THREE-DIMENSIONAL MODEL DATABASE FOR SPACE UTILIZATION AND PLANNING USING TERRESTRIAL LASER SCANNER DATA

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Special dedication to my beloved family:

Sulaiman bin Narawi

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ABSTRACT

Space management is not only concern about the quantity but also the quality of the space allocated as well. It is a waste of resources to have unused or underused space. Several factors influencing the quality of space management are limited information on rooms and spaces and number of occupants filled in a room does not reflect the room capacity. The difference between this research and others is in the utilization of Building Information Modelling (BIM) tools for indoor space management. By using BIM tools for space utilization and planning, user can freely design the 3-dimensional (3D) models either based on point cloud or design measurement. Furthermore, BIM tools provide users the power to manage and analyze the 3D model data in the database system. This research were conducted to achieve three objectives; to generate 3D models of existing indoor space and furniture using terrestrial laser scanner captured data; to create 3D model database system; and to manipulate the 3D model data to assist the decision-making process in space utilization and planning application. This research utilized the created 3D model which can provide the true geometry and condition of a room and by acting in accordance with the International Building Code, it can be used to tackle the problem of room capacity with respect to health and safety requirement. With geometrically accurate 3D model, it can give the right information for the analyses of functional area allowances, occupant load and exit capacity. Method proposed in this research can ease the process of space utilization and planning by having the ability to analyze space requirement and manage 3D model database in one software.

ABSTRAK

Pengurusan ruang bukan sekadar mengenai kuantiti tetapi juga kualiti ruang yang diperuntukkan. Ruang yang tidak digunakan sepenuhnya merupakan suatu pembaziran sumber. Beberapa faktor yang dikenalpasti mempengaruhi kualiti pengurusan ruang adalah maklumat ruang dan bilik yang terhad dan bilangan pengguna dalam suatu bilik tidak bersesuaian dengan kapasiti ruang tersebut. Perbezaan antara kajian ini dengan yang lain adalah dari segi penggunaan peralatan Permodelan Maklumat Bangunan (BIM) untuk pengurusan ruang dalaman. Dengan menggunakan peralatan BIM untuk perancangan dan penggunaan ruang, pengguna boleh merekabentuk model 3-dimensi (3D) secara bebas sama ada berdasarkan titik-titik awan atau pengukuran. Tambahan lagi, peralatan BIM memberi pengguna kuasa untuk menguruskan dan menganalisa data model 3D dalam sistem pangkalan data. Kajian ini dijalankan dengan tiga objektif; menghasilkan model 3D ruang sedia ada dan perabot menggunakan data yang diperolehi oleh pengimbas laser terestrial; menghasilkan sistem pangkalan data model 3D; dan memanipulasi model 3D yang dihasilkan untuk membantu dalam proses membuat keputusan untuk penggunaan dan perancangan ruang. Kajian ini menggunakan model 3D yang dapat memberikan ukuran dan keadaan sebenar sesebuah ruang dan apabila bertindak selari dengan Kod Bangunan Antarabangsa, ia dapat mengatasi permasalahan kapasiti ruang dengan mengambil kira keperluan kesihatan dan keselamatan. Dengan 3D model yang tepat geometrinya, ia akan memberi maklumat yang jitu untuk analisis muatan penghuni, pemberian kawasan berfungsi dan kapasiti jalan keluar. Kaedah yang dicadangkan di dalam kajian ini dapat memudahkan proses perancangan dan penggunaan ruang dengan memberikan pengguna keupayaan untuk menganalisa keperluan ruang dan menguruskan pangkalan data model 3D dalam satu perisian sahaja.

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LIST OF ABBREVIATIONS

3D	-	Three dimensional
AEC	-	Architecture, Engineering and Construction
BIM	-	Building Information Modeling
DBMS	-	Database Management System
DSI	-	Dewan Sultan Iskandar
ER	-	Entity-Relationship
FGRE	-	Faculty of Geoinformation and Real Estate
FM	-	Facilities Management
HDS	-	High Definition Survey
IBC	-	International Building Code
UTM	-	Universiti Teknologi Malaysia

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CHAPTER 1

INTRODUCTION

This chapter was written as to introduce, emphasize and highlight the main ideas of this research. There are seven sections under this chapter. It covers the topic on the research background, problems statement, the aim and objectives of the research, scope of study, significant and thesis organization.

