Flexible Airport Terminal Design: Towards a Framework

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Abstract

Flexibility is a key driver of any successful design, especially in highly unpredictable environments such as airport terminals. The continuing growth of the aviation industry requires airport terminals to be planned and constructed to allow for flexibility for future design, alteration and redevelopment. The concept of flexibility in terminal design is a relatively new consideration, where existing rules or guidelines are not adequate to assist designers. A shift towards the flexible design concept would allow terminal buildings to be designed to accommodate future changes and to make passengers' journey as simple, timely and stress free as possible. Currently available research indicates that a framework supporting the flexible design approach for airport terminals would facilitate the future design process. The generic principles of flexibility are investigated in the current research to incorporate flexible design approaches within the process of an airport terminal design. A conceptual framework is proposed herein, which is expected to ascertain flexibility to current passenger terminal facilities within their corresponding locations as well as in future design and expansion.

Keywords

Airport terminal, flexible housing, flexible design guideline, shearing layers.

1. Introduction

Airport terminals are volatile environments and subject to a whole range of cyclic and non-cyclic changes. If a terminal does not have the ability to adapt to these changes, it will become unsatisfactory and in the worst case scenario it could become obsolescent. Technological advances (e.g., introduction of new larger aircraft such as the Airbus A380, new check-in facilities, surveillance and security systems, etc), changes in regulation and changes in terminal facilities (e.g., internet check-in, e-passport, etc) have significant impacts on both operators and passengers. This continuous change indicates a need for new approaches to design to allow for short and long term flexibility. In order to adopt a philosophy of design for flexibility, airport planners and architects need to address a wide range of needs with an emphasis on both functionality and aesthetics. User flexibility or adaptability in building design in relation to residential and non-residential buildings is a widely used concept. Whereas the need for flexible design for airport passenger buildings is only recently gaining recognition [1-3]

Airport planning is shifting from the traditional pattern - driven by long term forecasts, fixed standards and established clients – to that of recognizing great forecast uncertainty, multiple standards of delivery and changeable clients [4]. Meeting this uncertain future requires terminal design to accommodate modifications that can not be anticipated. Significant studies have been undertaken to date to provide guidance towards planning and design of airport terminals. However, there are only limited studies that discuss the importance of flexibility in this area. In 'The Modern Airport Terminal', Edwards [3] covers the basic philosophy of how an airport terminal expands and changes within its total lifespan. He also sees terminals as a series of layers where incorporation of flexibility is a must. de Neufville [1, 2] suggested how airport owners and investors could apply flexible design processes to develop a strategy that would manage future uncertainties to maximize expected values. Chambers [4] focused on providing flexible responses that may prove useful in the growth of multi-airport systems and expansion of low-cost carriers. Since the concept of flexibility in terminal design is a relatively new initiative, there are limited guidelines or principles available to assist designers.

This paper explores the concept of flexibility by examining building design concepts and investigates flexible engineering system strategies. The literature review gathers definitions of flexible design and identifies examples of flexible and adaptable solutions in various design environments. The notion of flexibility is

explained in increasing levels of complexity starting from housing to hospitals leading up to its suitability for airport terminals. The paper also identifies some design principles practised in a small number of airport terminals to date. The paper then examines the significance of flexible terminal design and some basic principles are discussed that can be adopted in terminal design. Finally a conceptual framework is presented to utilize the flexible design strategies to develop an architectural layout. The proposed conceptual framework should facilitate the designers to appropriately handle the present requirements and to cope with the ever changing future needs.

2. The Concept of Flexible Design

The usage of a building and its design parameters can change widely during its lifetime and hence the provision to accommodate such changes is one of the most important factors to determine economic efficiency and performance in sustainability terms. Flexible design is intended to respond specifically to changing situations and operations [3]. The notion of flexibility in building design first emerged from the Second Congress Internationaux d'Architecture Moderne held in Frankfurt in 1929, where the debate for reduced space standards led to the concept of flexibility; this ideally means if there was to be less space, then the space needed to be used in an efficient and flexible manner [5, 6]. It is worth mentioning that the terms 'flexible' and 'adaptable' are sometimes confusing or used to describe the same thing. A clear definition was drawn by Steven Groak [7]; 'adaptability' is capable of different social uses, which means designing a particular space which can be used in a variety of different ways, whilst 'flexibility' provides the capability of different physical arrangements, which can be achieved by altering the physical fabric, by joining, extending or through sliding or folding walls and furniture. Flexibility (or adaptability) may, therefore, be defined as the ability to adapt to the environment without making any permanent change to the environment.

