Hillier and Hanson (1984), University College of London, is proven helpful for the organisation of space in architecture.

Space syntax is a set of techniques for representing space in a building or city concerning the social use of space. From the very beginning, space syntax research focussed on the relationship between space and social life, be this the social life of a simple building, a complex building (or set of buildings), a settlement or an urban district. Using this technique, the probable outcome of design decisions can be forecasted during the design process. Designs can then be modified so they will achieve levels of movement and space use appropriate to the functions desired on the site. At that time, the approach pioneered by Hillier and Hanson was unique, as it involved analysing solely the spaces between buildings as opposed to a building's (or buildings') geometric form (Hillier and Hanson, 1984).

According to Hillier & Hanson (1984), the important property of quantification is the permeability of the system; that is, how the arrangement of cells and entrances controlled access and movement. These properties can be represented by making a graph of the spaces in a building, with circles or nodes representing spaces and linking lines representing entrances, and 'justifying' it with respect to the outside world. This method measures the connectivity of spaces within built environment for example, the number of doors you have to go through to get to a particular space. This enables the comparison between the most linked and most isolated space layouts. The average minimum steps required getting from one space to another space, term as the depth value is to show the relationship of connectivity. The smaller the depth value the more accessible is the space.

Space syntax analysis is beneficial for measuring the local and global layout of the building, however, it does not measure the distance taken to pass through from one space to another space. However, such analysis requires converting the building layout into a specific model that can be analysed by using Space Syntax techniques. With large and complex building, this task can be tedious and lengthy. With recent development of the building information model, the spatial relationship has already been built into the model and similar analysis can be directly performed upon. Furthermore, other aspect of information such as accessibility criteria can be included in the analysis. In the following section of the paper, the building information model is illustrated to demonstrate how the spatial analysis can be performed.

3. BUILDING INFORMATION MODEL

The concept of a building information model (BIM) was introduced in 1970s. Much of the research in this field has been undertaken by academics (Eastman, 1999). Until recently, leading CAD vendors, such as Autodesk, Bentley and Graphisoft, have started to heavily promote the concept, Building Information Model (BIM). The BIM is a digital data model of building design information, which may also contain information about the building's construction, management, operations and maintenance. Unlike traditional 2D CAD systems in which the building design is represented in multiple drawing files made up of lines, arcs and circles, the BIM is a single information model that is constructed with intelligent 'objects' which represent building elements like walls, slabs, roofs, doors and windows. If a window is moved in the elevation, the corresponding plan or section will be updated automatically to show the window's new location. If the design parameters of the window are changed in the window schedule, those changes are automatically reflected in the drawing views as well (Graphisoft, 2003).

Various technologies and research projects have demonstrated the benefits of building information model concept (Lee et al., 2003). However, these technologies are based on different standards that are not compatible to each other. An open and neutral data format is required to ensure the data compatibility across the different applications. IFC (Industry Foundation Classes) developed by IAI (International Alliance for Interoperability) provides such capabilities.

3.1 Industry Foundation Classes

IFC is a comprehensive data representation of the building model and it is also a set of rules and protocols of how you define the data describing the building. IFCs have been defined by the AEC/ FM industry and provide a foundation for the shared project model. This works through the specification of classes of components in an agreed manner that enables the development of a common language for construction. IFC-based objects allow AEC and FM professionals to share a project model, yet allow each profession to define its own view of the objects contained in that model. This leads to improved efficiency in cost estimating, building services design, construction, and facility management. IFC enables interoperability among AEC/ FM software applications. Software developers can use IFC to create applications that use universal AEC/ FM objects based on the IFC specification. Applications that support IFC will allow members of a project team to share project data in an electronic format. This will ensure that the data is consistent and co-ordinated. Furthermore, this shared data can continue to evolve after the design phase and throughout the construction and occupation of the building. The information generated by the project design team will be available to the building construction team and building facilities managers in an intelligent, electronic format through their IFC compliant software (IAI-International, 2003).

