Process based synthesis to evaluate design flexibility in airport terminal layout

Sarah Shuchi[1] and Robin Drogemuller[1]

[1]Queensland University of Technology, Brisbane, Australia

ABSTRACT: Flexible design concept is a relatively new trend in airport terminal design which is believed to facilitate the ever changing needs of a terminal. Current architectural design processes become more complex every day because of the introduction of new building technologies where the concept of flexible airport terminal would apparently make the design process even more complex. Previous studies have demonstrated that ever growing aviation industry requires airport terminals to be planned, designed and constructed in such a way that should allow flexibility in design process. In order to adopt the philosophy of 'design for flexibility' architects need to address a wide range of differing needs. An appropriate integration of the process models, prior to the airport terminal design process, is expected to uncover the relationships that exist between spatial layout and their corresponding functions. The current paper seeks to develop a way of sharing space adjacency related information obtained from the Business Process Models (BPM) to assist in defining flexible airport terminal layouts. Critical design parameters are briefly investigated at this stage of research whilst reviewing the available design alternatives and an evaluation framework is proposed in the current paper. Information obtained from various design layouts should assist in identifying and defining flexible design matrices allowing architects to interpret and to apply those throughout the lifecycle of the terminal building.

Conference theme: Design education and computing

Keywords: Airport terminal, business process, design flexibility, flexible design framework

INTRODUCTION

Flexibility in building design can accommodate inevitable uncertainty and changes in design by re-arranging design commitments and preserving design decisions. Airport terminal buildings are one of the most complex building types that are used in our everyday life. The nature of their functions, the scale of the structure, the strict security measures and the function-specific components increase the level of complexity as a building type. In a real design situation, incorporating the variety of design parameters involved in an airport terminal could be a very difficult task to manage and might become an impediment to the design process. The continuous changes in such a volatile environment require new design approaches to allow for short to long term flexibility. However, determination of flexible design attributes and to evaluate flexibility in airport terminal design is a critical task; this will require accommodating a wide range of changes in design decisions, terminal operations and the relevant facilities. In order to adopt the philosophy of "design for flexibility", the aviation industry must change its view of the world and its place in it. Airport planners and architects need to address a wide range of differing needs with an emphasis on both functionality and flexibility. User flexibility or adaptability in building design, in the context of residential buildings, flexibility is a widespread concept, whereas the need for flexible design for airport passenger buildings is only recently gaining recognition (de Neufville and Belin, 2002; de Neufville et al 2008). The concept of flexibility in terminal design is a relatively new initiative and there are limited guidelines available to assist designers.

To understand the flexible design approach in airport terminal design, appropriate recognition of the relationships between the processes that take place within an airport terminal and the relevant designed spaces is one of the foremost requirements. The main challenge around the question of flexibility exists due to the difficulty in predicting the required spatial layout and their related activities over the time (Haworth, 2009). The spatial allocation contributes to a design process in two ways - by generating spatial layout that can appropriately respond to any changing situation and by allowing us to understand the correlation between a particular spatial relationship and its influence on physical solution (Eastman, 1975). Previous studies on space allocation for terminal buildings considering queuing theory approach (Ma et al 2011) attempted to establish relationships between passenger movement and terminal space. A number of researchers proposed some level of service standards to provide guidelines on the required amount of space per passenger (Correia and Wirasinghe, 2007;

de Neufville and Odoni, 2003; Mumayiz, 1990), whilst some other researchers investigated space allocation techniques for commercial activities (Hsu and Chao, 2005). The significance of business process for various terminal activities, however, has not been recognized in the literature; this has rarely been accounted for to optimize the design process of airport terminals. Business processes should play a significant role in allocating appropriate spaces within a terminal building. The traditional building design process ignores the significance of information flow from the process model to the actual building design. Synthesis of process model to support the development of more integrated design practice expected to contribute considerable benefit to the architects and the planners to understand the flexible spatial requirements of a specific function.

