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TOWARDS A SUSTAINABLE CITY: PIECEMEAL vs GRAND PLANNING

Guest Editors: Prof. Dr. Yurdanur Dulgeroglu-Yuksel, School of Architecture, Istanbul Technical University, Istanbul, Turkey.

Abstract
The main theme of this issue of Open House International is to make an inquiry into Piecemeal vs Grand Planning approaches to generating sustainable cities. The focus of the city is the human settlements. The selected papers will present both theory framework and cases which explore the issue of sustainability in its spatial, soci-cultural, economical and legal/policy dimensions. The experiences forming the infrastructure of the cases are collected from different cities /countries of the world.

The issue of sustainability has been a concern for many planners, architects, urban geographers and social scientists. The role of the professional is crucial in the development of cities to become more sustainable. It seems that development of cities, especially those in developing countries, in the post-modern age require a critique of existing housing and settlement policies. They somehow neglect the development dynamics in fast-growing metropoles. “Sustainability” is an old concept but has become a new solution criteria for generating liveable cities. While the natural phenomenon of urbanisation require piecemeal approach to spatial planning and development in Developing countries, their governments tend to adopt Grand policies of developed countries. Implementation of such policies often results in large wipe-outs in the city and social disintegration, following the replacement of existing neighborhoods. Furthermore, use of high-tech to serve as an end rather than as a means in the prestigious city in a developing country is a dangerous approach. Therefore an update into the sustainable characteristics of people needs to be integrated into community-oriented approaches and small scale projects. Physical and social integrity and slow growth of settlements is a crucial start towards sustainable cities.

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Editorial

In accordance with its commitment to discussion and dissemination of the Open Building principles and methods, the CIB W104 “Open Building Implementation” has been celebrating annual conferences since 1996. The main objective of these meetings held around the world is to promote research by various disciplines related to the improvement of the built environment by application of the Open Building concept, considering different cultures and interests.

In this special issue of Open House International we have invited some of the authors who participated in The 16TH International Conference “OPEN AND SUSTAINABLE BUILDING - O&SB2010” organised jointly by CIB W104 and TECNALIA on May 17-19, 2010 in Bilbao (Spain). In this Conference, more than 40 papers were presented, representing 16 countries. The winners of the 2nd International Open Building Student Competition “Detaching form Architecture” also participated in the Conference.

In the 11 papers that have being selected for this issue, we see the application of Open building principles in a general view but also applied to specific buildings and projects through case studies.

The first and third papers report on the implementation of OB in specific scenarios - a post-industrial scenario and the high-rise + high-density, a situation present in many of our modern cities using Hong-Kong as a specific case. Then an interesting study is presented, focused on the possibility of predicting the changes that can be afforded by an open architecture. Following this discussion is a report on current PhD research showing the need of designing the interfaces between the different parts of an open building system. Then a structural system is explained to achieve buildings of more than twelve storeys using modular technology.

The sixth paper explains the experiences of the application of the IFD (Industrialized, Flexible, Demountable) strategy in several Dutch projects, built or projected. The seventh paper describes the use of OB in the design and construction of an experimental facility named Kubik, located in Spain. The eighth paper analyzes the design of adaptable building in Japan giving two case studies.

The ninth paper discusses the history and development of residential infill systems, with a global view, in order to achieve the needs of inhabitants. The tenth paper explains the benefits of a modular construction system giving a case study as example.

For more information, all the papers presented are available at www.open-building.org.
THE TENDENCY OF “OPEN BUILDING” CONCEPT IN THE POST-INDUSTRIAL CONTEXT

Jiang Yingying & Jia Beisi

Abstract
When N.J. Habraken proposed the conception of support-infill in housing construction in 1960s, housing issues was centered by drawn material construction and consumption, although the needs of involving in the final occupants’ participation emerged. It reflected a transition from the industrial economy to the post-industrial economy. Since the rapid development and evolution in the field of technology and social culture in the last several decades, both the social structure and ideology have been changing. The consumption conception of dwelling has also shifted from physical substance to some invisible items, such as knowledge and service. Therefore, open building, as an architectural design method, should adapt to this situation in its future development. This paper firstly describes the characteristics of the post-industry society. Based on analyzing and summarizing the theories and some examples, this paper tries to re-explain the definition of “flexibility” in the context of the post-industrial society. It concludes that the possible tendency of open building is to establish a service system for future occupants to adapt to the changing living environment in addition to physical changeability of the building.

Keywords: Open Building, Post-Industry, Knowledge-Service Society, Participation, Housing.

INTRODUCTION
In discussions and studies related to housing, especially mass dwelling construction, the well-accepted theory is that housing is mainly influenced by the particularities of culture. Rapoport stated that the primary concern is that the house form must not simply be the result of physical forces or a single causal factor, but the consequence of a wide range of socio-cultural factors seen in their broadest terms (Rapoport, 1969: 47). Meanwhile, Habraken proposed the theory of “support-infill” in mass-dwelling construction, the very top level of which is the relationship between “field” and housing. He considered the field was not merely a physical environment, but included the population within it and the inhabitant culture shaped for years, which was a manifestation of the social ideology and culture of the particular area (Habraken, 2005: 36). He gave it the unambiguous definition of “the framework within which architecture, the self-conscious building that deliberately transcends the thematic, occurs” (Habraken, 2005: 77). Accordingly, its definition is implied not as “an aesthetic preference” but “the product of an entire culture with the meaning that the technological and social values could not be separated” (Habraken, 2005: 95). Although they used different terms, Rapoport and Habraken both explained the important and indiscreetible relationship among society, technology, and housing: a certain social culture is established according to the evolution of technology; and as one superstructure, housing utilizes the technology while reflecting the ideology of the culture.

Since the middle of the last century, obvious global social transformations have appeared. A new global economy brokered a variety of new ways of thinking, working, interacting, managing, producing, and distributing (Frankel, 1987: 27). Several of these include the transition from the production to the service industry, especially now that the era of material scarcity is about to end and the service industry population has continuously increased in the past several decades; the evolution of the electronic industry, which has been changing human participation- and communication-related activities in all fields; and the awakening of individual consciousness and the gradual realization of the importance of social participation. All these phenomena remind us that social culture has shifted increasingly with the transition of the industry and economy.
The Open Building concept is proposed as a transformation mechanism from quantity and function to quality. It aims to address changeability with individualized characteristics. In retrospect to the development of Open Building in the past several decades, most of the attention has been focused on the aspect of technology. Faced with issues related to housing mass-production, Dutch architects have focused on separating a structure into levels based on their various durations. This pattern has expanded to the fields of real estate and management (Fassbinder & Proveniers, 2009). In Japan, Open Building is applied as an approach to sustainable technology, as in the case of utilizing recycled resources. In America, Kendall indicates that the conception of long-term adaptability to environmental and social shifts in residential buildings has been more utilized in non-residential buildings in the past decade (Kendall & Teicher, 2000: 3). Despite the ideas related to housing based on a socio-cultural context as proposed by Habraken in the 1970s, less work has been done compared to the studies devoted to technology. Faced with the problems and dilemma that have emerged in the latest decade, discovering and studying the shift of the relationship among the main players involved in the entire housing process within the context of the post-industrial society may lead to the suitable direction of the development of Open Building and housing.

THE EMERGENCE OF THE POST-INDUSTRIAL SOCIETY

During the past half century, human society has experienced earth-shaking changes in all aspects. Social scientists around the world have tried to describe and summarize these changes with new terms to distinguish them from the previous ones. The term “post-industrial society” was first mentioned in a forum held in Salzburg in 1959 (Bell, 1973: 44). By observing the development of the three major industries and the alternation of the relationship among them, Daniel Bell divided the entire social process into three parts: the pre-industrial society, the industrial society and the post-industrial society, which are the formulations for competitions against nature, fabricated nature and among human beings respectively. The root of the differences among the three is the mode of production. In the post-industrial society, service and knowledge based on information are parallel with machinery (Bell, 1973: 146).