3.2 IFC Space Model

In IFC model, a space is defined by *ifcSpace* entity, which represents an area or volume bounded actually or theoretically. Spaces are areas or volumes that provide for certain functions within a building. A space is (if specified) associated to a building storey (or in case of exterior spaces to a site). A space may span over several connected spaces. Therefore a space group provides for a collection of spaces included in a storey. A space can also be decomposed in parts, where each part defines a partial space (IAI-International, 2003).

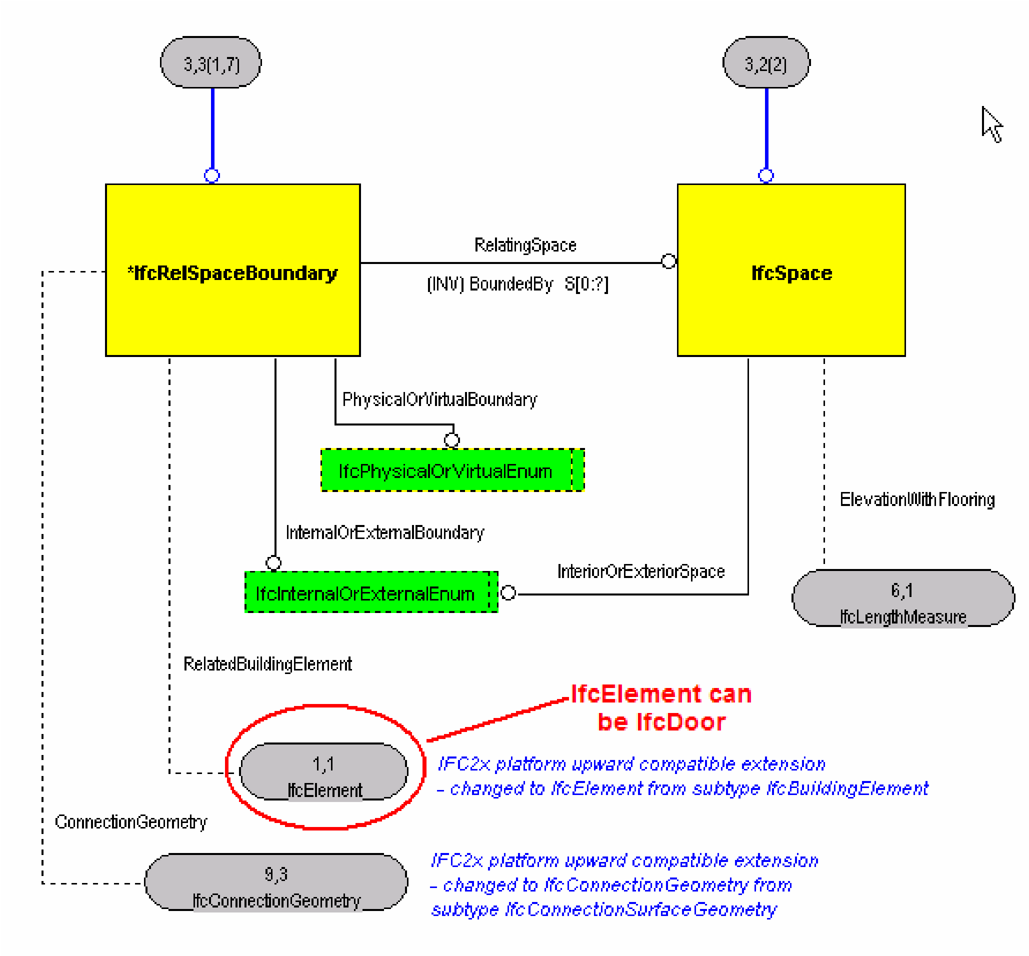

Fig.1 IFC Space Model (IAI-International, 2003)

The relationships between space and other building elements such as windows, doors, walls, are defined by *ifcRelSpaceBoundary* entity. The space boundary (*IfcRelSpaceBoundary*) defines the physical or virtual delimiter of a space as its relationship to the surrounding elements. (IAI-International, 2003) More detailed information about the IFC modelling specification can be found in IFC implementation guide (IAI-International, 2003).

