

TOWARDS CHANGEABILITY

The Adaptable Buildings Design (ABD) Framework

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Abstract. Many buildings around the world have undergone successive changes over their life cycles. These changes might be in the building's spatial, structural or service systems. This can be due to changes in the needs of occupants, the market demand or technological advances.

This paper proposes an *Adaptable Buildings Design (ABD)* framework to help design buildings that can adapt to change to increase the building's longevity. Using this framework, uncertainties are first identified. Flexibility options are then embedded and design rules are formulated to trigger these options when necessary. The value of adaptability is then assessed by implementing several simulations using Real Options Analysis (ROA).

To demonstrate the approach, the ABD is applied to a multi-use commercial building case study. Flexibility is embedded in the building's design across several systems allowing it to evolve over time based on a set of design rules. The building's flexibility value is then assessed using ROA. The positive results obtained demonstrate the strength of the proposed methodology in addressing future change and uncertainties.

1. Introduction

The longevity of built facilities is a concern for all owners, from large corporations to homeowners, as well as to the occupants and users of these facilities. The usefulness of facilities is often compromised by their inability to accommodate changes over time (Slaughteres, 2001). Therefore, we should consider change and uncertainty in the design process to increase the built facility's usefulness and value.

To address this, an *Adaptable Buildings Design* (ABD) framework will be presented in this paper. The framework has four main phases that include: identifying uncertainties, embedding flexibility, formulating design rules and value analysis. The ABD will be applied to a multi-use commercial building case study which includes office and retail spaces. The building is an actual project currently under construction in Riyadh, Saudi Arabia (figure 1).

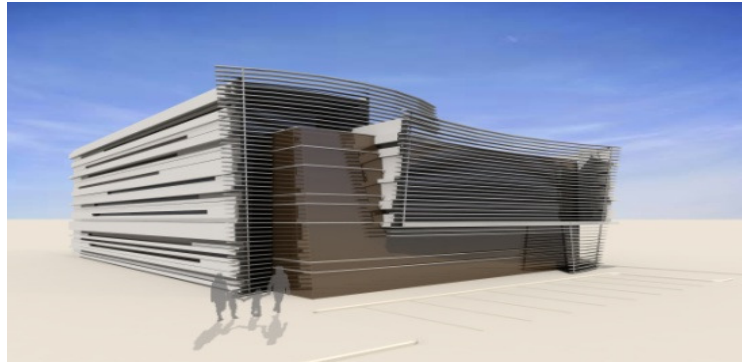


Figure 1: 3D visualization of the case study

In section two of this paper, the details of the framework will be discussed. This will include what uncertainties to identify, how to embed flexibility options in the building's systems, how to formulate design rules that define when to apply the possible options, and then finally, how to analyze the value of flexibility using real options analysis to choose and validate initial design solutions. The paper conclusions will then follow in section three.

2. The ABD Framework

The ABD framework aims to address future uncertainties through embedding a number of flexibility options in the design which can be triggered in the future when necessary. The value of that flexibility is then assessed for decision-making. As described earlier, the framework consists

of four phases: identifying uncertainties, embedding flexibility, formulating design rules and value analysis (figures 2). The phases are not necessarily carried out in a sequential manner, but rather a continuous move back and forth between the different phases could occur. However, for the sake of clarity, in the application of the case study, the ABD framework will be discussed sequentially.

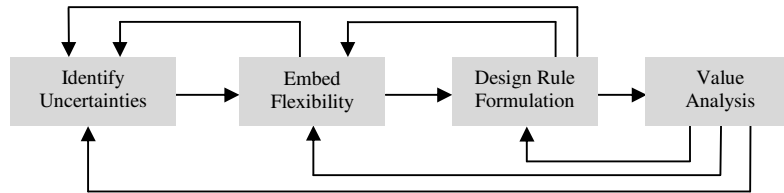


Figure 2: the framework for adaptable buildings

2.1. IDENTIFYING UNCERTAINTIES

The identification of uncertainties in a built facility is often difficult. This is because every project has special circumstances that will influence future changes. The main uncertainties that a built facility encounters are market and technical uncertainties.

