ADAPTABLE FUTURES: SUSTAINABLE ASPECTS OF ADAPTABLE BUILDINGS

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The research described in this paper addresses buildings that are designed to adapt in response to the changing parameters of our rapidly evolving society. These changes might be social, environmental or economic, all elements of sustainability, but they will affect the way we construct and use buildings. At the moment the majority of buildings are designed and constructed to suit a particular use at a certain time, with no thought for the future. The research focuses on two specific types of adaptable buildings, those that are pre-configured and those that can be re-configured through their lifetime and it aims to facilitate the development of adaptable buildings in the UK. Two case studies are being examined to enable this; a pre-configured components systems, Newways, envisaged by GSK (GlaxoSmithKline) and BWM (Bryden Wood McLeod) and a reconfigurable building concept, Multispace, designed by 3DReid. This paper will pay particular attention to the sustainability aspects of these two case studies. These, as well as other examples of adaptable buildings, will be investigated during the research through action research, interviews, focus groups, workshops, scenario models, literature review and Dependency Structure Matrix analysis. The research aims to: identify design criteria that adaptable building should adhere to; create novel product architecture models; optimise the configuration of components and systems; and invent cost-effective building systems and technologies that provide the required levels of adaptability. This paper concludes that sustainability is a vital part of adaptable buildings and that both sustainability and adaptability are becoming more important with the ever changing construction industry. Results presented from a workshop undertaken as part of the research highlight the sustainability of different aspects of adaptable buildings, focusing on their economic, environmental and social features.

Keywords: adaptability, lifecycle, pre-configuration, re-configuration, sustainability.

INTRODUCTION

A summary of the Adaptable Futures research project being undertaken at Loughborough University is provided in this paper. An introduction to the project is presented that includes an overview of the research, the key objectives, a brief description of the context and the methodology used. The case studies being developed by the industrial partners for the project are then explored, focusing on the aspects that relate to sustainability. Other case studies that are being investigated are also summarised and discussed to give an understanding of the variety of adaptable buildings being addressed. The initial findings from a workshop with industry partners that relate to sustainability are presented and the paper is concluded with next steps for the project being identified. The paper builds on previous publications by the research

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Beadle, K, Gibb, A, Austin, S, Fuster, A and Madden, P (2008) Adaptable futures: sustainable aspects of adaptable buildings. *In:* Dainty, A (Ed) *Procs 24th Annual ARCOM Conference,* 1-3 September 2008, Cardiff, UK, Association of Researchers in Construction Management, 1125-1134.

team on the same topic, including 'Towards Adaptable' (Gibb *et al.* 2007b) presented at ManuBuild's 1st International Conference, 'The Multispace Adaptable Building Concept and its Extension into Mass Customisation' (Davison *et al.* 2006) presented at Adaptables '06 and 'Adaptable Futures: Setting the Agenda' presented at the 1st International Conference on Industrialised, Integrate, Intelligent Construction (I3CON) (Beadle *et al.* 2008).

Overview of the Project

Adaptable Futures is a three year multi-disciplinary research project aiming to facilitate the development of adaptable buildings in the UK through academic research and examples from industry. The project involves researchers from construction, architecture, quantity surveying, business, project management and engineering.

The adaptability of buildings is being investigated by developing two design strategies, pre-configuration, dealing with initial design choices and re-configuration, looking at subsequent changes in use. A framework to describe adaptable buildings has been created as part of the research, Figure 1 shows the initial framework that is being developed.