2.1 The influence of time related shearing layers in flexible design

User flexibility in layout planning is one of the main architectural design objectives, which aims to meet the specific needs of users over a certain period of time. Various components of a building change at different timescales [3]. This requires diverse design strategies over this range of building components and hence universal rules or guidelines are difficult to establish. Like other buildings, the functional life of an airport terminal has a different timescale from its structural life. Frank Duffy [8] proposed a concept of building layers, where he identified four layers of buildings in time descending order: the Shell, the Services, the Scenery and the Set. His concern was to provide internally adaptable buildings so that the building can be separated from long service life to short service life. Duffy's layering concept was expanded by Brand [9] into a slightly revised and a more general six layers concept i.e. Site, Structure, Skin, Services, Space plan and Stuff. The concept of building layers can have a major impact on both the analysis and the design process of airport terminals. Edwards [3] highlighted the importance of incorporating the layering concept in terminal design.

2.2 Flexible design elements in the context of building design

Although the concept of flexibility started to grow around developing flexible dwellings, the main philosophy behind creating flexible space was to anticipate complex and changing requirements of human needs in general. Jeremy and Schneider [6] identified two broad methods for flexible housing design - soft and hard methods. 'Soft' refers to the techniques that allow users to adapt the plan according to their needs, whereas, 'hard' refers to the elements that specifically determine the way that the design may be used. Examples of hard and soft method techniques used in building design will be discussed in Section 2.3.

According to design and technical solutions, flexible housing solutions can be divided under two basic components such as planning (building level, unit level and room level) and construction. Planning mainly refers to the particular ways to promote flexibility to adapt changes and construction refers to the way a house should be structured and constructed to accommodate uncertain changes of the future. Schneider and Till [6] carried out a comprehensive analysis of past, present and future of flexible housing design. They investigated more than 170 case studies at different scales from blocks of buildings to individual rooms and classified flexibility in two broad categories: use and technology. The key elements identified by them are summarised in Figure 2.

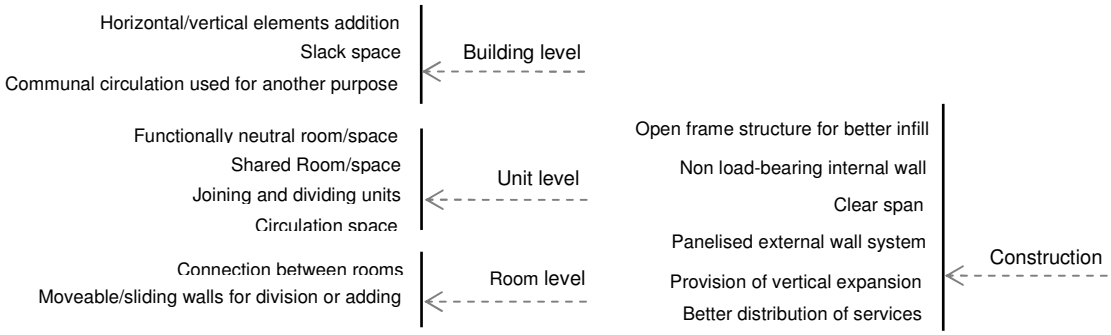


Figure 2: Design elements of flexible housing [5]

2.3 Case studies of flexible building design

Hertzberger's [10] famous project, Diagoon House (1969-1971), is one of the most successful examples of 'soft' design method. Houses as shown in Figure 1a were designed with the philosophy of 'incomplete buildings', where the basic frame leaves space for personalised expansion according to the user's needs. The occupants themselves were able to decide how to divide the space and live in it. Hertzberger followed the same philosophy in designing new offices for Central Beheer, Appeldoorn, Netherlands (1967-72), which was another successful project employing spatial flexibility. Figure 1b shows the office complex consisting of a precast concrete modular structure with equal sized spaces which could be linked together in different ways to meet the changing patterns of use. Hertzberger's [6]concept of flexible school design moved the notion of traditional hierarchical order of space (i.e. teacher at the front on a podium and children at a lower level sitting behind rows of desks) into a more informal arrangement of classroom areas to provide better learning environments. The Freeform Modular school project by Cartwright Pickard provides the opportunity of arranging various sized classroom areas to create a variety of zones [11].