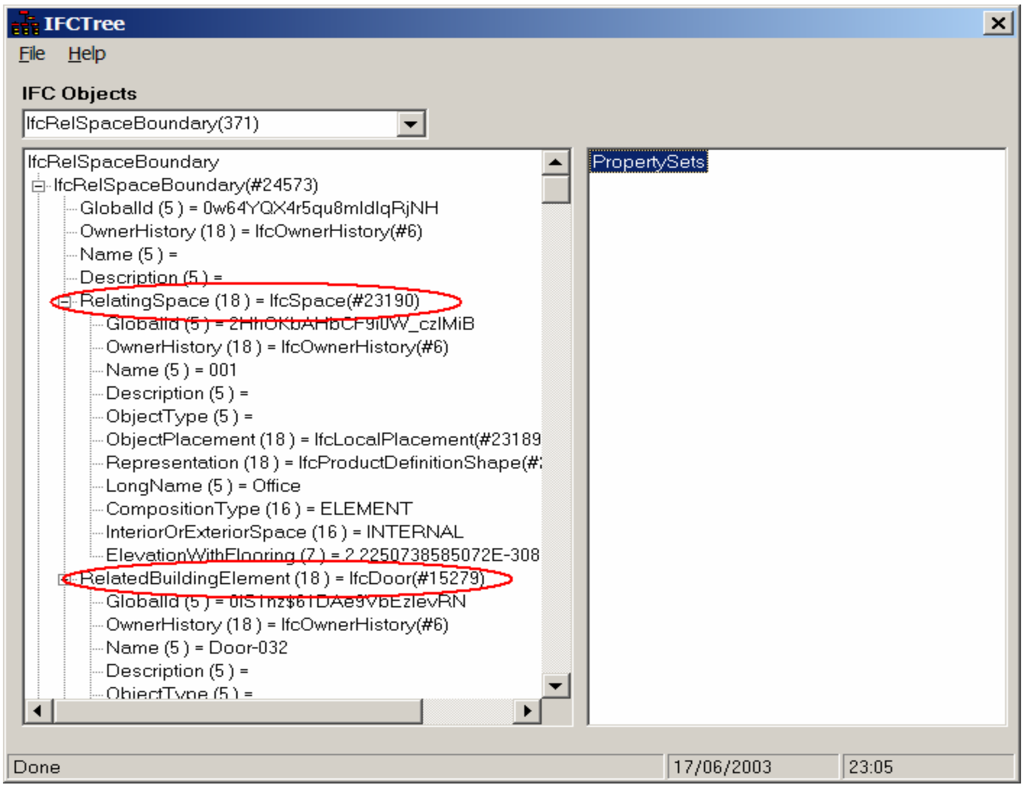

Fig.2 - an example of IFC space boundary definition.

The Fig.2 is an example of how to use ifcSpaceBoundary to define the relationship between a space and a connected door. It shows a space (ifcSpace, #23190) has a door (ifcDoor, #15729). It looks quite complicated and requires detailed knowledge of IFC modelling to implement relevant application. In order to ease the implementation, the IFC space model can be simplified into the following Graph (Fig.3), which only contains node (vertex) and links (edge) between the nodes (vertices). Graph theory is a branch of mathematics and a Graph is a very simple structure consisting of a set of vertices and a family of lines (possibly oriented), called edges (undirected) or arcs (directed), each of them linking some pair of vertices. In our model, vertex represents space and edge represents space exit (i.e. door).