TABLE 1: Uncertainties parameters

Uncertainties	Description	Example
Market	Demand	The size of future demand
	Cost	Capital cost
Technical	System performance	Success or frailer of new technology.
	Regulation	Introduction of new standards
	Timing of outcomes	Change of services type
	Climate	Global climate change

Handling market uncertainty can lead to a project's success or failure. Market needs change from time to time and the built facility has to change to cope with these changes. These market uncertainties can be divided into two main categories: market demand, and market costs. Market demand includes uncertainties in the size of future demand for facilities, while

market cost uncertainties consist of the varying costs of construction, equipment, materials, labor, and operation.

Technical uncertainties, on the other hand, consist of the technical aspects that could affect the building. Some of these aspects may be controlled, but others cannot be controlled if they were not considered at the inception of the project. The major technical uncertainties include system performance, regulation, timing of outcomes and climate, among others (Table 1).

To demonstrate how to identify uncertainties, let us consider our building case study discussed in section 1. In this case study we will focus on uncertainties of market demand and cost. Predicting market demand is a major issue for any commercial project. The demand parameters would typically be estimated using demographic projections and past data from similar projects. Based on the Saudi government statistics, growth in demand for offices and retails will increase by 30% by the end of 2010 compared to the 2009 (WAM, 2009). However, it is still unclear if this demand will be sustained over a long time period especially within the case study's location.

In our example, we will propose demand curves for offices and retail space over 20 years of the project's life time. We will propose that the initial demand during the first year of operation is expected to be 16 offices and 8 retail spaces. The demand projection will then grow by 12% for offices and 10% for retails during the next 5 years of operation to reach an expected demand of 25 offices and 12 retail spaces. The demand growth after 10 years of operation will increase by 9% for office and 8% for retail to reach an expected demand of 38 offices and 17 retail spaces. Demand growth after 15 years of operation is expected to grow by 6% for offices and 4% for retail to reach 48 offices and 21 retail spaces. The demand is expected to continue growth during the estimation project lifetime. Figure 3 shows the demand growth for both uses.

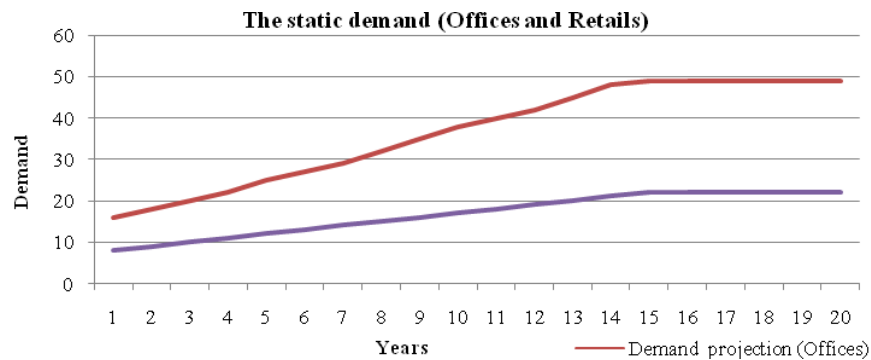


Figure 3: the demand projection chart for offices and retails

However, the demand is not certain and is expected to fluctuate up or down over the next two decades and therefore the possibility of demand volatility needs to be considered. We will assume that demand can be off by up to 50% and down by 20% for the offices, and can be off by up to 40% and down by 10% for retail spaces. It should be noted that these numbers are arbitrary and will be used only for the purpose of demonstrating the framework. Better demand curves and predictions can be assessed with the availability of more reliable data.

2.2. EMBEDDING FLEXIBILITY

After identifying possible future uncertainties, certain flexibility options need to be embedded in the design which can be triggered when necessary. The main types of options which are applicable to the AEC industry can be concluded from table 2. In a building facility, these flexibility options have to be considered in several building systems such as the spatial, structural and service systems.

TABLE 2: Option types (Source: Guma, 2008 and Mun, 2006)

Option	Description	Examples
Defer	To wait before taking an action until more is known or timing is expected to be more positive.	When to introduce a new product, or replace an existing piece of equipment.
Expand or contract	To increase or decrease the scale of an operation in response to demand.	Adding or subtracting to a service offering, or the right to increase or decrease the scale of a development.
Abandon	To discontinue an operation and shut down the assets.	Discontinuation of a research project, or product / service line.
A compound option	To commit investment in stages giving rise to a series of valuations and abandonment options.	Staging of research and development projects or financial commitments to a new venture.
A switching option	The right to change from one product type to another.	The Ability to select mode of operation (e.g. heater that burns gas or oil) Switching between modes is action.
A Growth option	An option acquired through investing in the creation of future growth opportunities.	New technologies or infrastructure.