Service industry and economic restructuring

A surprising but prevalent social phenomenon around the world is that “economic decisions and struggles no longer possess either the autonomy or the central importance they had in an earlier society which was defined by the effort to accumulate and anticipate profits from directly productive work” (Touraine, 1971: 4-5). In his work, Bell states that the post-industrial society is on the basis of the service industry, the core of which is no longer pure physical strength or natural resource but information and knowledge. The most obvious facts point to the rate of the service industry’s increase since the 1960s. This became the first pillar industry whose population surpassed those of the other industries. Toffler expressed the belief that a new shift has taken place between use-value and exchange-value of goods and services, and that the post-industrial society will be based on a do-it-yourself (DIY), non-market economy with a social structure composed of individual and communal goods and services (Frankel, 1987: 27-28).

Information-knowledge society and new social class

Just as mass-production made products affordable to all classes that a queen and a worker can wear the same stockings, the richness of material is no longer the rule among different social classes. The rule nowadays is the occupation of knowledge and information. This period is known as the information age within which men, knowledge, and production are connected together in a comprehensive and open pattern that has never existed before. This transition gives the public abundant opportunities to share knowledge and information; meanwhile it places people with specialized expertise in dominant societal roles (Bell, 1973: 156).

Compared with the industrial society, the post-industrial society is considered as a knowledge society with scientists and technologists as its main resources (Bell, 1973: 273). Bell believes that the primary social issue is the status and nature of the
national science, the politicalization of science, and the role of scientists in providing support to solve social problems, all of which combine science and technology with politics, paving the way for the emergence of a new social class consisting of politicized scientists and technologists (Bell, 1973: 148-150). This new class obviously has an extremely close relationship with the social decision-making process. On one hand, they give consultations to the ruling class and on the other, they communicate, explain, or disseminate knowledge to the public to make the decision making and strategy more open.

Public participation and control
Owing to widespread knowledge and technology, the public now enjoys more opportunities and privileges to understand and participate in the course of making any decision related to them. This gives birth to two developmental trends: further individualization and further integration into a whole. For the former, mass, standardized products and institutions of industrial societies give way to diversified and demassified products and processes (Frankel, 1987: 27) and individualized features of personal life where small communities and local societies are emphasized (Touraine, 1971: 5). For the latter, large scales of economic, political, cultural, and scientific institutions are developed to replace the roles played by the central government by providing various new ways of performing daily operations (Frankel, 1987: 27). As a result, new social conflicts arise between the centralized decision-making and those who intend to retain or express individual characteristics. Soon, this becomes a societal issue. However, simply collecting various requirements from the subsequent small units or individuals cannot overcome the conflicts, and could only result in a deadlock. For the sake of both sides, effective communication and negotiation are indispensable, which form some sort of “democratic participation” (Bell, 1973: 444) or “communal society” (Bell, 1973: 157) to give consideration to both parties involved in the conflicts.

THE DEVELOPMENT TENDENCIES OF HOUSING CONSTRUCTION

Evolving from the industrial society, post-industrial society and production can be considered as a successor of the former, resulting in similar characteristics shared by the post-industrial housing with that in the industrial society, including prefabricated components and their manufacture according to materials, functions, and costs (Demchak, 2000: 76). Apart from the development following industrial production, some other housing tendencies may
be found on the basis of the distinctive characteristics of the post-industrial society.

**Industry based on knowledge-service consumption**

As a reflection of economics, culture, and politics, architecture inevitably cannot continue without any changes while the industry gradually shifts from production to service. Since the public has obtained more opportunities to obtain knowledge on materials and construction, its concern at present is not merely on the final products, but also on the assorted services that come with the products. For instance, the respective maintenance periods of all kinds of commodities now draw much more attention than ever before; and the so-called service apartment and its conception appears in the center of some metropolitan areas as a kind of deluxe residence option.

In Japan, based on the objective of resource productivity and sustainability of construction, Yashiro and his colleagues conceive an alternative business model suggesting that the construction industry and business should shift from production to service (Yashiro, 2000) (Figs. 1 and 2). In this entire system, construction parts and buildings are neither the final goods, nor the resources of the total revenue, but are devices for realizing and manifesting the quantity and quality of service with the support-infill structure. The main structure and infill are provided to customers with the related knowledge and service, with which the customers can deal with the two major parts under their requirement. These integrate as material outputs, but the essence is the function and performance of the building (Yashiro & Nishimoto, 2002). When one lease ends, the former customer moves out and a new customer signs a new contract with his or her particular requirements; afterwards, the former infill system is dismounted and carried back for re-manufacturing and re-renting in the next turn while the main structure is retained. This model is applied in the market of building rentals, which includes not only housing but also any other kind of building (Kawagishi, Yashiro, Nishimoto, & Shida, 2005; Yoshida, Yashiro, Nishimoto, & Shida, 2005). The realization of this conception is based on the platform established by the support-infill system of the Open Building concept.

The conception of the service providing system coincidently reflects the transformation of the society from production industry to service industry as the basis of the post-industrial society. Widespread knowledge on construction making, which allows the public to understand the primary principles and rules, finally heightens the public’s concern about things beyond the material form. As a result, the emergence of polarization in the construction industry is understandable: the massive centralized production for the infill and structures with certain standards on one hand, and the diverse

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**Figure 2. The idea of service provider and leasing model**

demassified institutes or workshops as intermediaries connecting the original products and final customers' particular customer's requirements on the other.

Bypassing the characteristics of buildings such as longevity, aesthetics, and expense, dwellings can be compared to something very familiar in daily life such as computers. Although the process of transmitting data from one part to another is complicated, the truth that a computer is composed of three parts (i.e., external components such as case, screen, and keyboard; internal components such as hard disk, motherboard and memory; and software such as operating system and various programs) is easy to understand. When a computer is bought, what is actually purchased is the permission to use the software, and the ability to avail of periodical maintenance checks and upgrading which can essentially satisfy buyers. Nowadays, the manufacturing of the hardware is centralized to several big companies following the international standards. However, the development of the software is dispersed around the world with specific responsibilities which can involve only 5 or 6 people in each group. For what reason then do we choose one computer rather than another? It is the differences in service and promises between the systems and programs with similar functions. This choice becomes freer since the DIY concept has become a part of popular culture. And almost all the programs are designed with more space self-creation and a wide range of options for its users. In short, no two computers are the same.

The rapid development of the computer industry gives us a good lesson on one tendency of Open Building. With regards the dilemma of housing, the utilization of advantage technology helps less than we expect in improving the entire construction system toward becoming more sustainable. One of the reasons might be the asynchronous development of the service, which falls behind not only with technology but also with the main social culture. This brings to mind what Kendall says about mass housing not being able to provide any appropriate mechanism for the industrialization of the housing industry (Kendall & Teicher, 2000: 11).

A similar example in the Netherlands is the Matura Infill System and its patented products: the Base Profile and the Matrix Tiles, and the software program called MaturaCads. This system provides infill design following the matrix grid system, prefabricated products, and installation services. It can be utilized in both new constructions and old buildings. One of the famous projects is the Voorburg Renovation Project near Rotterdam in 1990 (Kendall & Teicher, 2000: 113-114). Nevertheless, the limitation is obvious: as the storage of the prefabricated products is limited, the system can only be utilized in some small projects. Since all the products are fixed on the Matrix Tiles, the design should follow MaturaCads and the main structure should be appropriate to the system, both of which limit the system’s utilization.

**Public participation and control**

Another characteristic of the post-industrial society is public participation in every aspect. This is expected to occur in the construction industry. Increasing public participation influences the role of
the architect in the industry. From being a designer or an authority, the architect becomes a consultant or the person balancing the profit of all the stakeholders involved in the project, or even an assistant helping the users understand and master the system. The responsibilities go beyond architectural design and now include compiling the ideas or requirements from potential users or owners and achieving consistency through repetitive communication. On this aspect, a typical example is the Maya High-Rise Residential Building project in Chongqing, China. Completed in June 2008, its distinctive façade demonstrates that these two towers underwent different courses of architectural design and construction processes (Fig. 3).