This paper presents an evaluation framework for process based synthesis and briefly discusses the relevant evaluation criteria. Both synthesis and evaluation are integrated in a single model for producing alternative design solutions to meet a given set of requirements. This paper is divided into three parts. The first part discusses the proposed preliminary Flexible Design Framework (flexDF) (Shuchi et al 2012) and then the framework is elaborated to suit the design purpose. The conceptual framework is discussed herein to explain the generic principles of flexibility in airport terminal design. The framework facilitates the designers to appropriately handle the present requirements and to cope with the ever changing future needs. In the second part, a generalized method (Shuchi & Drogemuller, 2012) for utilizing Business Process Models (BPM) has been discussed with a view of extracting design related information to incorporate within the design process. The final part of the paper brings the aforementioned concepts together that integrate and extend the focus on identifying flexible design parameters and design constraints to ultimately achieve a flexible design metrics. The goal of this research is to develop a design framework for flexible terminal layout that will provide a useful link between the proposed flexDF and the information obtained from the available business process models. The scope of the proposed integration framework is believed to go beyond the terminal design process towards a generalised conceptual flexible design concept to facilitate building designers as well as the clients involved.
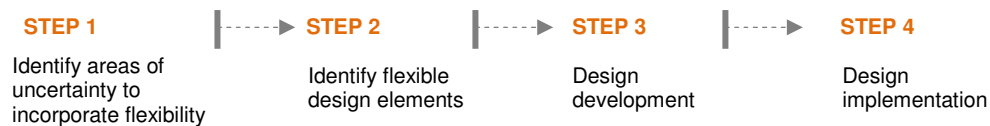
1. FLEXIBLE DESIGN FRAMEWORK (flexDF)

Although airport terminal buildings are relatively new building design type, the need for flexibility in airport terminal design has already been identified by several researchers (Edwards, 2005; Kronenburg, 2007; de Neufville, 2008). The overall perspective to achieve flexibility in terminal design depends on a large number of factors such as economical shifts, regulatory changes, uncertainty in forecasts etc. Within the functional pattern of an airport, the only basic and relatively stable element is the runway (Kronenburg, 2007). Flexibility in airport terminal design mainly concerns the passenger buildings, where occupants are mostly individual airlines and other stakeholders. Flexible development of airport facilities not only requires leaving sufficient room for expansion but also requires allowing spaces to accommodate major shifts in traffic patterns over its lifecycle. Appropriate prediction of the pace of changes throughout the lifecycle of an airport terminal is a prerequisite to implement flexibility in the design process. The typical changes that are expected within an airport terminal throughout its lifecycle may be broadly categorised under operational, strategic and tactical flexibilities. These are largely dependent on how fast the facilities of an airport terminal would require appropriate changes. Operational flexibility refers to the ability to adapt recurrent and quick changes in airport terminal on a daily or weekly basis such as furniture or other fittings of a terminal to deal with short term volatility. Sunshine Coast Airport in Queensland, Australia provides a good example of shared use facilities, where check-in counters are shared by airlines at different periods of the day. Tactical flexibilities are somewhat slower in changes, for instance day-to-day operational changes occur in ticket counters check-in desks, signs etc. Long term strategic changes take time and normally involve structural modifications. Adoption of a modular form is considered as a simple yet useful solution to add flexibility from the strategic perspective as it allows expansion or modification based on future demand.

A Flexible Design Framework (flexDF) has recently been proposed by Shuchi et al, 2012 makes an effort to correlate the knowledge in flexible design elements to the design principles specific to airport terminal design in a holistic manner. Functional effectiveness and flexibility in planning and in the design process of airport passenger buildings was analysed in three broad categories i.e. design development, timescale and design elements. The framework suggested achieving macro level flexibility in airport terminal design under two main categories – physical structure and spatial layout. Based on these two categories design decisions have been discussed in short, medium and long term perspective, which are further classified under appropriate timescales as operational, tactical and strategic flexibility accordingly. The presented framework is an initial step towards achieving a complete flexible design strategy for airport terminal design.

The current paper has expanded flexDF into a 'Four Steps Process' for developing flexibility in terminal design. Step 1 is to recognize the uncertainties of airport terminal design in terms of spatial layout and physical structure. Step 2 identifies the specific design elements that would enhance the flexibility of various airport facilities. Step 3 is the design development process that will implement the identified flexible design elements to cope with the possible uncertainties. Step 3 also evaluate design alternatives, where alternative design solutions will be evaluated by analysing the design elements identified in Step 2, at this stage, the selected design elements will be coupled with both the measuring factors (construction cost, operating cost and maintenance cost, time etc)

and the design constraints to achieve an optimum solution. The final step is the implementation phase, in which strategic issues will be identified and implemented. The design elements identified in the proposed framework are based on some preliminary findings. The amount of data to be collected, reviewed and analysed to identify appropriate design elements as well as the outcomes of the process will vary depending on the planning process, the size and the structure of the airport organization and the number of stakeholders involved in the process. The detailed considerations required to complete the aforementioned five phases will be developed in future research.