Let us now consider our case study. The facility includes both office and retail spaces. Due to the uncertainty of demand, office spaces could switch to retail spaces, or vice versa. This implies the need for embedding a switching option. In addition, demand could increase requiring additional rentable space. This implies the need for embedding an expansion option.

To address both the switching and expanding options the building spatial system was designed using a modular system that can accommodate change by expanding vertically or switching functions from retail to office or vice versa. Each level (floor) includes two units (modules) that can be used for office or retail space. An office unit includes 4 offices, while a retail unit includes 2 retail spaces. A facility entrance and a vertical circulation component are located beside each unit/module. This modularization can produce a large number of configurations. For instance, if we consider only two levels, 16 different configurations can be produced (figure 4).

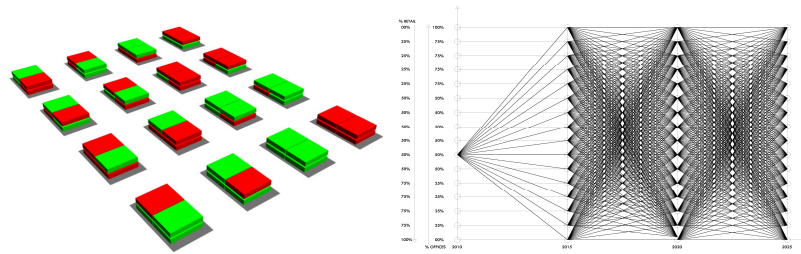


Figure 4: Spatial system unit variations of (offices and retails) combinations

The structural system is usually fixed and hard to change after construction. One way to accommodate future vertical expansion is to design the superstructure for a larger number of floors. This is the strategy we implemented in our case study to accommodate possible future vertical expansion. Although initially only a few floors might be built, the superstructure was designed to accommodate 8 levels (figure 5).

The services system in the case study should also respond to the two main flexibility options, vertical expansion and switching of functions. To handle the first option we enclosed all services in one cluster behind the vertical circulation beside each unit. This will assist in the future vertical expansion. To handle the second option, the system distribution components were laid out in-between the two units. The only incurred cost for changing the unit function will then be within each unit (figure 5).

2.3. FORMULATING DESIGN RULES

Within the ABD the design rule formulation represents the decision making mechanism. Decisions about the when to trigger the flexibility options embedded in the design are formulated within a set of rules.

Each design rule uses mathematical logic to identify when an option is applied.

For example, in our case study two main options were embedded, these are an expansion option and a switching option. Two design rules for each of the flexibility options were formulated. By implementing the design rules we address questions like: When do we need to expand? When should we switch the use of a unit from offices to retail and vice versa?