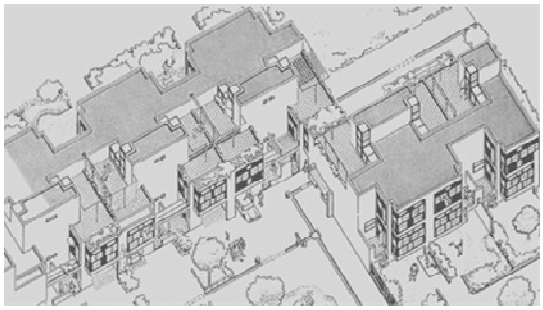


Figure 1a: Diagoon Experimental Housing [5]

Figure 1b: Central Beheer Appeldroon[5]

Another area where flexibility has been considered as a growing concern in recent years is healthcare design. Demand for flexibility in healthcare design is driven by lifestyle changes, rapid advances in medical technology and rapid regulatory changes. According to de Neufville and Lee [12], the main design features that make hospital buildings flexible includes the shell space, which results in a suitable structural foundation of a building to allow for expansion. If the demand is lower than anticipated, the building area can be downsized by sub-letting or selling part of the infrastructure. In this work, de Neufville and Lee [12] categorised flexibility as strategic, tactical or operational. Operational flexibility provides rapid methods of adapting infrastructure to deal with short term unpredictability. Tactical flexibility is slower, whilst strategic flexibility aims to produce a substantial increase in the lifetime of an infrastructure.

3. Flexible design strategies

Dealing with the uncertainties presents a common challenge for the designers of long-term engineering systems [13] as well in building design. This section identifies some principles of flexible design strategy used in various design fields to develop a new conceptual framework (in Section 5) for utilising flexible design principles specifically targeted for the use in airport passenger buildings.

3.1 Design strategies in general

Designing a project with the flexibility to adapt future needs and opportunities increases the long term value of the project. The following four steps process for developing design flexibility are suggested by de Neufville and Scoltes [13]:

Step 1 Recognize the major uncertainty of the project

Step 2 Identify the specific section of the system/design that provides flexibility to deal with the uncertainties.

Step 3 Evaluate alternative flexible designs to incorporate the best into design.

Step 4 Develop a systematic plan for implementation of the selected alternative and adapt the system to the new circumstances.

3.2 Design process to meet the expansion of airport terminals

The traditional process of airport planning depends on long-term forecasts, although serious doubts were raised [11] regarding the accuracy of the forecasting models used to predict the level of future traffic. Unreliable forecasting, as well as unanticipated changes in technologies and regulations, makes airport terminals a complex entity for the design field. The adaptation process of a house is considerably less complex than an airport terminal. Typically, adaptation process of a residential building evolves with the changes of its users, where residents are considered to be the one and only user. The expansion process of a terminal building, on the other hand, involves interaction among passengers, airlines and airport authorities. Three basic elements [1] of a flexible design process are; *recognition of the range of uncertainty, definition of flexible design opportunities,* and *analysis of the development strategies*. Flexible development of airport facilities requires leaving sufficient room for expansion as well as allowing spaces for major shifts in patterns of traffic. Three major design possibilities of developing a flexible airport terminal mentioned by de Neufville and Odoni [14] are connected buildings, temporary facilities and shared used facilities. These are briefly explained to understand their significance in the flexible design process.

(i) Connected Buildings: allows the operators to shift operations more readily since it is difficult to expand spaces across separate buildings which may lead to split operations that confuse both passengers and airline operations. Amsterdam Schiphol Airport and San Francisco International Airport are good examples of airports with connected terminals.

(ii) Temporary facilities*:* provides capacity required for tackling unpredictable traffic, such as use of transporters to connect passengers to the aircraft.

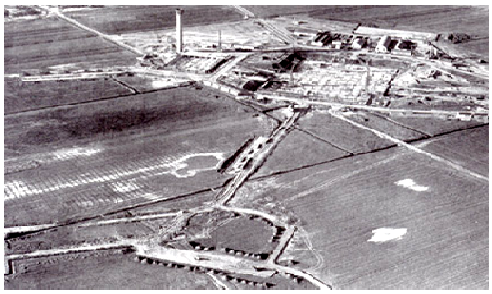
(iii) Shared use facilities*:* i if two or more clients share a space that helps to reduce the design load, it eventually reduces the total amount of spaces. When peak international and domestic traffic do not coincide, boarding and waiting areas can serve the international and the domestic passengers at appropriately allocated parts of a day. Shared use facilities will significantly increase flexibility of a terminal building. The passenger building in Edmonton International Airport in Alberta, Canada provides another good example of multi-functional activity. 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.