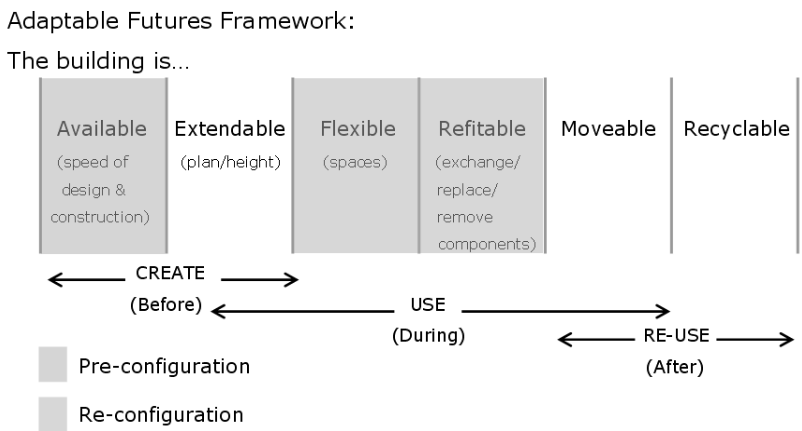

Figure 1: Adaptable Futures Framework

Research background

Currently, the majority of buildings are bespoke creations to suit a particular use at a certain time, with little thought for the future or sustainability (Gibb *et al.* 2007a). The 21st century has seen changes in social, environmental and economic frameworks, the 'triple bottom line', which will change construction enormously (Elkington 1994).

These changes include: faster design and production to reduce client uncertainty and cost; much wider adoption of lean manufacturing approaches (including offsite); increasing demand for infrastructure reconfigurable to future needs that are usually unpredictable (Gibb *et al.* 2007a); a greater focus on sustainable procurement and development; the introduction of energy performance certificates; and an increasing focus on zero-carbon buildings. Gregory (2004) found that 94% of high profile UK property developers and agents saw the need for an adaptable building solution providing associated capital cost increases were minimised. Larsson (1999) estimated environmental benefits of adaptable office buildings as a 15% reduction in (a) air emissions and (b) demolition solid waste. According to DEFRA (Cassar 2006), 24% (70Mt pa) of all waste is construction demolition materials and soil. Sustainable procurement has become more prominent since the UK government's Sustainable

Procurement Task Force (SPTF) was set up in 2005, charged with guiding the public sector's £150 billion budget on goods and services in a sustainable way (Ellinor 2007). 'Securing the Future' (HM Government 2005) set out the UK government's sustainable development strategy and required all central government departments and their executive agencies to produce a sustainable development actions plan. The 2008 budget (HM Treasury) presented an ambition for all new non-domestic buildings to be zero-carbon from 2019, starting with all new public sectors buildings from 2018. There is clearly both a business and sustainability case for extending the useable life of our building infrastructure.

There have been few recent attempts to incorporate adaptability into new buildings and those that exist have been almost entirely residential. The move to adaptable buildings requires an industry step-change in how structures are conceived, designed and assembled (Gibb *et al.* 2007a). The main geographic focus of recent flexible building design research has been Japan and The Netherlands (Scheublin *et al.* 2006). Japan has lead the way in developing mass-produced housing from a purely cost driven commodity item towards a customisable, high quality product which delivers a significant degree of flexibility to the end client (Barlow *et al.* 2003). Habraken promoted the concept of open building in the 1960s. The theoretical concepts behind open building have been researched but few projects have been built using this principle, mainly one-off housing projects (Schueblin *et al.* 2006) and rarely using the inherent flexibility as intended (Verweij 2006). Sustainability is becoming more influential on building design and construction, but there are few examples where its key principles have been successfully combined with adaptability.

Objectives

The objectives of the research are to:

- identify future scenarios and design criteria for adaptable buildings to respond
- understand technological and human successes and failures of past attempts
- create novel product architecture models and associated methods of analysis to optimise the configuration of components and systems against customer needs
- invent cost-effective building systems and technologies best suited to provide the required levels of adaptability over their life cycle

Methodology

The main sources of data collection are two real case-study solutions that fit the two design strategies and are being developed by the industrial partners of the project. These are a pre-configured example, Newways, developed by GlaxoSmithKline (GSK) and Bryden Wood McLeod (BWM) and a re-configured concept, Multispace, developed by 3DReid and Buro Happold. Newways is a pre-configured component building system designed to create any one of three building types that they require. Multispace is a reconfigurable concept that is a customisable multi-use building design that can be built as or changed into offices, residential apartments, hotel or retail. To collect data from these case studies, participant action research is being undertaken to help facilitate the goals of the industrial partners, who themselves influence the design and conduct of the research (David and Sutton, 2004). These case studies are explained in more detail in the following sections.

Other case studies are being investigated at present to identify parameters, materials and technology for successful adaptability as well as modular grids and key constraints. These focus on those that relate to building services, those imposed by client requirements and those involved in building standards/regulations. These will be investigated by collecting data from case studies adaptable building through documentary analysis, interviews and observations of the buildings themselves. Focus groups and workshops have also been used to collect data from the wide range of industrial collaborators involved in the project.