STEP 1 → **STEP 2** → **STEP 3** → **STEP 4**

Identify areas of uncertainty to incorporate flexibility

Identify flexible design elements

Design development

Design implementation

Figure 1: $ Steps of flexible design framework (flexDF)
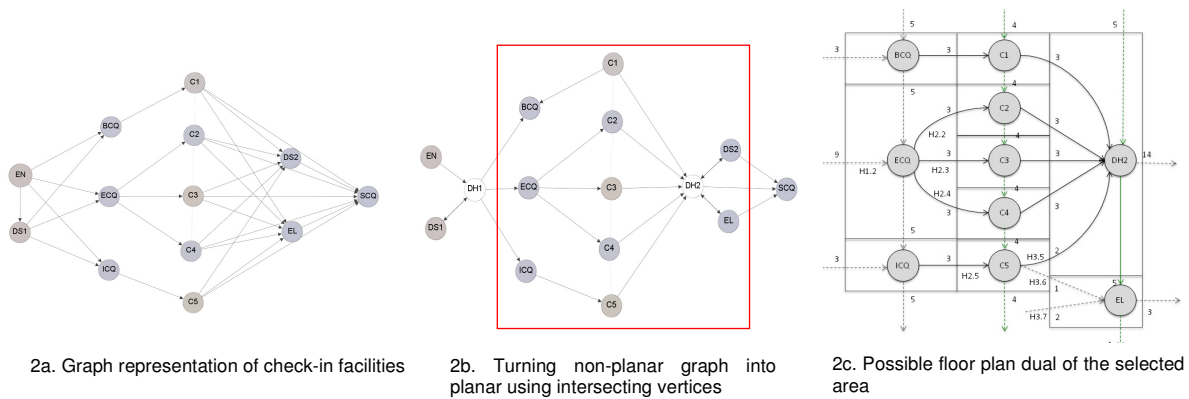
2. PROCESS MODEL TO SPATIAL ALLOCATION

A process may be defined as a specific order of activities across time and place, with a beginning, an end, and clearly defined inputs and outputs. Process models are gaining importance for studying operations within organizations generally in planning, re-engineering, automating or augmenting them (Eastman et al 2008; Lee et al 2007; Lee et al 2011; Smith and Tardif, 2009). Traditionally, building design process follows individual phases starting from initial concept drawings through to final detailed design and construction. The common idea behind all the design processes is to identify the sequence of distinct and identifiable activities in a predictable and logical order. Shuchi and Drogemuller (2012) recently proposed a framework to devise a generic method for utilizing business process models to develop an initial architectural layout in the context of an airport terminal design. The proposed method employed graph theory (Harary, 1969) to obtain an initial space allocation data using the modified process model, which allows identifying relationships among relevant objects (building facilities, rooms etc). Application of the graph theory to generate an optimum layout for a building was first initiated in 1964 (Grason, 1970). Use of graph theory enables a systemic progression from the required adjacencies towards achieving a space allocation model (Hashimshony et al 1980; Roth et al 1982). Further investigations based on the graph theory are also available in various literatures (Foulds and Tran 1986; Grason 1970; March and Steadman 1971; Roth et al 1982). Recently proposed generic method to obtain a preliminary design layout for airport terminals (Shuchi and Drogemuller, 2012) is briefly discussed in the following paragraph.

The entire process built around the following two major steps,

1. Identifying spatial requirements from process model, and
2. Providing space allocation utilising graph theory

Available Business Process Models for Brisbane International Airport (BNE) were used to devise the generic method of process model to design layout. Within the process of identifying spatial allocation, analysis of process models allows to identify both the required and the desired adjacencies. A simplified version of the process model mBPM (Shuchi and Drogemuller 2012) was proposed to sum up all relevant detail activities based on the space requirement - the major concern was with the location of spaces related to each other, rather than with the allocation of activities. The first step towards achieving a preliminary layout of a floor plan from the spatial adjacency information is to create a graph representation from the required adjacency data of the various activities. Each of the activities that take place during the check-in process (passenger entry, check-in queues, check-in desks, discretionary activities) was considered as vertex/node, whilst the connections between those activities were considered as edge/link. Figure 2a represents a non-planar graph showing typical activities taking place in a check-in counter. The adopted graph in Figure 2a is an isomorphs to $K_{3,3}$. According to Kuratowski's theorem (Harary, 1969) $K_{3,3}$ graph does not meet the Euler's formula of planarity and hence any graph containing subdivision of $K_{3,3}$ is not a planar graph. The non-planar graph is then transformed into a planar graph by adding an extra vertex. Addition of an extra vertex considers addition of a circulation area inserted between nodes connected by crossing links. As a result, the direct connection between the crossing links has been interchanged with an indirect link and the final result is a planar graph as in Figure 2b. Finally Figure 2c presents a possible floor plan dual obtained from the graph layout of the check-in area. Application of Kirchhoff's current law "The sum of all directed currents going in to a node must be zero" could generate a set of linear equations that define the possible wall lengths across the entire layout in Figure 2c. Detail description of the whole process is available in Shuchi and Drogemuller (2012).