The two towers of this project used a rectangle plan with 6.9 m X 6.9 m column network and two core tubes for the vertical transport in order to carry various flat types, in which 15 basic flat types come out from the smallest (occupying a half column network) to the largest consisting of a total of two column networks. All the drainage, pipes and outdoor parts for air conditioning are arranged in the public corridors, external walls, or the facility floors. After completing the podium, the first pre-selling round turned out well. The developer collected the feedbacks and other related information from the buyers and submitted to the architects for modifications on the proportions among the different flat types. The two tower buildings were built following the new design and consequently, the units were sold out to the first round customers. The second pre-selling round began when the floors up to the 22nd were constructed. The architects redesigned the rest of the parts following the same procedure (Fig. 4). The external walls of the different flat types are painted with different colors, which can be easily recognized from the outside (Li & Ren, 2008).
The Maya project shows a model of public participation in the construction process. The entire project was clearly divided into two parts: one that was handled by designers including the design conception for the entire project, the podium part, the main support structure, and the vertical transport parts. The other part followed the real needs of the consumers, such as the flat type. The potential residents were fixed by the pre-sale, while a survey on which flat types they required most was undertaken. The architects redesigned the plans following the result of the feedbacks, thereby ensuring that the customers could get the flats with their requirements, while ensuring that all flats will be sold. As exemplified by the differences in the two towers’ façades, the plans of the towers were decided indirectly by the customers rather than by authorities outside of the project. However, the data analysis on the project illustrates that the final flat type proportion is not exactly the same as the feedbacks showed. Obviously architects made adjustments to integrate flats into a whole (Fig. 5). Here, the role of the architects has not been limited to designing but also included balancing the relationship among the requirements of the building design, the individual customers, and the developers.

Unfortunately, this valuable architectural design model did not go further. Like almost all the other residential buildings, the architects withdrew from the project after the completion and sale. The project only focused on the requirement of the residents at the beginning stage but ignored the future evolution of the project. Any changes in the residents or their family structures will make the previous design model meaningless. In other words, the project was designed for a given group of people and cannot adjust to any more changes that could be brought in by future users. Therefore, future complaints may be expected just as in any other project.

Communal society and the NEXT 21 Complex House project
Temporary public participation in the Maya project indicates that it is not enough for the self-evolution of the residential buildings which lasts in the whole process of use. A more appropriate way is to establish long-term connections between participation and buildings. By far, the NEXT 21 Complex House project (Fig. 6) in Osaka City, Japan, is a relatively successful model of this long-term participation. As a part of natural resource saving and effective-energy use, the concept of support-infill system was included in the entire experimental system. Three experiment phases were scheduled from 1994 to 2011 after the project was opened to the public in 1993. The phases include high-efficiency energy utilization and greening for changes in future lifestyle in the first two phases, the flexible housing remodeling system in the third phase, and an experiment for establishing an urban community among residents along with all the three phases (“Osaka Gas Experimental Housing: NEXT 21,” 2007).

In the concept of flexible “support-infill” system, all the construction components, except the basic skeleton, in NEXT 21 are standardized, prefabricated, and modularly designed including partition walls, floors, ceiling, façade, and wire and piping systems (Fig. 7). All the 18 flats in five floors are varied and can be adjusted in accordance with the residents’ requirements. When the residents moved in, they were provided with “Rule Books” and keys. The books describe in detail how to use the building in every aspect. These books will enable the residents to use the building for 100 years without involving the original architects and builders (“Osaka Gas Experimental Housing: NEXT 21," 2007: 4). Apart from providing rule books, a public infill system test laboratory was established on the ground floor. It was opened to all the residents for testing and mastering various types of infill
components in the different positions of the house. As a result, the residents can update their knowledge and get what they need in tune with the newest technology. On the other hand, the residents were given the idea that the NEXT 21 project is more than a residential building but a small urban community unit. The purpose-designed three-dimensional street system and the public communication room on the first floor enhance the connection in three levels: between the local town and the NEXT 21, between the community and individual residents, and among all the individuals. The communal living rules were established in order to clarify the rights and responsibilities of each resident within the community.

All the people involved in the project’s construction wished to participate in the process of decision-making, just as Bell has explained that the
people have the influence to control their life (Bell, 1973: 157). Public participation in the NEXT 21 project can be classified into two levels: individual participation and communal participation. The former was realized because the relative knowledge and technology were well transmitted to the residents. This became a continuous process which also meant that the service from the developer will continue after the project’s completion. In reality, several dwellings were remodeled according to the changes of family situation even at the early stages of the first phase. The remodeling was implied as participatory in nature, where the roles that architects and builders played relatively declined. Synchronously, the community or “communal society” was established on the basis of communal participation of culturally diverse people who must share the same rights at present and in the future. The community appears as integrated when addressing public issues such as cleaning work in the public area and the greening of the entire building (Fig. 8). As a result, it can be assumed that the residents will actively and spontaneously participate in improving their residential environment as well as the building ("Osaka Gas Experimental Housing: NEXT 21," 2007: 22).

CONCLUSION

When the term “flexibility” is repeatedly discussed as a way leading to a sustainable construction pattern, it is often considered as a matter of technology. The Open Building concept takes the first step for breaking this brassbound tradition and tries to find various methods to make buildings flexible. For years, it has been proven that the power of technology is not enough to meet the demands of societal development. The transformation from the industrial society to the post-industrial society inspires a new perspective on the issue from dematerialized aspects—the relationship among people: service, participation, and control.

The service providing system gives a model that separates material production from final infill construction and adds an intermediary agency. This agency is in charge not only of design but of recycling the infill materials and components for different customers. This model can be realized in the house leasing market conceived by Yashiro and his colleagues. Maya high-rise residential project provides a pattern as to how public participation and control are carried out in the process of construction. A deeper thinking of the case reveals that this temporary participation and design comprise a kind of sales strategy to attract customers but one that could also lead to rigid formalism compared to the Open Building concept. Certainly, this should be avoided. The NEXT 21 project, although still in the experimental stage, can be considered as a rudiment of the post-industrial residential building, as it effectively connects the evolution of the building with the development of its users in a long-term scale and converts the building to a mirror reflecting the relationship among men. However, whether or not this model will work in communities with extant residential buildings and distinctive social ideologies should be looked into in the future. However, there must be some prominent projects of Open Building that has not been covered by this paper. Further work should be done to address this limitation.

ACKNOWLEDGEMENTS

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INTRODUCTION

Change is a reliable constant. Constant change calls for strategies in managing everyday life and a high level of flexibility. Architecture must also rise to this challenge. The architect Richard Buckminster Fuller claimed that “A room should not be fixed, should not create a static mood, but should lend itself to change so that its occupants may play upon it as they would upon a piano (Krausse 2001).” This liberal interpretation in architecture defines the ability of a building to react to (ever-) changing requirements. The aim of the project is to investigate the flexibility of buildings using evolutionary algorithms characterized by Darwin. As a working model for development, the evolutionary algorithm consists of variation, selection and reproduction (VSR algorithm). The result of a VSR algorithm is adaptability (Buskes 2008). If this working model is applied to architecture, it is possible to examine as to what extent the adaptability of buildings – as an expression of a cultural achievement – is subject to evolutionary principles, and in which area the model seems unsuitable for the ‘open buildings’ criteria. (N. John Habraken). It illustrates the significance of variation, selection and replication in architecture and how evolutionary principles can be transferred to the issues of flexible buildings. What are the consequences for the building if it were to be designed and built with the help of evolutionary principles? How can we react to the growing demand for flexibilization of buildings by using evolutionary principles?

Keywords: Evolution, Typology, Adaptability, Variation, Selection, Replication, Darwin.

VARIATION, SELECTION AND REPRODUCTION IN THE DESIGN PROCESS

The origin of adaptability in nature was explained by Charles Darwin in the mid 19th century with his theory of natural selection. Precisely because certain traits helped organisms to survive and successfully reproduce in the past, they have remained – as opposed to those with unfavourable traits – to the present day. Only the favourable traits have a chance of survival in the long-term. Individuals with such traits outclass the competition. They are more likely to reproduce, and because of heredity, their most favourable traits are found more frequently in
the next generation which in turn, give their offspring a further advantage. In this way, an advantageous variation automatically becomes more common and within time, spreads through an entire species. Single traits compete for survival (Zrzavý 2009) in which the three fundamental elements, variation, selection and reproduction from Darwin’s evolution theory play a key role. Together they form the evolutionary algorithm (VSR-algorithm) which aims at adaption for a particular niche and reproduction success.