Other methods used in later stages of the research project will include: scenario modelling to identify key challenges and requirements for adaptable buildings; Dependency Structure Matrix analysis to optimise components; life-cycle analysis to enable the economic benefits of adaptability to be investigated; Delphi Methodology to predict potential demand, highlight early adopter market segments and develop a successful marketing mix for adaptable designs.

MULTISPACE

3DReid, formerly Reid Architecture, conducted a concept study of reconfigurable adaptable buildings. The concept developed from this, Multispace, presents an adaptable, multi-use design that could form the basis of office, residential apartments, hotel and retail developments (Reid Architecture *et al.*, 2005). Multispace offers the opportunity for mixed-use buildings to respond to market conditions by changing use without significant adjustments to the external envelope (Gibb *et al.* 2007b). This could have benefits that lead to more sustainable developments, including: maximising commercial return; reducing risks to landlords; reducing waste; extending the life of the building; enabling people to live closer to work; and creating buildings that can change with the needs of society.

The aim of the study was to offer some potential solutions to the problems faced by creating multi-use buildings, these were addressed by identifying a set of design parameters (Reid Architecture *et al.* 2005). The technical requirements of these parameters were compared for each building use selected, enabling a generic specification for an adaptable building to be proposed (Gibb *et al.* 2007b). The design parameters included: storey height; building proximity, form and plot density; plan depth; structural design; vertical circulation, servicing and core design; fire safety design; and cladding design (Reid Architecture *et al.* 2005).

A summary of the proposed specification requirements from the Multispace concept is provided in Figure 2, while Figure 3 shows the residential, office and hotel perspectives of the Multispace concept.

	Ground floor condition	Upper floor condition
Proximity of blocks	Determined by spread of fire regulations	18 to 21m min. between habitable rooms
Plan depth	13.5m (preferably 15m) to 45m	15 to 21m
Internal ceiling height	3.5m single storey 5 to 7m double height	Approx. 2.7m
Ceiling zone	0 to 500mm	0 to 500mm
Floor zone	Preferably 100 to 350mm	Preferably 100 to 350mm
Structural slab & spans	Min. 7.5m span 260mm slab @ 9x9m; 330mm slab @ 12x9m	Min. 7.5m span; max. 12m span 260mm slab @ 9x9m; 330mm slab @ 12x9m
Design occupancy for fire	1 person per 5sqm	1 person per 6sqm
Travel distances for fire	30m two way (12m one way)	30m two way (12m one way)
No. and size of lifts	N/A	Design for mixed use as the worst case and offices as worst case for single use
Cladding spec.	Maximise glazing within fire, noise and cost constraints	40 to 100% glazing, NR 20-30; 1.5m module & option for opening casements

Figure 2: Requirements for adaptable buildings (Reid Architecture et al. 2005)

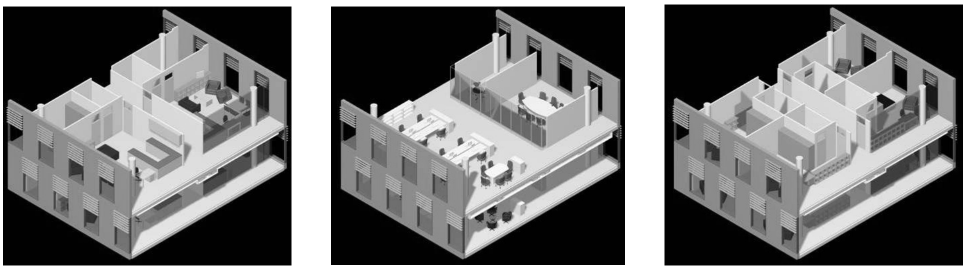

Figure 3: Residential, office and hotel perspectives of the Multispace concept (Reid Architecture et al. 2005)