2a. Graph representation of check-in facilities

2b. Turning non-planar graph into planar using intersecting vertices

2c. Possible floor plan dual of the selected area

Figure 2: Process model to spatial layout utilising graph theory

The benefit of applying this approach is that a range of BPM networks can be generated to match various options for design processes within a proposed or existing terminal building. Once the spatial adjacency of an area and its associated dimensions are identified, it is possible to get various design layouts that will suit the purpose. This method can also be applied to existing airport terminals to assess how existing processes are accommodated, or to assess how a revised process network will impact on the use of the building. This could then provide a rational basis for discussion about the impacts of proposed changes in process and spatial requirements for green field site (a completely new airport terminal design) or brown field site (alteration to an existing layout).

3. INTEGRATION OF flexDF AND PROCESS MODEL

The main focus of this paper is to explore ways for the possible integration between the process model and the proposed flexDF. The first step towards achieving this integration is to identify the specific areas within the whole design process or the specific terminal activities that will benefit from the process model analysis. In traditional architectural design spatial adjacency analysis is one of most basic and important methods of spatial planning. Previous literature suggests that flexibility could add value to a project and it depends on many interacting factors; the nature of the design/system, the intensity of uncertainty, also the types of uncertainty that will arise during its total life cycle. The analysis from BPM recognizes the relationships and the adjacencies among various terminal activities i.e. mandatory (check-in, security, customs & immigration and boarding) and optional (oversize luggage deposit, shopping, restaurant, toilets, ATM machines, internet kiosks etc). Application of Kirchhoff's current law assists to exploit the identified adjacencies to obtain possible shared dimensions in a rational way. It is worth noting that the success in applying Kirchhoff's current law to obtain a possible layout for a specific area will largely depend on assigning appropriate relative importance to each activity based on their hierarchy. This is a relative measure of importance, which could vary based on the location and purpose of a terminal building. Inherent flexibility will allow addressing these factors based on passenger interaction over a certain period of time.