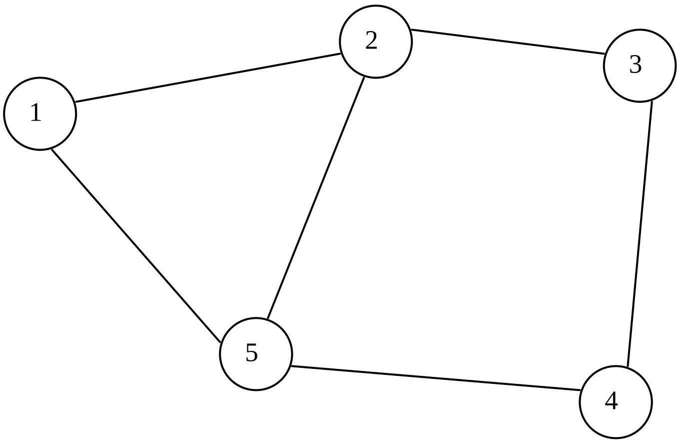

Fig.3 Simplified Space Model into Graph

4. GRAPH THEORY

The Graph Theory was developed in a research paper by Leonhard Euler in 1736 (Lloyd and Wilson, 1976). Euler discusses whether or not it is possible to stroll around Konigsberg (later called Kaliningrad) crossing each of its bridges across the Pregel (later called the Pregolya) exactly once. Graph Theory was born to study problems of this type. In the past two decades, graph theory has demonstrated that it is an effective tool for solving space problems/ floor planning (Grason, 1970, chwarz et al, 1994, Medjdoub et al, 2000).

A graph is a set of dots, called vertices or nodes, connected by links, edges or arcs. Depending on the applications, edges may or may not have a direction; edges joining a vertex to itself may or may not be allowed, and vertices and/or edges may be assigned weights, i.e. numbers. If the edges have a direction associated with them (indicated by an arrow in the graphical representation) we have a *directed graph*. Structures that can be represented as graphs are ubiquitous, and many problems of practical interest can be formulated as questions about certain graphs. (Wikipedia, 2003).

Although it is convenient to represent a graph by a diagram of dots linked by lines, such representation is not suitable for computer storing and processing. One way of storing a graph is by listing the vertices adjacent to each vertex of the graph, it can be represented by a matrix, which often called Adjacency Matrix.

Adjacency Matrix is quite simple. Given N nodes, from an enumerable set, just make an NxN matrix Adj. The value in Adj[i, j] says whether j is an immediate successor of i or not. For unweighted graphs, Adj[i, j] can just be true or false, or 1 or 0, e.g.,

- Adj[i, i] = 1, for every node i
- Adj[i, j] = 1 if node i is directly connected to node j, 0 otherwise

For weighted graphs, Adj[i, j] is a numeric value.
For above (Fig.3), the adjacency matrix would be:

$$\begin{bmatrix} 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 \end{bmatrix}$$

Depth first traversal algorithm (Tarjan,1972) can be used to find all the possible paths for given two nodes.

5. IMPLEMENTATION

The practical implementation consists of two stages. The first stage is to export the IFC space model into a graph. This requires using IFC toolbox (Yoshinobu, 2003 and Eurostep, 2003) to access IFC data model to extract relevant space information into a database. The second stage of the implementation is to carry out analysis based on the graph. For example, path finding is one of the possible analyses. Both stages of the implementation will be demonstrated through the following example scenario.

Example Scenario

The building model of this example is a created by ArchiCAD (Fig.4). There are 8 spaces that are defined in this model:-

- Space 1 – Reception Area
- Space 2 – Corridor
- Space 3 – Corridor
- Space 4 – Office
- Space 5 – Office
- Space 6 – Office
- Space 7 – Office
- Space 8 – Office

The IFC data file is generated by ArchiCAD IFC add-on, here is a snapshot of how the IFC data file looks like.