NEWWAYS

The main aim of Newways is to reduce design and build time for GSK's facilities from 24 months to 13 weeks to enable the drugs that they produce to get to market earlier (Barnes 2007) or to enable the delay of the design and construction of buildings until the drug is approved, thus reducing risk of producing sub-optimal buildings and facilities. To achieve this, GSK are working with BWM to develop a pre-configured kit-of-parts used to build three building types: research laboratories; primary production; and secondary production facilities. The kit-of-parts is shown in Figure 4 and consists of 900 parts, 90 components and 30 assemblies that make up the three building types or assets (Gibb *et al.* 2007b). The benefits from using Newways are numerous and cover economic, social and environmental aspects, including: reduced risk; reduced supply disruption; reduced capital contingency; reduced cost from the ability to replicate designs; improved technology transfer; buildings can be dismantled and relocated; parts, components and assemblies that can be reused; reduced transportation needs; reduced site disruption; and quicker construction time. The strategy used to develop the buildings is the 10:80:10 (context: products: enhancement) rule, where the majority of the building is standard components, but the site-related elements and the finishes are customised (Gibb *et al.* 2007b).

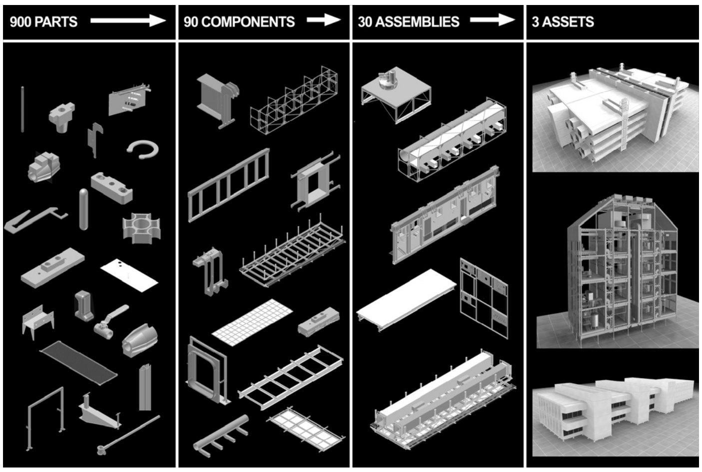

Figure 4: Newways kit-of-parts (GSK)

The Newways concept is being driven by the use of FlexiLab that creates flexible open plan laboratory spaces that can be reconfigured when necessary (Beadle 2007b). All services for the laboratory come through sockets in the ceiling that the equipment plugs into. The laboratories can be fitted out very quickly and can be easily reconfigured by the user. The life-cycle cost for the Flexilabs was calculated by GSK as being lower than conventional bench based laboratories as although the capital cost is higher, the reconfiguration cost was seen as being negligible (Beadle 2007a).

OTHER CASE STUDIES

A number of other case studies are being investigated to learn lessons from a wide range of previous examples of adaptable buildings. The selection of case studies encompasses examples that are reconfigurable, like Multispace, and pre-configurable, like Newways. The pre-configurable examples are all kit-of-parts buildings, but the reconfigurable ones have one or more of the following characteristics: multiple-use; extendable; internal rearrangement; relocatable; dismountable; refitable; and recyclable. The data collection and analysis of these case studies is a working progress. A small selection of these case studies, which are all pre- and re-configurable, that the author is investigating, are presented in this section, with the economic, environmental and social sustainability aspects highlighted. There will be more case studies and further analysis, including highlighting common themes, provided when this paper is presented.

Chiswick Park is a low-rise business park on a brownfield site in Chiswick, West London. The buildings on the park are both pre- and re-configurable, they are built from a kit-of-parts and can be rearranged internally. The park is being developed by Stanhope, Richard Rogers Partnership designed the masterplan and detailed design of the 12 buildings (Rogers 2007). It is estimated that 75% of the workers on the site will arrive by train, bus, cycle or on foot (Powell 2006b), unlike many similar developments. The buildings use standardised components and can accommodate open plan or cellular working. The buildings use external shading to reduce solar gain, which enables them to use natural ventilation and an air displacement system for heating and cooling, but at the same time optimising natural light and views (Rogers 2007). The aim was to create a high quality, highly distinctive environment that the workforce would enjoy working in within set commercial constraints (Powell 2006a).