1.1 Background of Study

Space management is an essential element within facilities management structure of either private or government buildings. ESRI (2009) defines it as a complex process projecting space requirements, identifying deficiencies, allocating available space to users in an equitable way, monitoring use, assisting users with space usage problems and solve space management issues. In a large organization, space management issues are placed under the responsibilities of in-the-house facilities management team. **Figure 1.1** below shows several tasks put under space management team of each organization, but in most organization, the scope of work are similar with each other such as space planning, space utilization analysis, change management, capital investment allocation and space inventory record. Similar to facilities management, space management not only concern with the quantity of

space owned but must address the quality of the space allocated as well. Space equals to costs. In term of funds, it is a waste to have unused or underused space. Hence, it has to be managed like other resources too. Many corporations have recognized the importance in having space management practice. Hence, they changed the way they buy or lease, manage, sustain and utilize their spaces. In term of space management, this research focuses on the matter of space planning and utilization only.

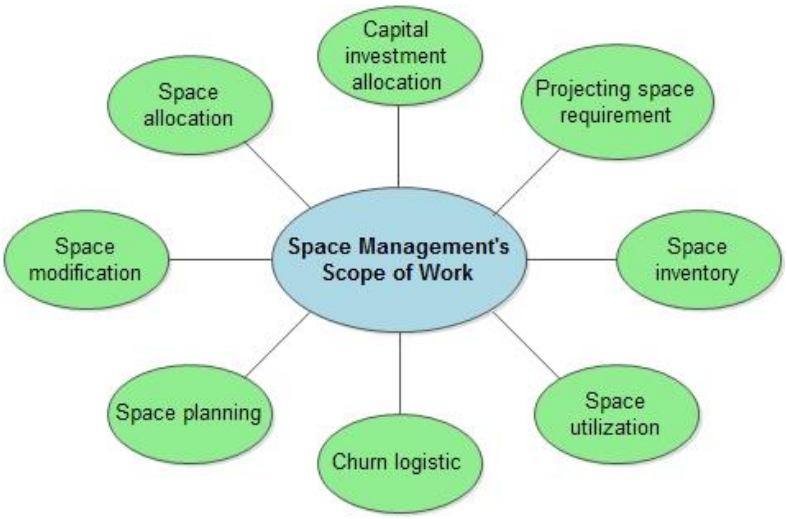


Figure 1.1: Scope of work in space management (modified from Maline, 2012)

Space utilization is considered as the most important, most challenging and perhaps most controversial issues face by organizations and agencies (Knaap *et al.*, 2009). It is a matter of how efficient a space is being used to fulfil the mission and purpose of the organization (Space Management Group, 2006). To measure the efficiency, analysis of space utilization must be done according to the standard, formula and calculation set up or followed by the organization itself (e.g. Canada government using standard published by Northwest Territories). Space utilization analysis is the process of providing analytical tools to determine space requirements and measure the practicality of existing or proposed option (Illinois, 2010). Requirement level of space utilization for each space depends on the standard or guideline adopted by the organization.

Space planning is the act of creating a layout of furniture coordinated with the physical space of a structure while performing an analysis of the layout design from the aspect of efficiency (Jarrett, 2013) as shown in **Figure 1.2**. To create this kind of environment, guidelines and standards with determined measurement has been published by many organizations, that when followed will guarantee a better access to any functional areas existed and at the same time can improve the productivity and quality of the occupants within the building space. Space planning is important to every size of area from indoor to outdoor. This statement is supported by a number of books, guidelines, policies and procedures created by bodies and organizations throughout worldwide regarding how space should be planned and managed (TEFMA, 2005; IPD, 2007; Manitoba, 2010; and Space Management Group, 2006) either for their own purpose or public, towards achieving a better space utilization. Until today, there is not much discussions regarding space management, but there are still a number of researches done regarding space management, optimization and utilization from the aspect of technology and efficiency (Yusdira *et al.*, 2012; Saifallah and Mehdi, 2000; Jo and Gero, 1998). Several published space standard/guideline and International Building Code were adopted to act as references in space evaluation later on.