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION (('ArchiCAD 7.00 Release 1 generated IFC file.', 'Build Number of the Ifc 2x interface: 00102 (22-04-2003)'), '2;1');
FILE_NAME ('spaceExample.IFC', '2003-06-17T23:51:59', ('Architect'), ('Building Designer Office'), 'PreProc - IFC Toolbox Version 2.x (00/11/07)', 'Windows System', 'The authorising person.');
FILE_SCHEMA (('IFC2X_FINAL'));
ENDSEC;
DATA;
#1 = IFCORGANIZATION ('GS', 'Graphisoft', 'Graphisoft', $, $);
#3 = IFCPERSON ($, 'Song Wu', $, $, $, $, $, $);
#4 = IFCORGANIZATION ($, 'University of Salford', $, $, $);
#5 = IFCPERSONANDORGANIZATION (#3, #4, $);
#7 = IFCSIUNIT (*, .LENGTHUNIT., .MILLI., .METRE.);
#8 = IFCSIUNIT (*, .AREAUNIT., $, .SQUARE_METRE.);
#9 = IFCSIUNIT (*, .VOLUMEUNIT., $, .CUBIC_METRE.);
#10 = IFCSIUNIT (*, .PLANEANGLEUNIT., $, .RADIAN.);
#11 = IFCMEASUREWITHUNIT (IFCPOSITIVELENGTHMEASURE (57.29577951308232), #10);
.........
```

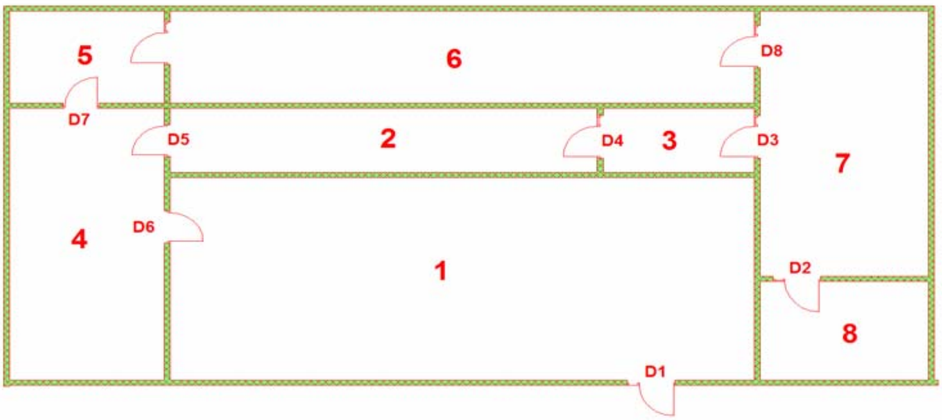

Fig.4 Example building model and IFC data file

5.1 Exporting IFC Space Model

First of all, a database needs to be developed to store space information from the IFC data file. The database structure is developed based on the simple space model shown in Fig., an entity relationship diagram is created to map the database tables (Fig.5). There are only two entities in the diagram, space and space exits (doors), the relationship between them is 'one space contains one or many space exits.' And 'one space exit is connected to one or two spaces.'

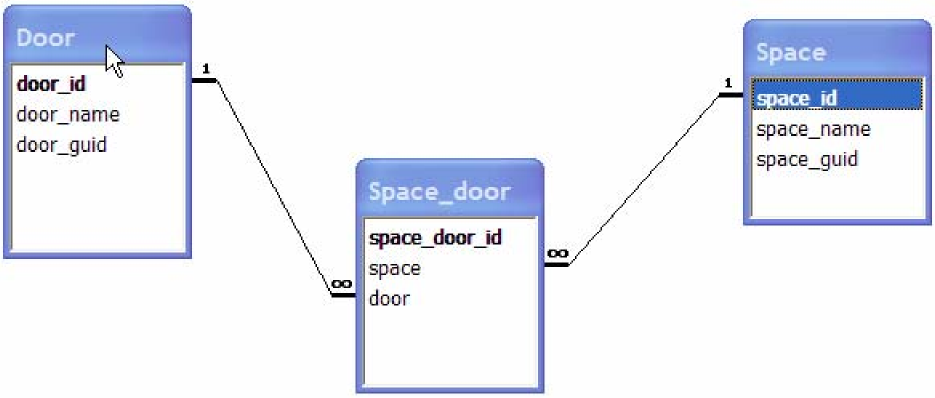

Fig.5 Space Data Table

The next step is to identify space information in IFC data file and export them to the database. The key IFC object for identifying the relationship between space and related building element is IfcRelSpaceBoundary, it has the following two attributes to enable the referencing.

- IfcRelSpaceBoundary.RelatingSpace – reference to a IfcSpace in question
- IfcRelSpaceBoundary.RelatedBuildingElement – reference to building element connected to above IfcSpace .

Here are the steps how to export the spaces information:

- Find all IfcSpace objects and IfcDoor objects to export into database
- Iterate through the IfcDoor objects and use INVERSE relationship with attribute, providesBoundaries to locate IfcSpace objects in the model which are connected to the IfcDoor object and export this information into database.
- From database, it is not difficult to establish a graph based on the space information, the spaces are the nodes (vertices) and the doors are the edges.

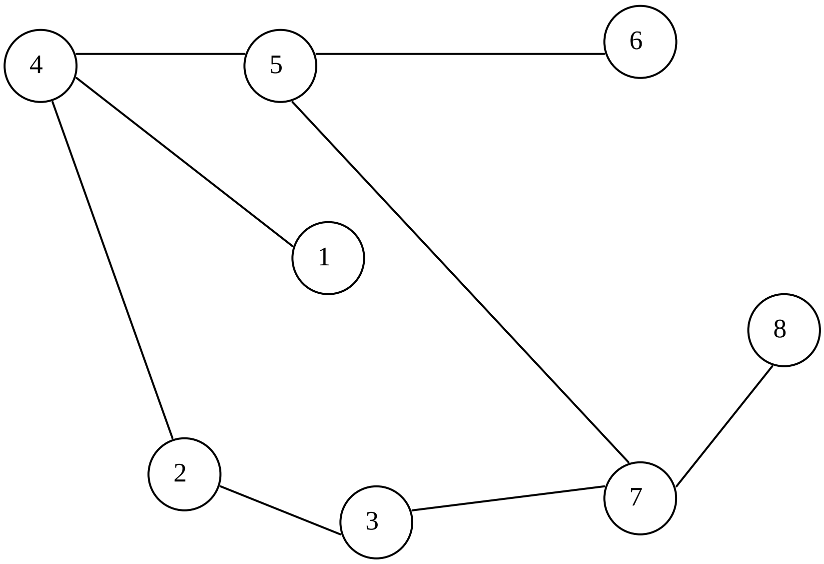

Fig.6 Graph Representation

The adjacency matrix of the above graph is:-

$$\begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}$$