But can biological evolution theory be translated without restriction to architectural design? Is not architecture a cultural achievement and therefore subject to other principles? And are not cultural works, in general, a deliberate, purposeful process, which is not the case in biological evolution which depends on mutation and genetic recombination. Nevertheless, the planning process of a building is characterized by variation, selection and reproduction.

The process from design to realization of a building is an iterative process which presents and selects solutions. At the end of this sequence of creating and critique, the solution appearing most suitable is chosen, giving the codified planning result. This is a four-phase process:

**Phase 1 – Defining the Program**

The program for the projected building is defined in this phase. The client commissions a planning specialist to design his building. As a rule, the client already has concrete ideas about the building and its use. These ideas are culturally embedded. Guided by experience, his knowledge and his architectural preferences, the architect (ideally) takes up these ideas, evaluates, reflects and discusses his client’s precise needs. He compares these with the fixed parameters such as location, orientation, building regulations, finances etc., highlights conflicting goals and sets priorities by selecting specific concepts. At the end of this phase, the requirement profile of the projected building has been determined and the target agreement (e.g. space allocation plan, use, cost ceiling, deadlines etc.) has been formulated.

**Phase 2 – Planning the desired program by generating variants and selection**

Variants are generated, selected and further developed in the design phase. In this internal generation of variants, ideas are generated in a creative process, reviewed and compared with the target agreement. Appropriateness and feasibility are key factors in the process. Deciding on a building component (e.g. a closed façade) allows only specific further architectural combinations which lead through internal selection to variance reduction. In addition to internal selection, there is also the external selection – in the sense of Rittel’s development etc. - which the planner can hardly influence. The concept is reworked until all influencing factors contribute to a sustainable compromise. This process can only be brought to a satisfactory conclusion, when priorities which enable different weightings to allow subsequent selection, are set between the parameters. Alberti’s definition of beauty pleasing architectural expression is a high
and only very difficult to achieve aim. For him, beauty is a particular harmony of all the parts, whatever the object, such that nothing can be added, taken away or altered without making it less attractive. Referring to his definition, Alberti also emphasizes that it is necessary to exert all creative and mental powers to reach this achievement. (Bertram 2000)

**Phase 3 – Codified Design Concept**
To evaluate the design concept, discuss it with colleagues, present it to the client and involve experts, ideas needs to be communicated on a level which is objective, understandable and clear. This level is termed by Bertram as the level of planning reality (Bertram 2000) where design concepts are determined by mathematical spatial concepts and represented in an objective, unprejudiced manner. As a rule, plans, sketches and models serve to illustrate the outlined building concept. The ideas, that is, the codified design concept in the building plan, are documented at the end of the design process. In doing so, the planner not only considers the invariable building elements (e.g. glass facades), but also imagines the variable elements such as change of mood (light, rain, time of day etc.). His professional knowledge enables him to arrange built elements in order to visualize the intended phenomenological variances of a particular setting. This serves as a guideline for the realization of the building (Schwehr 2002).

**Phase 4 - (Re)Production**
The building can now be built based on the codified planning concept. Each projected building therefore holds a magnitude of information and embodies awareness potential. Buildings at location or on paper conveyed architectural phenomenon offer potential for future solution models (Schwehr 2002). A building can be exemplary for planning problems of a similar kind and selected elements (e.g. building components, constructions details, design, spatial framework etc.) can be reproduced. Once the building has been realised, it is in competition with other buildings and subjected to different degrees of continual selection pressure. When a building no longer meets requirements, the selection pressure becomes too strong and the building has to be adapted. Certain elements (e.g. heating system) are completely renewed or the existing floor space allocation has to be adopted. Seen evolutionarily, the appropriate characteristics can be reproduced in the second phase of the building’s use.

**EVOLUTION IN INFORMATION PROCESSING**
In biological evolution, reproduction follows by passing on hereditary traits through genes. As part of a chromosome, they are responsible for the phenomenological characteristics (e.g. brown eye colour). All the genetic information found in an organism is collectively known as the gene pool. Different hereditary traits can emerge depending on gene constellation and dominance. This is known as phenomenological plasticity.

In architecture, there are no genes which are responsible for the features of a building. However, as mentioned earlier, each building has a set of information (Schwehr 2002) which can be extracted by the observer’s respective cognitive agent (Favre-Bulle 2001). A building’s appearance is the sum of all discernable features. In addition, every individual has a schema i.e. an internal representation of the outer world. This structure is also known as knowledge. Amongst others, this is where instructions (behavioural patterns) are stored. These enable us to react to situations accordingly. When a certain situation arises and no behavioural pattern is to hand, organisms find themselves in a state of uncertainty. Only by changing the structure of the internal schema, e.g. getting informed and creating new solution models, can knowledge be enriched. If the architect does not have a solution, he has to inform himself and create a new systema new variation which enables him to solve his planning problem. To develop and evaluate solution variations, the architect depends on certain information. Besides his own repertoire, he also taps into other information sources: his memory, built and documented projects. Apart from accessing information, the architect also generates information whilst working on the problem. He will document the results of his own work and compare notes with others involved in the planning process.

It is apparent that evolution, in both biologi-
cal and cultural understanding, is information processing which triggers a series of actions.

- In natural science, evolution is understood "(...) as the gradual development of a system which reacts to external influences depending on experiences made in the past." (Zrzavý 2009)
- For social science evolution is "(...) a process which memorizes and multiplies information, constantly producing new structures and characteristics. (Reichholf 2008)

Unlike Darwin’s evolution theory, in architecture, knowledge is consciously applied, information processed and other buildings are evaluated as an information memory. This information transfer can be explained by Richard Dawkins’ theory of the meme. For the evolution biologist Dawkins, the cultural analogy to a gene is a meme. Just as "genes propagate themselves in the gene pool by leaping from body to body via sperm or eggs", Dawkins theorizes "so memes propagate themselves in the meme pool by leaping from brain to brain" transferring ideas, concepts, ideologies and behavioral patterns. The external manifestation of a meme of a built structure corresponds to the characteristics of the phenotype in gene theory. A meme is a unit which can replicate itself. The reproduced information unit becomes effective in the coded planning result. The building is an external manifestation, or in Dawkins’ sense, a vehicle (Dawkins 2002)

In architecture, memes are both genotypic and phenotypic effective. In analogy with the evolution phenotype, the architecture phenotype carries all physical characteristics of a building. The phenotype is not restricted to morphological characteristics, but also includes physiological (heat transfer coefficient of the chosen wall structure) and functional characteristics (e.g. comfort). In contrast, the genotype of a building is to be considered as the entirety of the existing knowledge for this particular building type, its use and problems. During the planning phase, this knowledge is contrasted with the “achievable” in the process of generating variants and selection. At this point, we are reminded of the selective effect of the constraints resulting from building regulations, location, finances and social conventions etc. The codified planning project - the construction plan - is a result of these processes. Memes are therefore active on both the genotype level in generating information on the building type, as well as on the phenotype level. By selecting relevant features and system characteristics, they influence the decision as to which function, construction and interpretation of design ideas can be realized in the building project. The information memory “building” is therefore a meme pool of architecture. Besides functioning as replicators, memes are important for mutations and variance in cultural evolution. Development in architecture is not possible without memes.

**MUTATION AND VARIATION**

Accidental variation is the driving force and a condition of evolution. Variation within a population is the result of mutation and genetic recombination, and genetic rearrangement through sexual reproduction (Buskes 2008). No two individuals of a population are alike. Some traits give better potential of survival, others encourage biological fitness increasing chances of reproduction. Others are disadvantageous because they make survival and reproduction more difficult. Variations occurring in a population always happen by chance and not systematically. Depending on the niche (the relational position of the population in its ecosystem), variations can be an advantage or possibly wasted potential.