In a typical airport terminal, designed with several in-bound (arrival) and out-bound (departure) activities, some facilities ideally should be grouped within a close proximity, whereas grouping of some other facilities are not essential. Based on the general understanding of flexible design concept adopted for building and the design principles of an airport terminal, a conceptual framework was presented by Shuchi and Drogemuller (2012) that makes an effort to combine the knowledge in flexible design elements and design principles specific to airport terminal design in a holistic manner. Considering this, the authors have identified that the mandatory activities, that must be performed to complete the departure procedure by a passenger, are also accompanied by some optional activities. This means, while considering a flexible layout, the designers should emphasize on the adjacency for both the mandatory and the optional activities. Airport terminals are typically open-plan type design, where primary flexibility in airport terminal building can be achieved by choosing a layout that will allow expansion and contraction according to the activities performed. Analysing the BPMs for airport terminals will provide useful information which could be integrated in Step 2 and in Step 3 of the proposed flexDF as shown in Figure 3. BPM will allow recognising relationships among terminal activities as well as providing a preliminary layout for performance evaluation. The proposed generic method exploiting graph theory should generate some alternative layouts, which could be integrated in Step 3 for further evaluation to achieve an optimum solution. Critical design parameters will be thoroughly investigated whilst reviewing the available design alternatives.
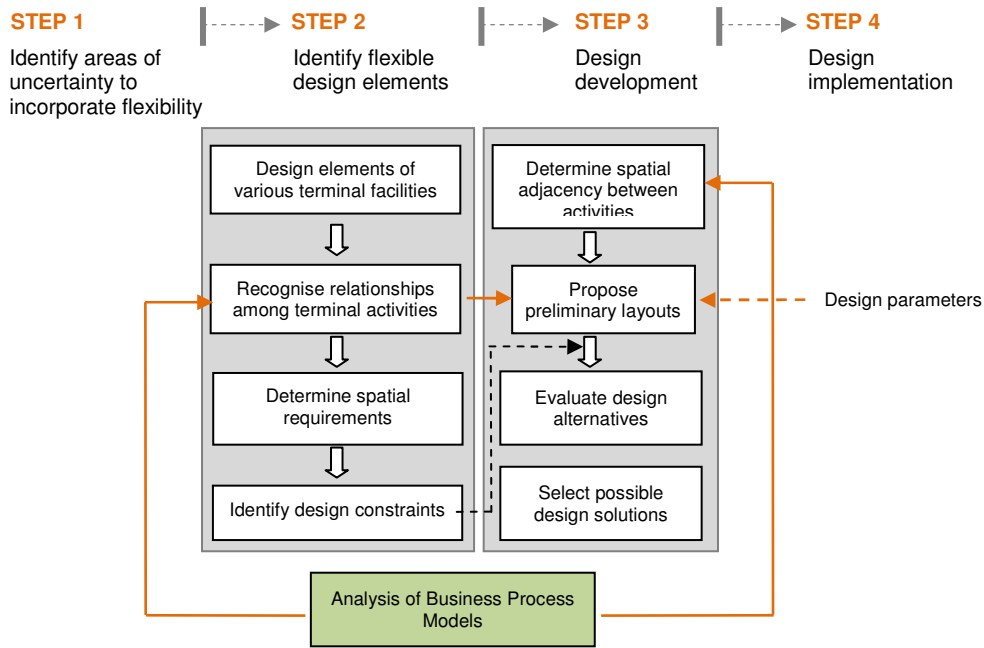
Figure 3: Integration of flexDF with process model analysis

4. FLEXIBILITY EVALUATION FRAMEWORK

Flexible layout for an airport terminal is a relatively recent debate in the design industry that would require a new paradigm of defining design parameters and design attributes. This paper proposes a new evaluation framework to develop an approach for assessing flexibility in airport terminal design layout. It is worth noting that the proposed evaluation framework is not a comprehensive manual on how to measure flexibility in building design layout, rather it would offer a conceptual road map that can be adapted to a variety of settings. In order to achieve a flexible and, at the same time, a meaningful design layout representing the range of possible configurations for passenger terminal layouts, careful consideration should be given to the alternative preliminary solutions obtained using BPM analysis. The conceptual evaluation framework proposed in Figure 4 couples process model to obtain suitable design layout and finally suggests performance metrics to evaluate flexibility in a holistic manner. The identified design parameters are expected to produce various design layouts to meet the governing design constraints.

Two key components of the framework are discussed in the following subsections.
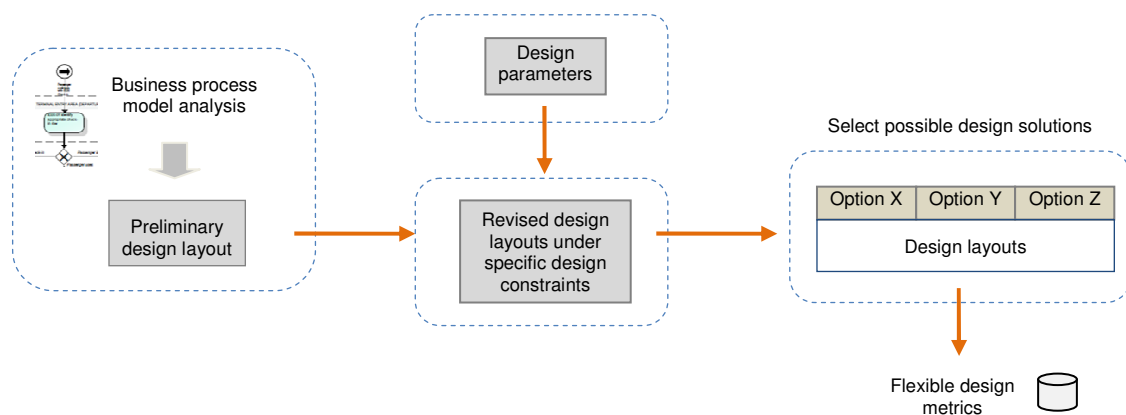
Figure 4: Flexibility evaluation framework