With depth first search algorithm, paths for given two nodes can be generated, which means all possible routes between two spaces can be identified. Since the Space Syntax techniques are primarily based on the graph theory, most of the Space Syntax techniques can be used for spatial analysis. In this paper, the authors are looking into how the accessibility design criteria can be integrated into space flow analysis.

6. INTEGRATION OF ACCESSIBILITY DESIGN CRITERIA

The Building Regulation and the Disability Discrimination Act 1995 (DDA) has a major influence on accessibility and its requirement should be take into account in the design and management of buildings and the environment. From October 2004, it is intended that all service providers will have to make reasonable adjustments to the physical features of their premises to overcome physical barriers to access (Sawyer and Bright, 2004).

The Building Regulations that directly relate to access are Part M – Access and facilities for disabled people and Part B – Fire Safety. The Approved Document for part M regulation gives detailed guidance as to how the requirement may be met. It is overhauled to reflect the recommendations in BS8300:2001 (Sawyer and Bright, 2004). The following table is a summary of the accessibility criteria directly related to the space analysis based on the Approved Document and BS8300:2001. This list in the table is not exhaustive, and it is intended to highlight the areas for accessibility design criteria and how they can be analysed with the building information model. The Italic texts inside brackets are the analysis methods that the author suggests to use in the proposed analysis model. 'Check in IFC model' means to check relevant IFC entity to extract the information for analysis, such as doors – ifcDoor, dimensions of the doors. Usually the information is already included in the building model (IFC model) and checking can be carried out automatically to ensure that the criteria are met. 'Flag as information' refers the information required to perform the analysis is not directly available in the building model (IFC model) and the accessibility criteria information can only be highlighted to remind user (designer) that this information has to be considered in the design.

Items	Criteria *(Analysis Method)*
Entrance	• Access by everyone • Visible on approach • Location relate to external route and car parking • Sufficient space • Lighting level
Entrance Door	• Minimum clear opening 800 -900mm for single leaf *(Check in IFC model)* • Minimum 300mm space beside the leading edge of the door *(Check in IFC model)* • Door closer should be avoided or adjusted to minimum force *(Flag as information)* • Outward opening door should be recessed or adequate swing area *(Check in IFC model and flag as information)* • Vision panels should be provided in frequent use door *(Check in IFC model and flag as information)* • Glazed doors and side panel require manifestation to increase visibility *(Flag as information)* • Edges of glazed door should clearly visible *(Flag as information)* • Door furniture should be distinguishable *(Flag as information)* • Lever handles allow use by elbows or edge of the hand *(Flag as information)* • A kicking plate can protect a door from wheelchair *(Flag as information*