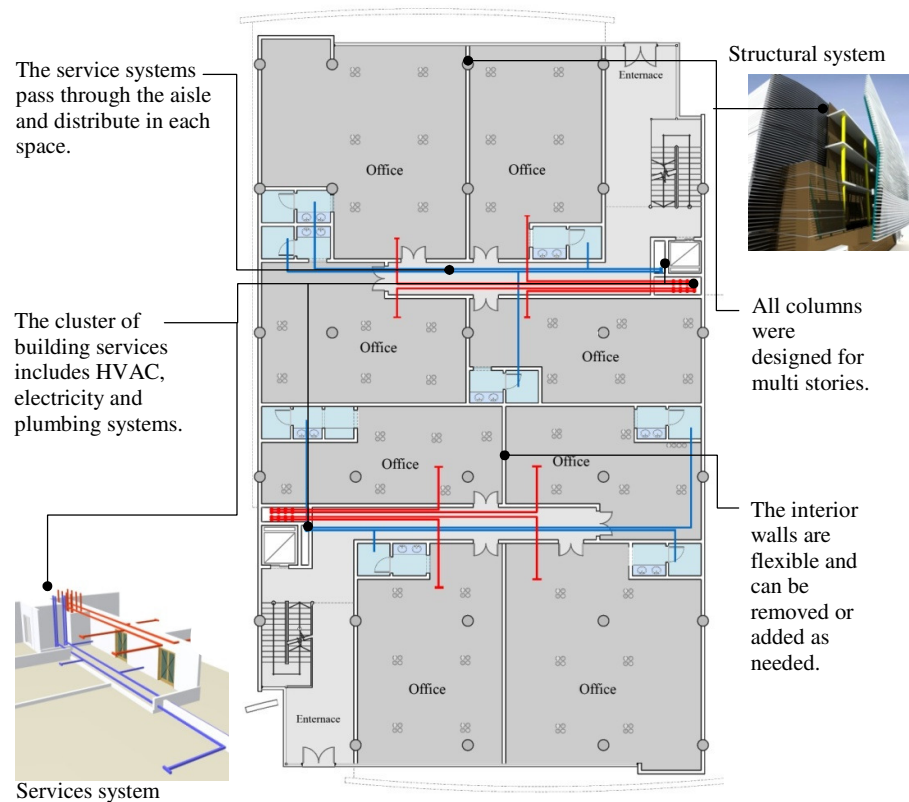


Figure 5: the flexibility of the building systems

The expansion rule specifies when an additional level is to be added, while the switching rule specifies if a unit should switch its function from office to retail, or vice versa. These rules are dependent on several parameters that include the demand for offices and retail, percentage of occupancy, profit and ratio of offices to retail in the built facility. These parameters together can evaluate the facility's real estate performance at a particular point in time to identify which design rule to apply. The following formulas describe the expansion and switching rules respectively.

*If (a>b; If (c<=d; If (b>c; If (c<(e*f); If (g<>"switch";"expand";""); ""); ""); ""); ""); "")*

(1)

Where: a: the expected demand of the next year of office use;
 b: the expected demand of the current year of office use;
 c: the capacity of the current year of office use;
 d: the capacity of the next year of office use;
 e: capacity limit per unit of office use;
 f: the number of levels limit; and
 g: switch.

If (a>b; If (b<c; If (d>e; If (c>=f); If (g >h;"switch";""); ""); ""); ""); "")

(2)

Where: a: the expected demand of the next year;
 b: the expected demand of the current year of office use;
 c: the expected demand of the current year of retail use;
 d: the capacity of the current year of office use;
 e: the capacity of the current year of retail use;
 f: the expected demand of the next year of retail use;
 g: the net revenue of office; and
 h: the net revenue of retail.

2.4. VALUE ANALYSIS

The basic toolset at work when valuing a project includes a multiyear Discount Cash Flow (DCF) analysis and decision based on a Net Present Value (NPV). The NPV is frequently understood to allow a method for making decisions based on exclusive opportunity outcomes by identifying the greatest value (Guma, 2008). However, this process forces a decision based on a range of assumptions, but does not provide information that addresses the uncertainties of the project (De Neufville et al, 2006).

The evaluation of the value of flexibility can be carried out by the application of Real Option Analysis (ROA) which provides a methodology to assess a projects ability to respond to uncertainties in the future. ROA is a valuable tool to assist in making decisions on what options to implement

and is based on two aspects: financial options-pricing theory and uncertainty modelling (Mun, 2006). ROA is carried out by evaluating the expected net present value (ENPV), which depends on several parameters such as the future demand, revenue, operation and maintenance cost and capital cost. The possible outcomes of ENPV can be arrived to by incorporating uncertainty in the design using Monte Carlo simulation.

To understand how to apply ROA in our ABD framework, let us consider again our case study. We assumed that the design options of concern are the expansion and switching. The issues we would like to address now in the analysis are: How many levels do we need to build initially? What combination of office and retail unites should we start with? What is the project ENPV? In our analysis of the case study we will compare a base case in which neither uncertainty nor flexibility are considered, with a solution which implements ROA and considers both uncertainty of demand as well as flexibility and options of the building design solution. This analysis was influenced by the garage example carried out by De Neufville et al (2006).

In the base case the facility is designed for the best NPV. We assume 10% as the cash flow discount rate. The net cash flow is the difference between the costs (capital, operation, maintenance costs) and revenue. This will be calculated by applying the expected offices and retails demand over the next 20 years as discussed in section 2.1. The best design for the base case design was found to be 6 levels, with 6 office units and 6 retail units delivering a total NPV of about 12M SAR.