In architecture, innovation can be regarded as the counterpart to mutation. Although innovation is often “developed” purposefully, due to easier access to information sources and knowledge transfer outcomes are frequently characterized by powerful inherent dynamism which is controllable to a limited extent only. A “recombination” of knowledge is for example prefabricated parts. Successfully applied in the automobile industry for decades, they are now making an impact in building refurbishment with prefabricated retrofit modules i.e. for façades (Schwehr, Fischer 2009). Another example of recombination is the current discussion on greenhouse gas emission reduction into the atmosphere, which has a significant influence on the typology of future buildings.

The result of mutation and recombination is
variety and variance. These factors make it possible for the niche to be used optimally in the sense of an advantageous environment, which means, to successfully defend it against other competitors or to occupy it respectively.

In this context, adaptive radiation seems especially worthy of mention. It describes the process of species splitting within a relatively short period of time into several species, each of which is adapted to different ecological niches. Adaptive radiation occurs when there are a lot of unoccupied ecological niches, geographical separation and a less specialized parent species. "An evolutionary species is a line of ancestors-offspring-populations which maintain their identity against other such lineages and have their own evolutionary tendency as well as historical destiny." (Buskes 2008). The architectural equivalent to the evolutionary species is the building type. Adaptive radiation is its variance, through which many modifications of a basic pattern (e.g. ground plan) are achieved by adapting to different topographical, urban, climatic and user-specific conditions.

Variance is also a key factor for success in spreading its own meme in the meme pool. Highly specified solutions are often one-way solutions. For example, Gründerzeit (Wilhelminian style) apartments are still today very appealing and of stable value because of their high use flexibility. On the other hand, apartments with specific solutions for a specific way of life are at an evolutionary dead end. Lack of flexibility e.g. apartment layouts of the 60s, nowadays makes them difficult to let because society values and in turn, tenant’s requirements have changed fundamentally. These are solutions with an inadequate degree of flexibility which results in restriction of use and therefore not suitable for further distribution. Buildings which have memes with the necessary phenomenological plasticity in construction, design or layout are fitter than other buildings.

If existing building types have an "evolutionary" past, they also have characteristics which help them to "survive". These characteristics are accurately reproduced when planning future buildings (seen from an evolutionary point of view: to propagate – to reproduce) and to find their use in existing and future building stock more easily. The result of these suitable characteristics is adaptability which shows its flexibility potential. That means buildings which can be adapted have a higher flexibility potential than other buildings. Flexibility is an indication of long-term value retention (Plagaro Cowee, Schwehr 2008). The building can react quickly to new requirements at acceptable cost, time and effort.

Based on concepts described by the Fraunhofer Institute and supported by typology-based building evaluation (Fischer, Schwehr, 2008), four main building types of adaptability were iden-
Extension Flexibility (E) refers to extension and retrofit in architecture. This involves analysing and classifying the positioning and structural properties of extensions and retrofit systems.

Internal Flexibility (I) defines the adaptability of a building: in which degree are modifications within an existing structure possible. What are the risks and time requirements? How does the extension influence the building?

Use Flexibility (N) analyses building flexibility in relation to how it reacts to change of use. Concepts concerning the reversibility of changes and the future mono or multi-use are also considered.

Planning Flexibility (P) refers to characteristics which determine whether and how a building reacts during the entire planning and construction phase. It also investigates which measures can be implemented during the planning phase in order to facilitate flexibility during a building's operation time, with the least possible cost and effort.

Extension, internal, use, and planning flexibility are building strategies to be able to resist selection pressure as long as possible and to retain high value stability over the entire (renovation) life cycle.

SELECTION AND SELECTION PRESSURE

Selection is a key mechanism of evolution. Selection is responsible for different levels of reproduction success (= fitness) of selected individuals (Zrzavý et al 2009). This means an irregular heredity of traits from different individuals in the gene pool of the next generation, leading to a deliberate change of traits in the population over time.

In analogy to the biological, the cultural evolution underlies a selection process which corresponds to natural selection. When two or more buildings become competitors, the construction which best satisfies market needs "survives" and through the meme pool, its characteristics will have a stronger influence on the future building stock.

Figure 3: Typology of adaptability (Plagaro Cowee, Schwehr 2008)

Figure 4: Refurbishment as a Selectionprocess ©Schwehr. 2010
Selection can be differentiated by the type of selection strength, level, direction and intensity (Zrzavý et al 2009). These principles have been assigned to architectural themes in the following table.

**CONCLUSION**

In summary, it can be said that it is possible to explain and illustrate adaption processes in architecture on the basis of Darwin’s principle of natural selection. It is essential to always exploit the niche, to occupy an advantageous environment by being more successful than the competition. Transferring this principle to flexible buildings i.e. buildings which successfully resist selection pressure as long as possible, the following requirements for sound, future-oriented concepts can be deduced:

- Variance: Flexible buildings have a number of concepts which can react individually to their context. Variance makes it possible to successfully occupy the niche and in Darwin’s sense, to be “fitter” than the other buildings. This variance concerns the genotype as well as phe-
nomenological variance.

- Margin of error: Flexible buildings are planned and built knowing that their value can only be maintained over a longer time period if they can adapt to meet future demands. With this in mind, buildings are fault tolerant and not highly specified.
- Deconcentration: Flexible buildings have predetermined breaking points to allow building parts and systems (e.g. telecommunication) to be exchanged with little effort. Separation into primary, secondary and tertiary systems is an essential requirement.
- Open mind: Flexible buildings have innovative building concepts which are sustainable. Innovations thrive on an open mind and foresight. These can be achieved by exchanging information and transferring knowledge in the interests of improving the current and future environment. Interdisciplinarity and an open mind can prevent the evolutionary dead end.

**OUTLOOK**

This paper is the start of a research cycle on VSR-Algorithms in architecture. More extensive research on selection and variation is already being done. Further publications on this theme are in progress.

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OPEN BUILDING IMPLEMENTATION IN HIGH-RISE RESIDENTIAL BUILDINGS IN HONG KONG

Wai Kin Lau & Daniel Chi Wing Ho

Abstract
Aging of building stock is emerging. Open Building as a sustainable approach to deal with the problems associated with the aging housing stock is seldom applied in high-rise, densely populated built environment. With aims to identify the constraints and seek rooms for Open Building implementation in aforementioned context, a survey of 495 building layout plans from ten major housing estates in Hong Kong is conducted. The floor plans are analysed against the Open Building characteristics and criteria laid down by Tiuri (1998). Facts and obstacles of achieving Open Building in the territory are unearthed, and opportunities for implementation are then discussed.

The layout and structure of the surveyed private residential buildings in Hong Kong are very much alike. They are in fact closed buildings without the capacity to adopt, so any change in user requirements cannot be accommodated easily. Implementing Open Building using flexible and green fittings remains a viable option that enables transformation in existing housing stock.

Keywords: Aging Building Stock, Building Layouts, Existing Housing, High-Rise Built Environment.

INTRODUCTION
Aging of building stock refers to the transition characterised by falling building mortality and sinking new completions. It is beyond question that buildings nowadays will stand longer than before, and old buildings will constitute a larger portion of the stock. It has far reaching implications, from problems in building management and maintenance at micro level, to urban decay at macro level. As can be seen in statistics (Figure 1 and 2), developed regions are now undergoing such transition and sooner or later it will occur in those currently emerging regions. On that account, there are imminent needs to figure out ways to alleviate the problems associated with aging of building stock.

Figure 1. Aging trend of housing stock in the United Kingdom – expanding overall stock (at slower pace in recent years), shrinking new completions, i.e. existing stock gets older (source: DoE, various issues)

Figure 2. Aging trend of housing units in the United States – expanding overall stock (at slower pace in recent years), increasing mean age (also built year) of housing units (source: American Housing Survey, various issues)
As buildings age, they are more likely to become obsolete. Design and constructing buildings for maintainability and adaptability can be a way to counteract obsolescence and strengthen building functions. In spite of the contended benefits, Open Building in high-rise, high density context is under-researched. The aim of this paper is therefore to study the constraints and the opportunities for achieving Open Building in high-rise and high density built environment. The case of Hong Kong will be studied for its predominantly high-rise and densely populated environment. The scope will be confined to private residential buildings so as to fill the research gap in earlier works (e.g. Mahtab-Uz-Zaman and Lau 2002).