Automatic doors	• Automatic activation, manual activation should be clearly signed *(Flag as information)* • Swing door requires protection to swing area *(Flag as information)* • Sliding doors are generally preferred *(Flag as information)* • Doors should remain open for long enough *(Flag as information)* • Automatic doors require safety devices to ensure that the door does not close if there is an obstruction *(Flag as information)*
Thresholds	• Should be flush *(Flag as information)* • Maximum change in level is 15 mm *(check in IFC Model and Flag as information)*
Reception areas	• The waiting area should be quiet and well lit *(Flag as information)* • Sufficient space and unobstructed routes *(Flag as information)* • Furniture should be adequately contracted in term of colour and luminance *(Flag as information)*
Horizontal Circulation	• Clearly identifiable routes and layouts • Clear directional information should be provided
Corridor and passageways	• Minimum width of 1200 mm for corridors • Minimum width of 1800 mm when there are significant numbers of wheelchair users • Corridor widths should be unobstructed • Outward opening doors should be recessed
Surfaces	• Highly reflective finishes should be avoided *(check in IFC model and flag as information)* • Colour and luminance contrast will define different building element *(Flag as information)* • Floor surface should be firm, flush and slip resistant *(Flag as information)* • Carpet should be firmly fixed *(Flag as information)* • Surface-laid rugs and mats must be avoided in public buildings *(Flag as information)*
Internal Doors	• Minimum clear opening width 750-800 mm for single door *(Check in IFC Model)* • Sufficient space around door for manoeuvre *(Flag as information)* • Door opening into a circulation route should be recessed *(Check in IFC model and flag as information)*
Fire Doors	• Closing force exceeds 20 N, electrically powered hold open device should be installed *(Flag as information)* • Closing force with a push action in one direction should not exceed 30 N *(Flag as information)* • Smoke seals, install an angel seal as an independent item in the doorframe *(Flag as information)*
Visibility and Vision panel	• Similar to entrance door
Vertical circulation	• Ramps or lifts should be provided at all changes of level • All internal changes of level should be clearly indicated
Internal step and stairs	• Handrails should provided *(Check in IFC model)* • Isolated single step should be avoided *(Flag as information)* • Minimum width of stairs is 1000 mm *(Check in IFC model)* • Landing of minimum 1200 mm should be provided at each flight *(Check in IFC model)* • Maximum number of risers between landing is 12 *(Check in IFC*