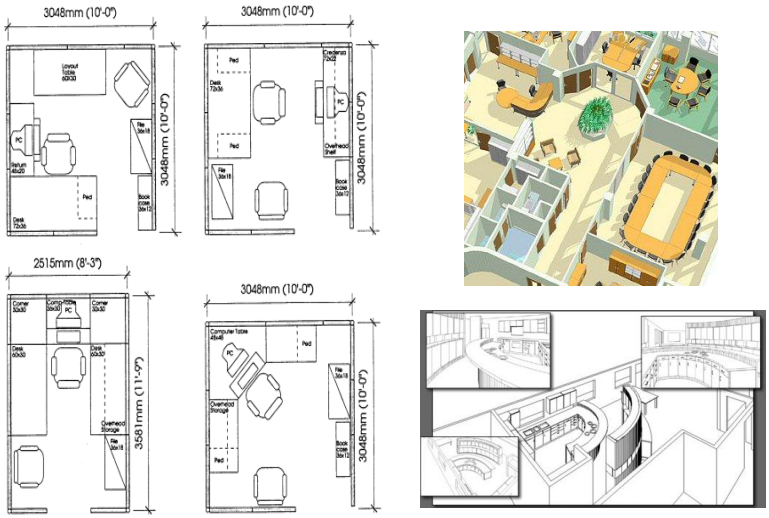


Figure 1.2: Space planning with human ergonomic factor (modified from Queensland Government, 2012 and State of Alaska, 2013)

The best way to present an idea efficiently is through three-dimensional (3D) model or 3D visualization. In this day and age, these methods have always been a technique for persons especially in the AEC (Architecture, engineering and construction) industries to communicate their ideas, be it for construction, electrical or interior design (Fischer *et al.,* 2003). These methods are used to achieve an improved knowledge of spatial structures and phenomena of each building. Moreover they are used to communicate projects to public, stakeholders and decision makers. According to Ross and Kleinschmit (2007), 3D visualization is the best way to communicate and exchange ideas with someone who is not in the same profession, who only has a little knowledge in reading the layout plan (e.g; architect and client, contractor and administrator etc.).

To make the 3D model become more meaningful to other group of users, Building Information Modelling (BIM) must be introduced to the system. International Facility Management Association (2010) defines BIM as a digital representation of physical and functional characteristic of a facility and a shared knowledge resource for information regarding the facility, forming a reliable basis for decision making during its life-cycle. BIM incorporates many different tools and processes. BIM provides a 3D representation of a building, database storage mechanisms for properties and parameters of all the elements in the building (Zyskowski and Valentine, 2009) and at the same time provides tools to analyze space usage. This research adopts BIM into interior design task by placing, documenting and scheduling objects and items such as furniture and equipments. According to Johnston (2011), some benefits by integrating BIM for interior design are;

a) The speed and ease of creating an interior design model, coupled with the ability to visualize the design,
b) The ability to capture and manage the design such as space layout and material selection in a single model, and
c) The richness and reliability of the data embodied within the model.

In conclusion, this research focuses on how 3D model data can help facility manager, designer or planner to analyze space requirement, utilize and manage a space. 3D models are created based on terrestrial laser scanner point cloud data. For a better application of space planning and space utilization, created 3D models are stored in BIM software, specifically Autodesk *Revit Architecture*. Furniture creation and layout are part of tasks in architectural field. Autodesk *Revit Architecture* provides functions for 3D models creation, database management together with building-related analysis, which is suitable for the purposes of space utilization and planning. The created 3D models are then manipulated, also in *Revit Architecture*, as to conduct analysis on space evaluation for space utilization and planning, which require information on geometrical data of the area.

1.2 Research Problem

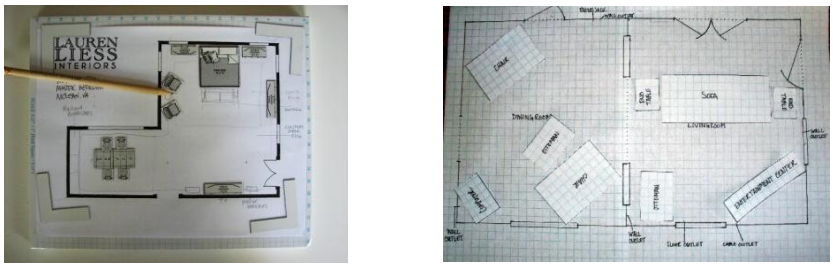
Malaysia government expects the country to be a fully developed country by the year 2020 with one of its great mission in becoming one is to create at least an average status in economy while having full possession of an economy that is competitive, dynamic, robust and resilient (Prime Minister's Office, 2010). Studies on space management in Malaysia revealed that expenses related to space are the second highest after staff salaries (Ihfasuziella *et al.,* 2011). Space management has always been an issue in Malaysia government sectors especially where a number of failures have been recorded for spaces to achieve functional optimization and limited number of facilities to support space functionality (Yusdira *et al.,* 2012). These problems can be tackled with a good space management practice which will increase the financial profit and source usage efficiency and reduce operational and maintenance cost in a long run. Mohd (2009) mentioned several factors influencing space management including space planning and space utilization as;

a) No space management guideline,
b) Person in charge of space management has no background of the related field,
c) Low understanding of space utilization, and
d) Limited information on rooms and spaces.