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. The design features also relate to the type of terminal configuration. The basic notion is to achieve a universal configuration that will suit best with the future expansion but there is no single solution that is fit for all purposes. One of the key considerations for choosing an appropriate configuration is walking distances between various facilities. The design configuration also varies with gate spacing, space requirement for aircraft manoeuvring and terminal block dimensions [12, 14]. The optimal flexible configuration will also depend on the traffic level, transport technologies and modes of managing the expected queue [12].

4. Case studies: Identifying the significant design elements of Airport Terminals

A number of airports around the world are analysed to understand the importance of flexibility whilst designing an airport terminal. Amsterdam Schiphol International Airport – Europe's fifth largest airport started in 1916 as a military airbase consisting of a few barracks and the airfield opened in 1919 to serve as a civil airport [15]. The current airport terminal building was opened in 1967 and is still running successfully with the addition of

new terminal buildings. Figure 4 shows the initial and present layout of Schiphol Airport, which has successfully evolved through a number of adaptation and expansion schemes to respond to the continuous increase in passenger demand. Gradually Schiphol has evolved from an airport to an airport city. The inherent flexibility of the design layout allowed this airport to operate for nearly a century.



1967

2001

Figure 4: Development of Schiphol International Airport, Amsterdam [15]

New York City's John F. Kennedy International Airport (JFK) opened in 1962 and was highly praised at the time for its innovative beauty and creative design. As a work of architecture, the TWA Terminal (called "Bird in Flight'') was an unparalleled success but as a passenger terminal building, it proved over time, to be functionally deficient [16]. The radial and compact plan, as shown in Figure 5, of the terminal was inefficient by comparison with other linear planned terminals. The terminal was eventually closed in 2001 after the American Airlines bought TWA. This clearly demonstrates the significance of not having the flexibility to adapt to the future demand.

Now the question is why do some airport terminal buildings become redundant or inflexible, whereas the other remains functional or adjust over time? A very simplistic explanation would be that one design was insufficient/inadequate compared to the other. Nevertheless, this explanation is not enough to cover the long-term view of understanding the changing pattern of air traffic growth and passenger needs. Flexibility could provide an indication of what works and what doesn't in these instances. But what are the elements of flexible terminal space, what makes it flexible? Vancouver Airport provides a good example of flexible design. It is basically a large open hall, separated with glass panels which divide the hall into spaces which can be connected in different ways by means of escalators. This flexibility allows the airport to easily accommodate both short and long term shifting patterns in traffic.

Figure 5: TWA Terminal, aerial view [16]

The concept of the modular airport also assists the designers to develop expandable and flexible facilities that can meet airline requirements in a cost-effective manner. The regional airport at Southampton, UK [17] is an elegant example of the modular airport terminal concept. The building form facilitates future expansion, where the required expansion could be easily achieved without any disruption to the existing operations. The adopted form provided an economical solution; the target price was 50% of the unit rate normally required on the development of typical gateway terminals. The modular technique offered rapid construction due to commonality of building elements at a lower cost. Bangkok Suvarnabhumi Airport, Thailand, is another example of a simple and flexible design concept: a series of large modular terminals, each served by wings of airside corridors with aircraft gates on either side [19]. The long span, lightweight steel structures with lightweight building materials constructed in five phases helped to reduce construction cost.

5. Developing a conceptual framework for flexibility in airport terminals

A conceptual framework to address the flexibility issue for airport terminal design is presented herein after reviewing a number of relevant hypotheses. Airport infrastructure is typically designed for a 20 to 50 years lifespan [11]. Given this lifespan, Edwards [3] compared the growth of the airports with the growth of cities, postulating that the airport behaves like the city it serves. Even though the airport expands gradually and systematically and the expansion is constrained by space, function and time [18]. Edwards [3] highlighted that an airport terminal should be designed to allow separate layers that can be renewed without any significant disruption. Appropriate recognition of separate layers within a typical terminal should allow the terminal to be renewed if and when required, at different rates. It also allows the designer to anticipate changes even without knowing every detail of the exact configuration. Edwards [3] divided terminal buildings into two basic layers i.e. technological change and management change, as shown in Figure 6.