	model)
Risers and goings	• The height of the riser should be 150mm – 170mm *(Check in IFC model)* • The going should be 250 – 300mm, 300 mm is preferred *(Check in IFC model)* • Open risers and deeply recessed risers should not be used *(Flag as information)* • The nosing of each step should be adequately contrasted with the reminder of the step *(Flag as information)*
Internal Ramp	• Ramps in internal corridor should be highlighted to increase visibility. *(Flag as information)* • Ramps should always have suitably designed handrail *(Flag as information)*

Table 1 – Accessibility design criteria

Fig.7 is a flow chart for space analysis with accessibility perspective. It starts with calculating the possible routes for two selected spaces and all the possible routes information will be stored in a database. Each route in the database will be checked against accessibility design criteria. The accessibility design criteria is a rule based database that includes information such as dimension requirements of space, size requirements for doors, and functional requirements for space, etc. For example, typical rule is 'width of door shall be big than 800mm'. Therefore, each route is checked against all the rules in the database to ensure that the door is wider enough for wheelchair user, space is accessible to all users, etc. However, as listed in table 1, accessibility design criteria are not limited to the physical dimension of spaces or doors and it also includes lots of subjective requirements and such information can not be directly analysed by current proposed method. Other IT tools such as Virtual Reality can be used and further research of how other IT tool can support the accessibility analysis needs to be carried out.

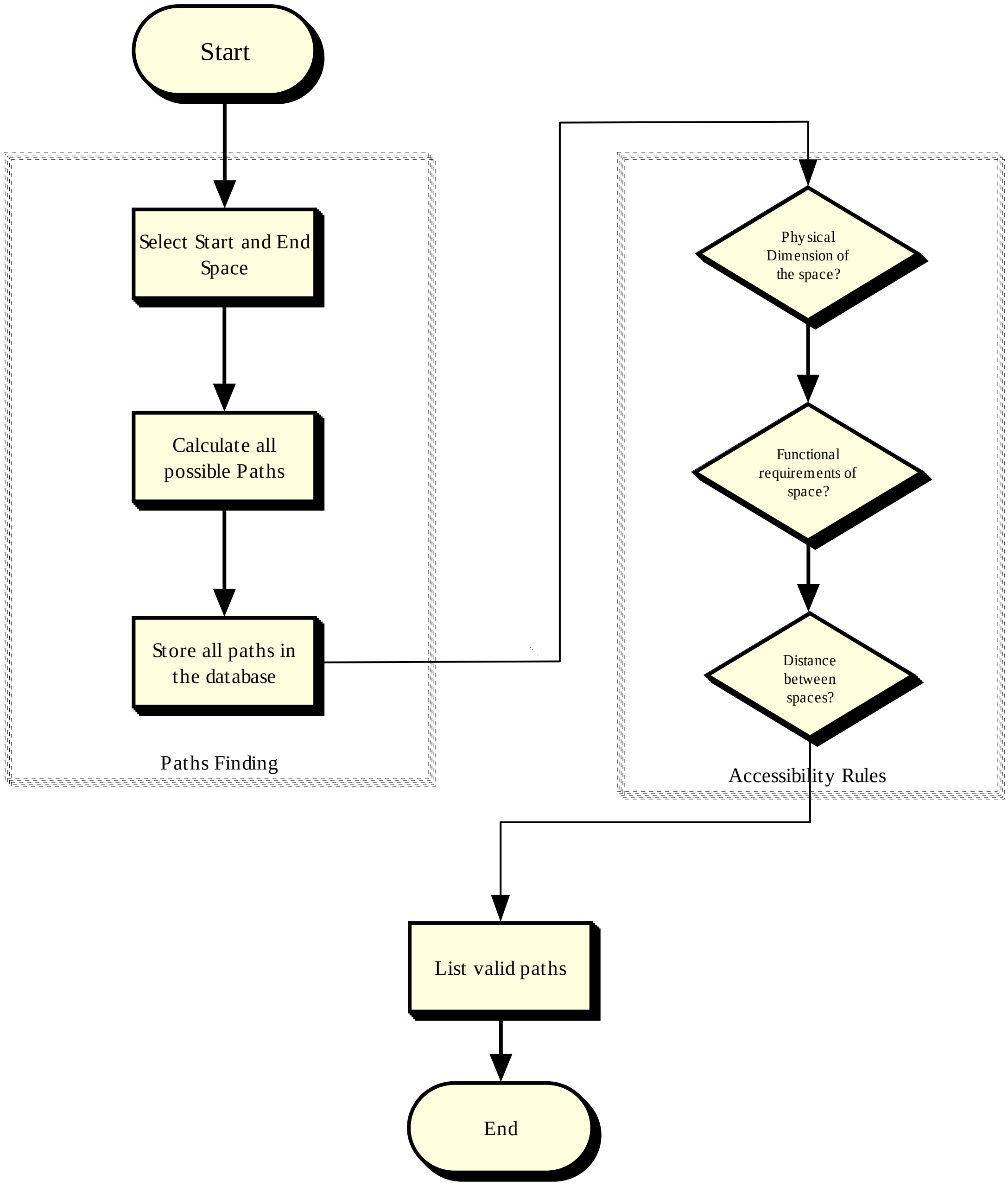

Fig. 7 Space flow analysis for accessibility

8. CONCLUSION

Over the years, inclusive design has become an important concept in the built environment. It aims to create a friendly and welcoming environment to everyone regardless of their age and physical ability. With the introduction of DDA and part M of the building regulations is going to take full effect in May 2004, the compliance of the accessibility design criteria is more important than ever before. This paper is an attempt of simplifying the accessibility assessment process through exploring the potential of the IFC based building information model with existing space analysis techniques. The research has demonstrated the capability of the technology and its potential.

However, further research is required to investigate how the more subjective information can be integrated and analysed and practical implementations need to be carried out to validate the outcome of the research.

ACKNOWLEDGEMENT

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