According to Rozilah *et al.*, (2012), the cost of maintaining space has contributes a large portion into the cost of operational and maintenance of facilities. In order to reduce the unnecessary cost in space maintenance, an organization must understand the concept of space utilization. Space utilization is a qualitative measurement of whether and how space is being used (Space Management Group, 2006). Based on National Audit Office (1996), the level of satisfaction on space utilization are divided into three categories; poor (less than 25%), fair (25% to 35%) and good (more than 35%). Lately, researches regarding space utilization in Malaysia have been extensively conducted. From the findings, the quality of space utilization in Malaysia falls under the category of between poor and fair (Rozilah *et al.*, 2012; Mohd, 2009; Yusdira *et al.*, 2012 and Ihfasuziella *et al.*, 2011). Factors affecting the quality of space utilization discover by Mohd *et al.* (2012) are;

a) Number of occupants filled in a room does not reflect the room capacity,
b) Limited number of space and facilities, and
c) Lack of understanding in space utilization.

Space planning problems are listed as the problems of object placement, space partitioning, cutting-stock and circulation or routing (Charman, 2004). Many organizations in Malaysia especially which belong to government still practice on traditional methods for space planning such as pencil and tracing paper, drawing grids and on-site arrangement (**Figure 1.3**). On-site arrangement is when the person responsible for space planning has to go down to that particular area or space to inspect the condition and make a decision on how to arrange the furniture on the spot. A good space planning needs a guideline as a reference for proper furniture arrangement corresponding to organization's mission and goals. An interview conducted with responsible person for space planning in Universiti Teknologi Malaysia, Musaad (2013) mentioned that the university still practices manual methods for space planning which is on-site arrangement and to make it worst, there are no references for the furniture arrangement. It is only based on logical thinking of the planner.



(a) (b)

Figure 1.3: Conventional methods for space planning; a) Pencil and tracing paper; and b) Drawing grid (Copenhagen Furniture, 2005)

Alternative and modern ways for space management such as 3D model and BIM has already been used by other countries such as United States, United Kingdom and Australia (Keegan, 2010). There is a high demand on the usage of 3D model and BIM in project development (Huber *et al.,* 2010). But in Malaysia, due to short of experts in related field, lack of skill and low understanding and awareness, these technologies seem to be lagging behind in terms of implementation and understandings (Teo, 2012). There are still too many responsible groups who are not been exposed yet to these tools which can somehow simplify space management task. These technologies are very important as they meet the standards and expectation of today's world where efficiency of both time and content management takes priority for success to emerge.

With limited building spaces, the need for a better space planning and space utilization is indeed essential for an organization in order to provide satisfaction towards the needs of customer as well as to efficiently use the spaces and properties. An organization need a mechanism to ensure that their spaces shall be effectively managed for maximum utilization which is then lead to cost reduction. It is envisaged that this research can give some contribution in space management field by showing a method which can simplify the task and at the same time create awareness among users especially facility managers on how to use the proposed technologies and method to create an efficient workspace environment while fulfilling the purpose and mission of the organization.

1.3 Research Aim

The research aim is to investigate the use of terrestrial laser scanner data to model and visualize space for space planning and utilization and space evaluation.

1.4 Research Objectives

This research is conducted to achieve the following objectives;

a) To generate 3D models of utilized indoor space and furniture using terrestrial laser scanner captured data,
b) To develop a 3D model database system for the application of space planning and utilization, and
c) To manipulate the created 3D models so it can be used to assist the decision-making process for the application of space planning and utilization.

1.5 Scope of Study

Recently, the technology of terrestrial laser scanner has been applied for 3D modelling of every kind of objects and geometric data acquisition such as building and machine. Since the use of terrestrial laser scanner as an instrument for 3D data acquisition has attracted considerable attention worldwide in various type of application such as 3D modelling of indoor environment, building, cultural heritage and facilities (Yokoyama and Chikatsu, 2004), hence, terrestrial laser scanner is used as an instrument in this research to capture and utilized indoor space which have already been filled with furniture and equipments. From the data acquisition, 3D indoor models is generated which consists of the room itself and objects, furniture and equipment within. Measurements from captured point cloud data are then be compared with measurements acquired from total station and distometer. Besides that, the point cloud data are also compared to the created 3D model to check on the

reliability of the software used (*Revit Architecture*) to create an accurate 3D model using point cloud as reference.