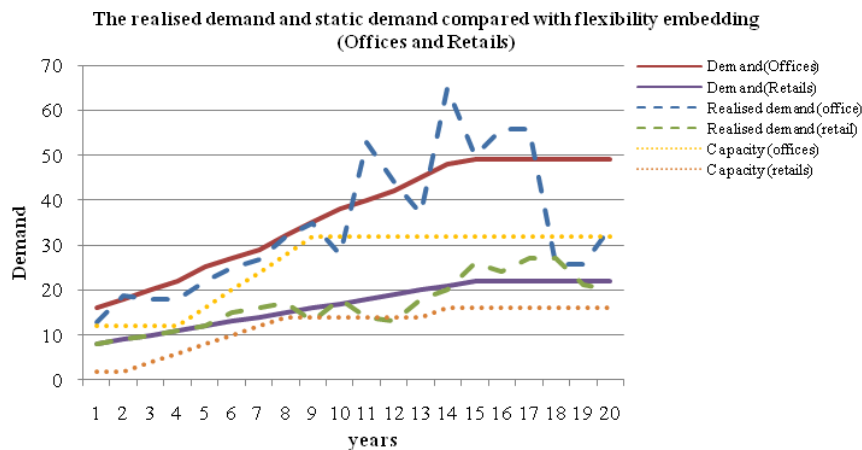


Figure 6: The Static, realized demand compared with embed flexibility

In the second analysis of the case study we will use ROA and consider uncertainty and flexibility. To address uncertainty in demand we apply a Monte Carlo simulation. As discussed in section 2.1, demand is volatile. The Monte Carlo simulation will help us identify ENPV by running 2000 scenarios of possible future outcomes. To achieve the net present value of cash flows, a twenty years DCF is performed for this case based on the assumptions. In addition, flexibility is embedded as expanding and switching options. Decisions about when to implement each option are formulated within the design rules as discussed in sections 2.2 and 2.3.

One of the simulation outcomes suggests we begin the facility with two levels, which have three office units and one retail unit. Then, in year 3 we may expand by adding one level which will include one office unit and one retail unit. This will also be repeated in years 4, 5, 6, 10 and 15. However, in years 7, 11 and 18 there might be a need to switch the use of units from retail to office due to higher demand, which means that the number of offices will increase as a consequence (figure 6).

The application of the ABD and the flexibility embedded in the design deliver much greater net present value than the best solution with the 6 levels of the base case. The NPV of two levels with flexibility design is 17M SAR compared 12M SAR in the base case with the fixed 6 levels (Figure 7).

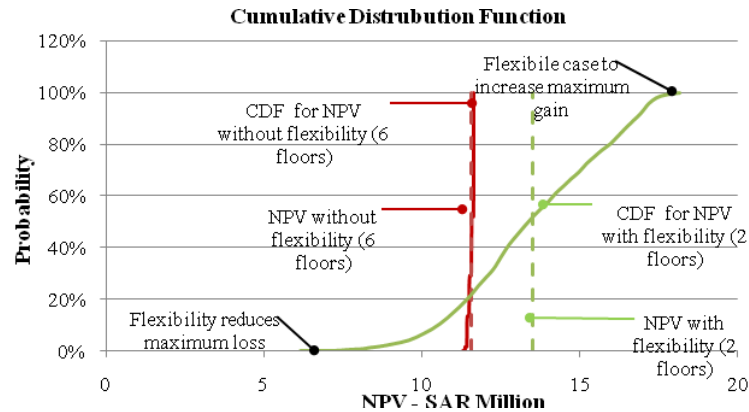


Figure 7: Target curve for fixed design compared to flexible design using ABD

3. Conclusion

This paper presented a framework for adaptable buildings design (ABD) to help increase the facility's flexibility which can lead to an increase in the life of the facility, as well as raise the building's value. The ABD is composed of four phases: identifying uncertainties; embedding flexibility; formulating design rules; and value analysis. The ABD was applied to a multi-use commercial building case study. Uncertainties of market demand were first identified. Flexibility options for switching and expanding were then identified and embedded within the spatial, structural and services systems of the facility. Design rules were then formulated to identify which option to apply at a particular point in time in the facility's evolution. Finally a value analysis using Real Options Analysis was carried out to assess the flexibility of the building. The value analysis was applied to two cases, a base case that does not consider uncertainty or flexibility, and a case study that applies the ABD and considers both uncertainty and flexibility. The results of applying the ABD proved valuable in managing the demand uncertainties which could avoid the future risk, while providing an adaptable building which can expand when needed or switch the use of its office and retail space units. In our future research we will consider additional flexibility options as well as implement better demand prediction methodologies.

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