4.1 Flexible design parameters

Design parameters are qualitative or quantitative aspects of physical and functional characteristics of a component, device, product or a system that give valuable input to a design process (Business-directory). The first step towards formulating a flexible layout is to identify and to appropriately classify all the required design parameters. In general, a layout deals with objects and some inherent as well as imposed relationships among the considered objects. Design of an architectural layout corresponds with the relationships to the function and geometry (and size) to its related functions (Lobos and Donath, 2010). Considering a brief history and development of the spatial layout planning, Lobos and Donath (2010) provided a list of rational and general design decision criterion for an architectural floor layout plan. The decision on design parameters affects a large number of factors in building design process. Some parameters create constraints for other parameters; they bring about limitations on the choices for other design parameters. When an architect starts to design a new architectural layout or to re-arrange an existing layout some basic criteria must be fulfilled to achieve the desired functions. A list of design parameters is presented below, which are required for the flexible development of an airport terminal layout.

1. Critical distances between various terminal activities,
2. Area per passenger for terminal facilities (both for mandatory and auxiliary activities)
3. Area for each terminal facilities
4. Relative position of terminal facilities
5. Circulation area
6. Space enclosing material or partition

Designers need to set the rules and requirements for the design based on the spatial and functional relationship between the building spaces. The spatial relationship and the adjacency requirements between different terminal activities are considered as inbound and outbound passenger activities in airport terminals. For architectural layout of an airport terminal the adjacency requirement between terminal activities (both mandatory and auxiliary activities) and the relative importance of various terminal activities are the two main determining factors. Traditionally, walking distances between terminal facilities is considered as an important element to analyse design configuration of passenger terminals and hence determination of relative position of the terminal facilities could help to optimize walking distances. One of the most common features in flexible space/building design is the use of sliding/folding partition and wall design.

Defining design constraints

Space allocation problem belongs to the class of topological constraints. Constraints represent design rules, relations, conventions, and natural laws to be maintained. Designers have to deal with numerous constraints, which could originate from a number of sources. Design constraints come from a multi-dimensional region where each dimension represents an independent design attribute; each point represents a variant, or alternative solution (Gross, 1986). Considering the complexity of airport terminal design, the following preliminary design constraints are identified as mandatory for an efficient design process.

1. Adjacency requirements
2. Spatial allocation/ relative positioning of terminal activities
3. Allocation of circulation area
4. Critical space dimension of terminal facilities

The main thought behind determining design constraints is to create spatial layout under the given constraints and then to evaluate the spatial layouts for various design criteria. Further detailed research is currently underway to propose a complete list of design parameters based on available literature on spatial layout planning and various requirements for airport terminal facilities. The information is intended to produce necessary pre-conditions for developing algorithms to evaluate design solutions.

4.2 Flexible design metrics

A building design process starts with a consideration of the various performance objectives that interest to a mixture of users of that specific building. The development of a flexible design metrics for the design process targeting airport terminal design will set a number of variables that efficiently improve the design and operation of a new airport terminal design and re-construction. The aim of the design metrics is to appraise the effectiveness of the proposed flexible design strategy and its usefulness in the design process. A set of key design elements required to achieve this goal will require a method of documenting airport terminal activities for alternative spatial solutions and hence accommodate terminal activities effectively and efficiently.

5. CONCLUSION AND FUTURE WORKS

The evaluation framework proposed in this research presents a fundamental starting point for formally understanding the flexible design approach for an airport terminal design. Appropriate integration of the process

model prior to the design process could uncover the relationships that exist between the space and the relevant functions. Results obtained from the initial research provide the basis for flexibility analysis of a departure terminal layout against the possible future scenarios. Defining the appropriate flexible design metrics is currently underway. The research findings are expected to support new design approaches and as well as re-configuration of existing passenger terminals with more flexibility. The future research activities include investigating the development of an algorithm to show the practical implementation of the proposed flexible spatial layout and hence optimize the airport layout.

The evaluation framework presented here will be refined and verified in the future research work which will involve testing of associated design parameters using appropriate parametric models. The future research findings are expected to support the development of parametric spatial models for departure facilities to evaluate the relevant parameters qualitatively and quantitatively. This framework contains a new conceptual knowledge; this should provide novel practical information for the architects in the field of flexible architectural design. The benefit of the research is not only limited to the airport terminal design, the intension of the research work is to serve a wide array of similar types of larger commercial developments, such as railway stations, hospital and shopping centres. Adoption of this conceptual framework is believed to offer a new theoretical change in the initial process of flexible building design.

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