To create an efficient working environment, it is important for an organization to follow some standard and guideline. In this research, two type of study areas has been used; 3D Measurement Lab and Dewan Sultan Iskandar's (DSI) multi-purpose hall. Both study areas are the properties of Universiti Teknologi Malaysia. At present time, the development of space planning standards for Universiti Teknologi Malaysia is still in progress and has not yet completed (Mohd *et al.,* 2012). So, for the analysis of space evaluation later on, several guidelines and standards which have been published by other organizations are selected. There are many aspects which can be looked through in each standard or guideline such as size of workspace, waiting area, cabinet and printing area. Each of the aspect adopted one of the standard or guideline, whichever suggests the smallest size of the functional areas. The reasons why this research used two different areas are due to the differences in size and utilization level. DSI multi-purpose hall is a large and semi-utilized area, while 3D Measurement Lab is a small but a fully utilized area.

The created 3D models are then manipulated to obtain the actual area of desired part of the room and compared them to the adopted standard/guideline. From the obtained area value, occupant load and functional area allowances can be calculated. Occupant load can be defined as permissible number of occupants can be accommodated by a building at a time by using the information on total area of the room and floor area allowances per occupant as stated in International Building Code (International Code Council, 2012). In the analysis of functional area allowances, the area of each functional area are compared to corresponding adopted space planning standard or guideline in order to check whether each functional area has achieved the adopted standard requirement or not.

From the created 3D model, the width of existing doors in the area is measured to calculate the exit capacity of the room and compare it to the calculated

occupant load. Exit capacity can be defined as the maximum number of occupants can access through an exit safely during emergency outbreak. The calculated exit capacity are then compared to the value of occupant load in order to determine the most suitable maximum number of occupant can be accommodated in a building taking into consideration the floor area allowances per occupant and the total area of the room.

Database system is developed for the 3D model data. In order to make it seems more meaningful towards other users, data attribute for the furniture and space such as furniture information have been inserted into the database system. The database system consists of fields and tables with 3D model geometry data, information on the space and furniture and calculation required to determine space requirement. From the tables created in the database system, space evaluation can be conducted which cover the analysis of occupant load, exit capacity and functional area allowances. Other analysis was also conducted to check on the reliability of the created database in term of database management.

1.6 Research Gap

A research chronology was mapped to emphasize the difference between this research and others. Referring to **Figure 1.4**, there are five stages involved to represent the chronology of this research; 3D data collection, 3D indoor modeling, space planning and utilization, space evaluation and database development. For 3D data collection, 3D indoor modeling and space evaluation, techniques used are the same as other researches. But there is a difference in the technique used in space utilization and planning and database development.

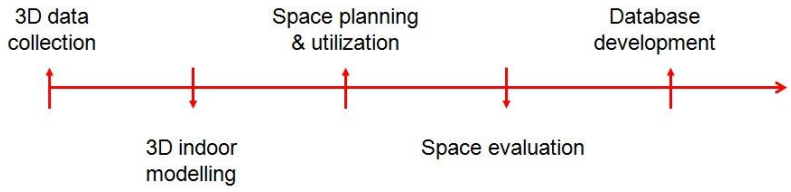


Figure 1.4: Research chronology

Space planning can be done towards the interior or exterior of a building. For this purpose, many organizations use 3D models to represent the environment. Depending on the application, the 3D model created may set to be editable or non-editable. Referring to **Table 1.1**, Yu *et al.* (2005) and Merrel *et al.* (2011) have created a system which can automatically rearrange all of the furniture in a room according to the set standard. This system was meant for all type of users with or without knowledge on 3D model creation, since the 3D model of furniture has been generated and stored in the system catalogue. For editable 3D model, it is usually used for exterior space planning (Keegan, 2010; and Gore *et al.*, 2012), where there is a need to manipulate the 3D model itself to fit into the situation. A system created with non-editable 3D model can only be used in a simple environment (e.g. home planning) and is not fit to be used for other purpose. So, that type of technique is not practical for multilevel building and multi-purpose function. For that reason, this research used editable 3D model for indoor space utilization and planning purpose.