The Sainsbury Centre for Visual Arts, designed by Norman Foster, was built in 1978 to house a collection of art donated to the University of East Anglia by Sir and Lady Sainsbury. The building is both pre- and re-configurable as it is made of a kit-of-parts and can be internally rearranged, refitted and extended. As well as housing the permanent Sainsbury collection it contains: temporary exhibition space; a café; the School of World Art Studies and Museology; a restaurant; and quiet study areas (SCVA 2008). The structure was constructed from lightweight prefabricated components, which were manufactured in factory conditions and brought to site to be assembled, reducing transportation and site disruption. The building features a double skin in which services are located creating a open flexible space for occupants that is naturally lit and ventilated. Low-running costs and reduced environmental impact was achieved by the decision not to air-condition the entire space. The building was designed to be extendable, but, in practice, when further capacity was needed, a partially-underground crescent shaped wing was created (Ibid).

The Terrapin Hire Fleet consists of standard components from Terrapin's Unitrax panelised timber frame system. The hire fleet buildings are both pre- and re-configurable as they are a kit-of-parts that is relocatable and dismountable. The shell and envelopes for buildings are made of these components and these are then hired out to create temporary buildings for certain periods and the components are recovered after use, refurbished and reused in another temporary building. Components for the internal spaces are being investigated, such as modular partitioning, services, fittings, fixtures etc.

Halley VI Antarctic Research Centre was commissioned by the British Antarctic Survey in a competition launched by the RIBA to replace Halley V. The brief for included the base needing to be relocatable. Faber Maunsell and Hugh Broughton Architects Ltd designed a base from a number of standard modules that would be situated on hydraulics legs on skis, so that the base could be relocated when necessary. All the pieces for the base are from a pre-configured kit-of-parts that when put together the space can be internal rearranged, the base can be extended, dismounted, refitted and relocated. The base is designed so that over its lifecycle it will have no impact on the environment, with all waste being removed from the site and the ability to remove the entire building. The operation of the base is much more efficient that the previous base, with many less people needed to maintain the base for winter use.

The stadium for the London Olympics and various other venues are being designed to be pre- and re-configurable and many can be reduced in size, relocated, dismantled and/or transformed for another use after the games. The Aquatics Centre designed by Zaha Hadid will change from a 17,500 seat centre to one that will hold between 2,500 and 3,500 for local use and major competitions. The basketball arena and Greenwich arena will be taken down after the games and relocated to provide legacy facilities elsewhere. The hockey centre will be relocated and will also be designed to be reduced in size from a 15,000 to a 5,000 seat arena. The main Olympic stadium will be made from standardised components and be able to be reduced from an 80,000 capacity venue to hold 25,000 seats when the roof will be able to be covered. There are plan for many of these buildings to have features to reduce their environmental impact, including renewable energy, sustainable materials and reuse of water.

WORKSHOP RESULTS

In this section results from a workshop (Beadle 2007a) with the industrial collaborators and the reference group are presented. The workshop focused on the two design strategies addressed by the research; pre-configuration and re-configuration. During the workshop participants were asked to document their experience of adaptable buildings that could be categorised under these design strategies. They were asked to discuss, in small groups, the pros and cons of these examples and the opportunities and challenges for delivering the two types of adaptable buildings identified. In this paper themes from the workshop are discussed in relation to sustainability and data were analysed to explore the social, environmental and economic aspects. The themes include: Components; Systems; Offsite construction and supply chain implications; and Flexibility.

Data were collected from workshop participants using digital audio recordings. The discussion elements of the workshop were treated like focus groups, with specific questions being asked and discussed. Group were made up of 4-5 industrial collaborators and members of Loughborough University. Participants were split up according to their backgrounds, which included: industry bodies; producer/contractor; academic/researcher; designer/consultant; and client/developer, this enabled a mix in each group. Each group had a facilitator to guide the discussion.

Components

Standardised components were used in a variety of examples from around the world that were discussed by workshop participants. In many examples the components could be reused, reducing resource use by extending the components life and increasing their value as they could be used again. Terrapin's Hire Fleet utilises components in this way by creating temporary buildings that can be recovered and reused a number of times. Buildings made from discrete components can be dismantled and the components recycled, if they are not able to be reused, however, it was acknowledged that this is often not done in practice. The workshop participants noted that there was a reduction in waste when using components as less improvisation was needed on site as the exact number and type of components needed was known. The quality of buildings was also said to be better as the specification of the components was known and their quality reassured, resulting in a better environment for occupants and a more robust building.