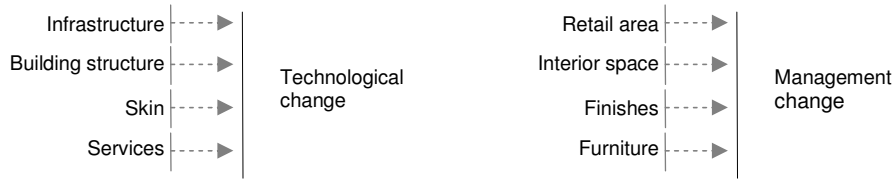


Figure 6: Airport terminal layers in a conceptual sense [3]

The concept of shearing layers is utilised in the current paper to restructure and reorganize the terminal spaces from a time-layered perspective. The pace of change in an airport terminal throughout its lifecycle have been categorised under *operational, strategic* and *tactical* flexibilities. 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 to deal with short term volatility, for instance day-to-day operational changes occur in ticket counters, check-in desks, signs etc. Tactical flexibility is somewhat slower and requires significant commitment in capital, whilst strategic flexibilities effect on substantial increase of the life-time of an infrastructure. Tactical flexibility deals with the spatial plan and services and strategic flexibility effects changes in building structure and building envelope. Figure 7 presents the proposed concept of shearing layers for flexible airport terminals, which combines Brand's shearing layers of change and the concept of two layers of terminal design proposed by Edwards. Changes in building technology tend to dictate alteration in outer layers (service, skin and structure) and management policy dictates the changes in inner layers (stuff and space plan). Less visible or slower changes made to the building services, skin and structure reflect technological changes. Each layer has a distinct timescale; operational changes that occur in more frequent and regular basis, are mainly concerned with the interior stuff. The tactical changes affect the spatial organisation of an airport interior as well as the relevant services and hence tactical changes overlap both management and technological changes.

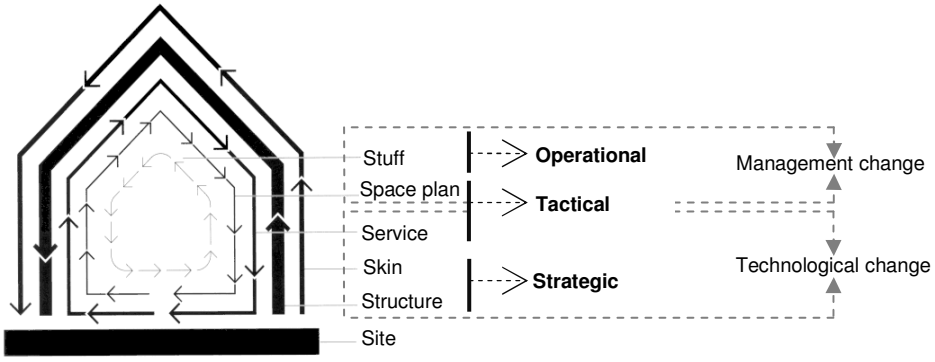


Figure 7: Proposed shearing layers for a flexible airport terminal.

A conceptual framework is presented in Figure 8 which combines the knowledge of design principles adopted for residential and non-residential buildings with the design principles recognized for airport terminals. The design elements identified in the proposed framework is a preliminary step towards developing a flexible design strategy for airport terminals. The framework utilises the knowledge of flexible design elements and design principles that are specific to airport terminal design, in a holistic manner. Functional effectiveness and

flexibility in planning and design of airport passenger buildings are discussed with respect to physical structure and spatial layout. The relevant design elements are identified based on appropriate timescales i.e. in short, medium and long term perspectives. Short term daily and weekly changes are categorised as operational, medium term tactical changes run for 2 to 5 years, whilst the long term strategic flexibility issues could take up to 50 years to address. Operational and tactical i.e. short and medium term changes primarily involve spatial layout changes to meet the needs based on specific requirement at any particular time. The functional requirement of an airport terminal is highly dynamic in nature and these flexibilities will allow a terminal to adapt to these ever changing scenarios. 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.