Table 1.1: Research gap in space utilization and planning

Author (s)	**3D Model**		**Space Planning**		**Application**
	Editable	**Non-editable**	**Interior**	**Exterior**	
Yu *et al.* (2005)		√	√		Space planning
Merrel *et al.* (2011)		√	√		Space planning
Keegan (2010)	√			√	Renovation
Gore *et al.* (2012)	√			√	Construction
*This research	√		√		Space planning

Database system is used for data management. For the purpose of analysis, a lot of research such as Ihfasuziella *et al.* (2011) and Shahabuddin *et al.* (2012) did not use any database system. Mostly, the analyses were done to determine the result on occupancy which dealt with the attendance of the occupants. This research is conducted to determine the result on the utilization of space by fittings and furniture. For this research, a database system was developed to store all the documents related to space utilization and planning which is useful for other application such as indoor renovation and asset management. **Table 1.2** shows the research gap on database development.

Table 1.2: Research gap on database development

Author(s)	**3D Model**	**Database on Asset/Space**	**Space Evaluation**		**Purpose**
			With Database	**Without Database**	
Ihfasuziella *et al.* (2011)				√	Space analysis
Shahabuddin *et al.* (2012)				√	Space analysis
Yu *et al.* (2009)	√	√	√		Maintenance management
Zhang *et al.* (2009)	√	√			Asset management
*This research	√	√	√		Space analysis

1.7 Significant of Study

One of the outcomes of this research is 3D models of indoor space and furniture and equipments within. 3D models are known to be a very useful tool in many applications (Yokoyama and Chikatsu, 2004). 3D models represent the true condition and geometry of an object. So, it can be used by facilities manager, technical department and even planner or designer for measurement purpose or visualization. The generated 3D models can then be used to assist space planning task which will allow respected person for space planning to view the relative size and proximity of the indoor space and thus allowing them to visualize current conditions and plan for a better space planning solutions. The 3D models also allow a planner to manually adjust the conditions of the room while keeping abreast with organization standard.

By using 3D model for space planning, it can illustrate much more useful information (e.g. true object dimension and position; ground, over-the-head and on-the-wall object) rather than the typical 2D model. Through an efficient planning approach, space will be ensured to be used efficiently and effectively alongside with the organizational goals for both now and in the future. Referring to Department of Army (2006), the purpose of space planning and space utilization is to create efficient space within facilities to support assigned tasks. 3D model integration will help a lot in space planning and management for many type of users with the purposes are to;

a) Use existing facilities, property, and space in an efficient manner,
b) Reduce the need to construct, rent, lease, or acquire new space unreasonably, and
c) Take action to deal with shortfalls or excesses in shorter time period.

Space utilization must be analyzed and evaluated to determine the qualitative measurement of whether and how space is being used. The analysis will tell whether

the space is under utilize, fully utilize or over utilize. It can then be used for space audit to determine further action to be taken for that particular space; remodelling, renovation or moving out. Space evaluations are conducted using International Building Code and other space planning standard or guidelines as reference. For standards or guidelines, there are many different suggestions on the most appropriate size for each type of functional area. Since Malaysia has a problem of limited number of facilities provided (Mohd *et al.*, 2012), hence in the opinion of the writer, it is only proper to use the smallest size suggested. Not only it can solve the problem, but at the same time the suggested size for functional area provides comfortability to occupants (Bozarth and Vilarinho, 2006).

1.8 Thesis Organization

Altogether, there are six chapters in this research thesis. Chapter 1 highlights the mains ideas of the research. This chapter can be assumed as a brief summary on how and why this research was being carried out by putting an explanation on the background of the study, problems arise in current method, the aim and objectives of the research, the scope and limitation of the study, significant or contribution of this research and the organization of the thesis.

Chapter 2 reveals the previous and current methodology in capturing and processing spatial data and the technique used by organizations in space management, particularly space planning and utilization.

Chapter 3 discusses the methodology used in this research, from spatial data capturing and processing, 3D modelling to spatial data utilization in assisting the application of space planning and utilization. At the end of the chapter, there is a brief explanation on the type of analysis which can be conducted by utilizing the captured spatial data.

Chapter 4 converses in detail regarding the results obtained and analyses which can be conducted towards the captured spatial data which eventually transformed into 3D model in order to assist the application of space planning and utilization.

Chapter 5 summarizes the overall research and at the same time answers the aim and objectives of this research. Furthermore, suggestions of recommendatic are being explained on how this research can be further improved in the future.

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