THE CASE OF HONG KONG

Land is as valuable as gold – this expression portrayed the reality in Hong Kong where land is highly scare and expensive. It has an area of 1104 sq km but the terrain is largely mountainous and hilly. Developments are concentrated in Kowloon and Hong Kong Island alongside the Victoria Harbour. The tall skyline and densely populated area, nevertheless, comprised a quarter of the territory only. The remaining three-quarters are mainly countryside that are not suitable for or protected from development.

Hong Kong has an enormous and probably the largest public housing system in the world, where 47.5% of the population (i.e. about 3.35 million) is housed (HKHA 2010:2). In other words, more than a half of the population is accommodated in private housing. The private housing stock, according to the Rating and Valuation Department (RVD), was 1,090,600 units at the end of 2009 (RVD 2010:15). Much the same as other developed regions, an aging trend is observed in the private housing stock that is reflected in shrinking new completions and demolitions. In Figure 3, on the one hand, annual demolition of private domestic buildings in Hong Kong is almost negligible, ranging from several hundred units to about two thousand units. On the other hand, new annual completion dropped significantly from 26,500 units in the 1990s to 7,160 units in 2009. The aging argu-
ment has been in the meantime cross validated by the increase in estimated mean stock age from 15.2 years in 1996 to 22.7 years in 2008.

OPEN BUILDING IN HIGH-RISE, HIGH DENSITY CONTEXT

What is Open Building? It is a broadly shaped idea that encompasses sets of principles leading to a sustainable building stock (Kendall 1999:2). These principles, according to Habraken, are:

- The built environment is being intervened by levels – physical elements by human actions;
- The involvement of multi-parties in the design process, with users being able to make decisions; and
- The continually transforming built environment must be recognised, and it is the produce of unceasing design process.

The characteristics that define Open Building are further described in Kendall and Teicher (2002:44-49). They were based on earlier works by Jia (1998) and Tiuri (1998) (Table 1). In her paper, Tiuri (1998) laid down 16 characteristics and criteria of Open Building and 3 improvements towards Open Building (Table 2). These criteria depicted the concept of Open Building more clearly and they will form the skeleton of subsequent investigations to find out the constraints in achieving Open Building in Hong Kong.

In addition to building capacity for future adaptation into design, and participation of users during the design process, it is necessary to provide barrier-free access in existing buildings, notably in densely populated built environment where vertical architecture prevails. When the case of Hong Kong is specifically considered, the challenges ahead in relation to Open Building are extracted and discussed below:

- The dilemma between rehabilitation and redevelopment – the rehabilitated, older stock may still fail to cope with the changing user requirement, while on the contrary, the replacement approach is environmentally unfriendly producing enormous Construction and Demolition (C&D) waste, and from Hong Kong’s experience, there is no guarantee that the newer is the better.
- Mahtab-Uz-Zaman and Lau (2002) inquired the limitations in design in meeting the future demand in mass, public housing context. The future demand includes 1. changing design parameter 2. tendency to smaller families 3. improving housing standards and 4. rising aspiration of residents. At the same time, the large number of users in mass, public housing renders problems to allow for user participation in design process.
- Real estates are very expensive in Hong Kong. Space optimisation through Open Building process can avoid excess or under purchase of space so that the state of space disequilibrium can be eliminated. Neither extra purchasing power is locked in nor unused purchasing power is drained away from the building sector. This is the social and equity issue of Open Building raised in Kendall (1999:11), however, creating extra space is of particular interest in Hong Kong for the living space is mostly tiny.
- Hong Kong has been blamed for the vast amount of C&D waste produced, with redecoration works as a major contributor. A practical way to

Table 1. Specific approaches to Open Building by Tiuri (1998) and Jia (1998); source: Kendall and Teicher (2002)
reduce C&D waste from redecoration works is to extend the life of interior fittings. In Jia (2005), the environmental impact of partition walls with different degree of flexibility were evaluated and the possible rooms for using flexible partition walls in Hong Kong were examined.

RESEARCH METHODOLOGY

How to conduct this study is something we are going to discuss. To study the constraints and the opportunities for Open Building Implementation in private residential buildings in Hong Kong, it is pivotal that typical designs and layouts are included in the sample. In this connection, ten major housing estates in Hong Kong are chosen for study. They are indeed very large-scale estate type residential developments that were completed between late 1970s and 2000s. The term ‘ten major housing estates’ is actually originated from the three biggest property agencies in Hong Kong (i.e. Centaline Property, Midland Realty and Ricacorp Properties), who carry out analyses and report the transactions in these estates regularly. From one point of view, the transactions in ten major housing estates are regarded as indicators of the state of residential property market for the high volume of transaction undertaken. On grounds like building quality and location, these estates are also desirable homes that are welcomed by users. A total of 495 buildings’ floor plans are in the end examined, that represents more than 102,000 units, or 9.35% of the private housing stock by the end of 2009. The particulars of ten major housing estates are shown in Table 3.

In earlier literature review, insights into the characteristics of Open Building are gained. The solicited plans are analysed using the Open Building characteristics and criteria laid down in Tiuri (1998). Her criteria for assessing Open Building characteristics in multi-family housing projects are relevant to the current study for they focus on the support and the infill levels only. Through

<table>
<thead>
<tr>
<th>User as decision maker</th>
<th>Separation of support and infill systems</th>
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<tbody>
<tr>
<td>A1 User decide on the infill or the changes concerning the infill</td>
<td>A5 Open frame structure</td>
</tr>
<tr>
<td>A2 User can participate in decisions concerning the support level</td>
<td>A6 Independent distribution of service systems to each potential spatial units</td>
</tr>
<tr>
<td>B1 A few optional floor available to first user</td>
<td>A7 Intermediate floor or installation zones accessible from the apartment</td>
</tr>
<tr>
<td>B2 User participation for the first user in the design</td>
<td>A8 Infill systems for services in the apartment</td>
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<td>A9 Infill systems for partitions (demountable partitions)</td>
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<tr>
<td></td>
<td>A10 Façade infill system</td>
</tr>
</tbody>
</table>

Table 2. Characteristics and criteria of Open Building laid down in Tiuri (1998)
desktop survey of building layout plans, structural characteristics of private residential buildings in Hong Kong and then their adaptability are recognised. Emphases are therefore given to open spatial structure and separation of support and infill systems in Tiuri’s Open Building criteria. Remarks on Open Building process and user participation during the design process are added afterwards. In Table 4, the items of analysis of the layout plan against the Open Building criteria are shown.

**FINDINGS – OPEN SPATIAL STRUCTURE**

Not surprisingly, the layouts of the surveyed buildings share many commonalities. They are typified by the presence of a central core, which is principally the ‘support’ level of these high-rise residential buildings. Within the central core are elevators, corridors and stairs that form the common passages. Electrical systems and telecommunication systems are distributed through this core as well. Round the central core are load bearing walls and pre-parcelled units. Under most circumstances, the number of units in each floor is 8 (Figure 4 and 5). In addition to the typical layout exemplified in Jia (2005), subject to the location of the kitchen in the default layout, the space is divided into living-dining area and bed-washrooms separated by structural walls (Figure 6). A summary of the survey result is provided in Table 5.
As illustrated in Figure 4 and 5, distribution of spatial unit is fixed. The distribution is bounded by the structural wall sandwiched between the pre-parcelled units and the central core. Redistribution of space by merging two adjoining units, however, remains a viable option provided that the common party wall is non-structural (Figure 5). Whampoa Garden and Kornhill, for example, are cases that merging is possible while Metro City (Figure 4) is not. Apart from technical constraints, redistribution of spatial units in existing buildings is legally restricted. Because the common area is delineated in the Deed of Mutual Covenant (DMC), redistribution of spatial units is prohibited unless such instrument is revised.