The design framework presented in Figure 8 adopts the four step process for developing flexibility in terminal design as suggested by de Neufville [13]. Step 1 is to recognize the uncertainties of airport terminal design in terms of spatial layout and physical structure as discussed in the previous paragraph. Figure 8 shows the flexible design elements identified in terms of short, medium and long term basis for an airport terminal. Step 2 identifies the specific design elements that would enhance to flexibility of various airport facilities. Step 3 is the evaluation phase which includes an evaluation of alternative design solutions by analysing the design elements identified in Step 1. At the evaluation stage, the selected design elements are coupled with the measuring factors (construction cost, operating cost and maintenance cost, time etc) and design constraints such as site to obtain an optimum solution. The final and 4th step is the implementation phase, in which strategic issues are 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 structure of the airport organization and the number of stakeholders involved in the process. The presented framework is an initial step towards achieving a complete flexible design strategy for airport terminal design. The detailed considerations required to complete the aforementioned four phases will be developed in future research.

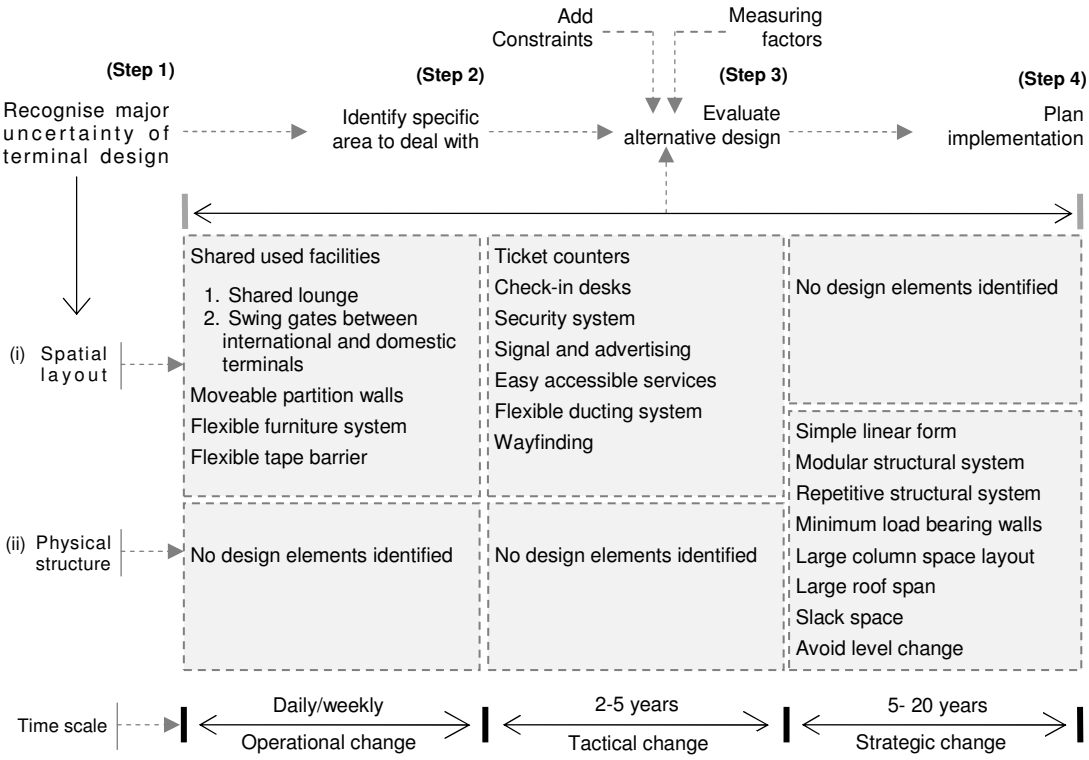


Figure 8: Conceptual framework of flexible airport design

6. Conclusion and future works

Available information about flexible infrastructure has been presented and analysed in the current paper with a view to extend the flexibility concept in airport terminal design to cope with the ever changing needs.

Appropriate application of the flexible design principles identified in this paper will assist designers to incorporate frequent changes occurring both in technology and management. The proposed flexible design framework is in a preliminary stage which requires more detail understanding of design elements, the study is expected to facilitate various stakeholders to expand and to contract their activities easily and effectively as required. Practical application of the proposed framework and design principles is necessary to improve the concept. Hence, developments of appropriate design tools are required to assist architects in understanding and adopting the proposed framework. Further research is currently underway and it is expected that explicit methods for assessing flexibility will emerge to provide further assistance to designers and airport owners in planning new facilities as well as to assist in modifying existing amenities. In future generic spatial models of the airport terminal will be developed to evaluate flexible design parameters qualitatively and quantitatively. The results are expected to be used as a reference model for further design development of the airport terminals.

7. Acknowledgement

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