Systems

During the workshop, participants spoke in depth about systems used to create buildings that were made up of a set of standard components, panels or modules. It was noted that these systems were able to mix and match between component, panelised and modular systems. Component systems are a kit-of-parts used to create a building, panelised systems use a standard set of panels, whilst modular systems use modules that can be arranged to create different configurations. System buildings benefit from reduced transportation costs and environmental impact. Maintenance and replacement of parts was said to often be easier as parts were often designed to be demountable. Buildings were often planned so that they could be extendable, like the Sainsbury Centre by Norman Foster, which was said to be one of the best examples that could be infinitely extended, although it never was. Using the systems approach the workshop participants thought that design and construction time was reduced and that systems were well suited to busy and restricted sites to decrease impact. Economic advantages from shortened processes and reduced disruption for local residents and the environment were seen. System buildings are easily replicated which saves time and resources and leads to an improved product, as lessons are learnt after each replication. The workshop participants gave examples of hotels, stadiums and services that took advantage of replication. Travelodge have been working with Verbus and Buro Happold to develop a modular system using shipping containers stacked on top of one another. These are fitted-out before being brought to site and are quickly stacked up reducing the building period and creating faster income generation.

Offsite construction and supply chain implications

Offsite construction was seen, by the workshop participants, to increase productivity and quality whilst also reducing waste. Quality was seen as a driver by clients whose business related to selling a product, with some using offsite methods to achieve this. Off site was seen as taking advantage of controllable factory conditions to: increase the implementation and regulation of environmental standards; improve health and safety for workers; and automate processes. The supply chain for offsite adaptable buildings was of great interest, with many participants thinking that the most benefit could be achieved when it is in place and easily accessible. This can lead to reliable job creation, economic advantage to the manufacturer and the buyer, as parts are available when you need them, with no need for storage.

Flexibility

The workshop participants thought that flexibility was very important to adaptable buildings, this was looked at in several different forms with many environmental, social and economic benefits. Internal flexibility achieved through rearrangement of spaces was the most prolific type of flexibility discussed, with many examples given. The NHS have created a design rule book which works around standard sizes of bed units and offices allowing interiors to be reconfigured to adapt to rapid change. This has cost savings, as spaces can be easily and cheaply rearranged for a number of different uses, which also saves time and reduces disruption. Internal flexibility has great advantages for occupants as they are able to rearrange their live/work space to meet their needs, which could result in better productivity. Being able to separate building fabric that has different life cycles was seen as key to flexibility by some workshop participants. In one example, 'Flexilab' used by GSK, many elements are easily manoeuvrable and have the ability to be rearranged like furniture, such as fume cupboards, which would usually be fixed. The life-cycle cost of this approach has been calculated by GSK as being lower than the conventional system as although the capital cost is more, the reconfiguration cost is negligible. Flexibility was also mentioned as being achieved by designing buildings that can be relocated, dismantled and extended. The portal frame was given as a very good example of a structure that was dismantled and reused on a regular basis. Multiple use buildings were explored as examples of flexibility where the building is designed to suit several uses over its life cycle. This has environmental benefits as buildings have the ability to change use with market conditions, enabling them to have a longer useful life.

CONCLUSIONS

Sustainability has been shown, in this paper, as a vital part of adaptable building, both of which are becoming more important with the changes occurring that affect the construction industry. The Adaptable Futures research hopes to identify lessons from case-study adaptable buildings to encourage and facilitate the development of sustainable adaptable buildings in the UK. The case studies being looked at, some of which were introduced in this paper, cover a wide range of adaptability. Some are pre-configurable and others re-configurable, with many having aspects of the two to create exemplar adaptable buildings that are made from kit-of-parts and can be rearranged internally, dismounted, relocated, extended and refitted. The workshop results highlighted the sustainability of different aspects of adaptable buildings, focusing on their economic, environmental and social features.

The next steps in the Adaptable Futures project include in depth analysis of data collected from the case studies to identify parameters, materials and technology for successful adaptable buildings. The investigation of the life-cycle economics of adaptable buildings will also be explored as well as the business case, impact of processes and people and innovation.

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