On top of the fixed spatial unit free configuration of flat layout is not viable. Consider Figure 6, readjusting the layout is not possible because of the presence of the structural walls that separate the living-dining area and the bed-washrooms in both layouts. Furthermore, there are additional restrictions from gas supply, plumbing and drainage systems whose in-outlet is almost fixed. The chances to relocate the kitchen and the washrooms are further reduced.

### SEPARATION OF SUPPORT AND INFILL SYSTEMS

A striking contrast is observed between the theoretical support and infill systems, and the actual configuration in the sample buildings, that the latter is far from open yet showed a high degree of inflexi-
Figure 4. Typical cruciform with structural wall in between two adjoining units, units in more rectangular shape.

Figure 5. Typical cruciform without structural wall in between two adjoining units, units in “diamond” shape.
At the support level, the inflexibility is due to the gas supply, plumbing and drainage systems running from external walls. Although they are distributed to individual units separately, there are still restrictions to readjust the floor plan. Unlike gas supply, plumbing and drainage systems that are more restrictive, the electrical and telecommunication systems are arranged according to the concept of support. They run in trunkings and distribute to users on each floor via the central core where space for connection and maintenance is provided.

In respect of accessibility, elevators are installed in these high-rise residential buildings. Minor improvements such as providing clear signs and adequate rails would be sufficient to create a barrier-free environment up to contemporary standards.

For the infill systems, both the partitions and the facades are conventional. It is not until recently the use of prefabricated components including prefabricated façade becomes more common in the territory. This move is initiated by the financial incentive offered by the government, that the prefabricated non-structural external walls can claim exemption from Gross Floor Area (GFA) calculations starting from February 2006.

**OPEN BUILDING PROCESS**

As a matter of fact, the surveyed residential buildings are not Open Building for they are not designed and built for future adaptation. Thus, Open Building process is not involved.

**USER PARTICIPATION AND INVOLVEMENT IN DECISION MAKING**

Perhaps it is inappropriate to tender facts in addition to the survey findings, however, user participation in the design process is extremely rare among private residential buildings in Hong Kong. Like most foreign countries, home buyers and sellers (i.e. developers) meet each other only when the building works have almost completed. Not only the ten major estates but nearly all of the high-rise, private residential buildings in the territory are also sold in similar manner in the first market. That is to say, users in general have no say in both infill and support levels as they are excluded from the design process. Given the irremovable structural walls and inflexible partitions in their units, users can merely decide the interior fittings (i.e. choose finishes and furniture). Alternatives to user participation include optional floor plans and participation of first user, nevertheless, they are absent in Hong Kong. As a remark, further study in user participation and customisation is recommended.

**OPPORTUNITIES FOR OPEN BUILDING IMPLEMENTATION**

In his own words, W. A. Ward (1921-1994) said, ‘The pessimist complains about the wind; the optimist expects it to change; the realist adjusts the sails.’ Shedding light on Ward’s words, the mode of ‘adjust the sails’ of private residential buildings in...
Hong Kong is to adapt by adjusting the interior fittings.

From the findings, private residential buildings in Hong Kong are subject to the following constraints:

- Redistribution of spatial units is infeasible. The only exception is to merge two adjoining units, however, keeping in mind the sky high property price in Hong Kong and the difficulties to acquire units that are already in occupation rendered this option impracticable; and
- Limited variety of layout due to the small space; freedom to readjust restricted by structural elements.

Adapting within pre-parcelled units is, for this reason, more practicable. This can be achieved through designing and applying fittings that can change according to user requirements and their lifestyles. Flexibility and environmental sustainability should be introduced into the fittings. The use of flexible partitions is an example that encompasses the aforementioned features (Jia, 2005). Features to save or even create space will definitely add merits – not only in Hong Kong but also in any other places where the demand for space is keen.

**CONCLUSION**

Aging of building stock is a global issue that demands urgent attention. If buildings are capable to adapt, problems arising from aging existing stock may be alleviated. With aims to recognise the constraints and seize the opportunities to implement Open Building in high-rise, high density built environment, layouts of 495 high-rise, private residential buildings from ten major estates in Hong Kong are examined. The survey result suggested that the sample buildings are far from open. A high degree
of structural similarity is shown. Their ability to adapt is limited by structural elements and certain services, resulting in inflexible layouts that fail to meet the changing requirements of individual users. Meanwhile, neither user nor Open Building process is involved during design and construction of these high-rise buildings. To tackle challenges of aging housing stock, transforming within pre-parcelled units is more practicable. An opportunity to adapt is through the use of flexible and green fittings.

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INTRODUCTION

The philosophy of Open Building suggests that a building is composed of different environmental levels, each with a certain lifespan. Ideally, independency between these levels is required, which achieves that building levels can be adapted separately, resulting in more freedom to change. Options to realize the ambitions of Open Building have been researched extensively (Brouwer & Cuperus, 1992; Cuperus, 1998; Kendall & Teicher, 2000; Cuperus, 2003; Habraken, 2003; Kendall, 2004; Durmisevic, 2006). In the Netherlands, the IFD (Industrial Flexible Demountable) concept has been introduced as a technique to create buildings with a higher quality, more flexibility and with better environmental characteristics. IFD is as an application of the Open Building philosophy (van Gassel, 2003; Scheublin, 2005; Durmisevic, 2006).

However, notwithstanding its clear advantages, the successful adoption of IFD principles has still not occurred. One of the main problems is the type of connections that are needed between building components. Therefore, this paper describes PhD research at the University of Twente that has the objective of designing a typology of flexible interfaces for IFD building that can be widely applied in the construction industry and aims to standardize connections, at the various levels of technical composition of a building, to create compatibility between building products from different suppliers. Such a typology of interfaces will increase the re-use and recycling of building parts, resulting in the increased sustainability of the building process. Furthermore, it will help accelerate the industrialization of the housing industry and mass customization of housing. A preliminary case study, in which a sustainable, flexible bathroom is designed, illustrates the various types of interfaces that can be applied, based on existing research. The paper illustrates the importance of interfaces, and aims to increase environmental benefits of buildings (less construction waste), improve the social aspects (higher user satisfaction in buildings) and achieve economical advantages (lower overall costs) by designing new interfaces.

Abstract

Open Building and IFD (Industrial Flexible Demountable) building are philosophies that aim to create high quality buildings with increased flexibility and better environmental characteristics. However, a successful adoption of IFD principles has not yet occurred because of concerns for the types of connections that are needed between building components. Therefore, this paper describes PhD research at the University of Twente that has the objective of designing a typology of flexible interfaces for IFD building that can be widely applied in the construction industry and aims to standardize connections, at the various levels of technical composition of a building, to create compatibility between building products from different suppliers. Such a typology of interfaces will increase the re-use and recycling of building parts, resulting in the increased sustainability of the building process. Furthermore, it will help accelerate the industrialization of the housing industry and mass customization of housing. A preliminary case study, in which a sustainable, flexible bathroom is designed, illustrates the various types of interfaces that can be applied, based on existing research. The paper illustrates the importance of interfaces, and aims to increase environmental benefits of buildings (less construction waste), improve the social aspects (higher user satisfaction in buildings) and achieve economical advantages (lower overall costs) by designing new interfaces.

Keywords: Interface Design, Open Systems Building, Ifd Building, Interface Typologies, Sustainable Building.
THEORY

Open Building aims to involve users in the building process and to create buildings that have increased flexibility. Habraken, the founder of Open Building, states that Open Building has two perspectives: social and technical. Firstly, the social perspective aims to respond to user preferences by offering flexibility of a building. Such flexibility makes it possible for (parts of) the building to adapt. Secondly, the technical perspective aims to divide a construction into several systems and sub-systems that can be “changed or removed with a minimum of interface problems” (Habraken, 2003). However, applying Open Building principles in practice is challenging. Kendall explains that on the one hand it is essential to design a built environment that supports stability, which is important for long term community interests, but on the other hand, change is necessary to meet the individual preferences of users. This prompts the question of how we can plan and implement, as Kendall describes it, a “regenerative built environment” (Kendall, 2004).

If the capability to change is needed, a high number of options (or variants) need to be established in the house building industry. It is challenging to achieve this in a cost-effective manner in the building process. However, research indicates that applying platform-based development in the housing industry could achieve this (Halman et al., 2008). Applying platform-based development increases flexibility in product design and increases the efficiency of product development (Halman et al., 2003). However, applying a platform-based approach in the housing industry is difficult, as other studies indicate (Hofman et al., 2006; Veenstra et al., 2006). The proposed research in this paper aims to apply a platform-based design approach to design a typology of demountable connections for IFD building.

IFD building

A building method that aims to achieve flexibility as a key aspect in the construction industry is that of IFD building: Industrial, Flexible and Demountable building. It is a method based on the principles of Open Building and is increasingly applied in the Netherlands but also in the United States and Japan. The three aspects of IFD building are (van Gassel, 2003):

- **Industrial**: most of the construction takes place under factory conditions, compared to the conventional way of building that mostly takes place at the building site.
- **Demountable**: the connections that are made between the components of the building can be demounted, which make reuse, configuration and replacement possible.
- **Flexible**: the building is designed with the facility to make changes at the various levels of technical composition of a building.

One of the OBOM initiatives - “The Building Node Research Project” (Cuperus, 1998) - mentioned that the industry has to aim to agree on a set of connection conditions for building parts. The aim was to come up with building components that can be designed by different companies, while maintaining a certain type of standard, resulting in the mutual compatibility of components. To develop such a
system, it is important to separate the functions of systems and subsystems so dependencies between components will be decreased (Brouwer & Cuperus, 1992). This is important for achieving flexibility. Figure 1 (left) shows the various levels of a building. The right diagram shows the hierarchy of the functional and technical decomposition of a building into independent systems and subsystems. The displayed composition is the ideal situation of a building in which every building function corresponds to an independent part of a building (Durmisevic, 2006).

Extensive research in the field of Open Building was performed by members of the OBOM group (van Randen, 1976; Brouwer & Cuperus, 1992; Cuperus, 1998; Durmisevic, 2006). Their research all stresses that a building must have the ability to adapt in response to changing circumstances. However, to realize flexibility, the connections between building components (called interfaces) also have to be adaptable. In research on flexible connections, Durmisevic defines two key criteria that determine the performance of a building configuration with respect to disassembly at connections: independency and the exchangeability of building components. The level of independency is determined by the functional decomposition of a building, while the level of exchangeability is determined by technical and physical decomposition (Durmisevic, 2006). Also, research has been conducted on the actual connections (or joints) between building components: Olie created a so-called “typology of joints” that supports sustainable development in building (Olie, 1996). However, a uniform set of connections that can be applied by different manufacturers in the construction industry and aims at IFD building, is not yet available.

**METHOD**

The objective of the proposed PhD research as presented in this paper is to develop a typology of interfaces for the building industry that can be applied in IFD building which improves mass customization and industrialization of the building industry. In this context, an interface is defined as a common boundary or interconnection between systems. In the case of a building, the interconnections will be the joints that hold together the different parts (or building blocks) of the structure and which separate the different functions of the building. A typology is defined as a systematic classification of types that have common characteristics. Therefore, a typology of interfaces can be considered as a set of joints. From the research objective, the following research questions are derived:

1) Theory: What are existing interfaces in the construction industry?
   i. To what extent are these interfaces applicable for IFD building?
   ii. How can these interfaces be best arranged in a typology, taking IFD building as a criterion?

2) Design: How can interface typologies and interface configurations be designed for IFD building that are broadly applicable in the construction industry and aim to achieve mass customisation and industrialisation of building processes?

3) Application: How can the designed interfaces be applied and tested in the building industry?

4) Reflect:
   i. What are the improvements, limitations and applications of the designed interfaces? (Conclusions)
   ii. How can the limitations for further implementation be minimized, by improving the design? (Recommendations)

The three questions will be answered by dividing the research project into four phases, each with its own focus. Figure 2 shows the project schematically.

In the first phase, a theoretical framework will be built by reviewing the literature and conducting a field study analysis. The literature review is concerned with the research fields of Open Building, IFD building, joints, Industrial Design methods and Product Platforms. The field study analysis will be conducted by interviewing experts: both academics in the previously mentioned research fields, as well as construction companies that already apply the principles of Open Building and IFD building. The interviews in the field study analysis will complement the literature review, together creating a thorough theoretical framework.

Using the theoretical framework, in the second phase, different interface typologies and con-
figurations will be designed. The deliverable of this phase is the design of a compatible set of interfaces at various levels of technical decomposition that can be widely applied in construction industry and conforms to IFD building principles. The design process is iterative and includes feedback from several construction companies throughout the process, hereby optimizing the design. This design will be presented as a detailed 3D CAD model, ready to be manufactured as a prototype.

In the third phase of the research, the design of the set of interfaces will be manufactured as a set of prototypes and tested at a test building site at the University of Twente. The application of the prototype will function as a test case, providing data about the functioning of the design. Again, companies will participate in this phase and give feedback. The result will be a working prototype which will lead to a set of conclusions and recommendations for the design in the fourth and final phase of the research.

Research will be conducted in close collaboration with several construction companies in the region of Twente, the Netherlands. The participating companies are members of a working group called IDF (Industrial Sustainable Flexible building) which focuses on IFD building. The participating companies are: 4D Architects, Winkels Techniek, de Woonplaats, Raab Karcher, Plegt Vos, van Dijk Groep, Hodes Bouwsystemen, de Groot Vroomshoop and Twinta. These companies are mostly construction companies, but also include housing associations, suppliers, installation companies and architectural firms. The research results will be applied in several of the participating companies.

To kick off the PhD project, a small pilot project was conducted, functioning as a preliminary case study for the research. In this project, a sustainable and flexible bathroom was designed as an illustration and clarification of the proposed research.

PRELIMINARY CASE STUDY

A case study was performed for the local district water board “Waterschap Regge en Dinkel” (WRD) in Twente, in the Netherlands. The requirement was to design an adaptable (and therefore flexible) bathroom that would also be sustainable by saving both water and energy. The project was executed in collaboration with two Masters Students in Architectural Building Component Design & Engineering at the University of Twente.

In the literature, several models are available that decompose a building into different levels. An example is the model developed by Duffy that defines a building through four different levels in terms of the so-called four S’s: Shell, Services, Scenery and Set (Duffy & Myerson, 1998). This model is shown on the left in Figure 3. Another systematization of building levels is the model developed by Brand which distinguishes six levels: Site, Structure, Skin, Services, Space Plan and Stuff (Brand, 1995). This model is shown at the right of Figure 3.

Both Duffy’s and Brand’s models indicate that different levels of a building have different life spans. In conventional building, levels often overlap in functionality. If flexibility is to be achieved, it is necessary to design every level apart from one another. By doing this, conflicts of interfering level properties do not arise. Such separation of functionalities per level is applied in the design of the bathroom in the preliminary case study.

To help indicate the levels of the bathroom, the models of both Duffy and Brand were com-
combined. This resulted in the following set of levels:

- **Shell**: this is the building in which the bathroom will be located; it is defined as the walls and floors of the building.
- **Structure**: this is the structure that holds together the bathroom; in this case the aluminium frames placed against the wall and the blocks on which the floor will be laid.
- **Services**: these are the technical components, such as piping, electrical wiring and ventilation ducts.
- **Scenery**: these are the covering of the walls and the floor with tiles.
- **Stuff**: these are the appliances such as the toilet, shower and sink.

**Interfaces**

The different levels of the building are connected with each other by means of interfaces. If flexibility is to be achieved, the interfaces have to be demountable. The research published by Durmisevic proposed a classification of seven different connections, ordered from fixed to flexible. Figure 4 shows the different principles behind these seven connections (Durmisevic, 2006). These will be used to illustrate the possible interfaces in this case study.
**Design**

The new bathroom design consists of different levels, with each level providing an individual function. This offers a flexible design because changes can be made per level. Figure 5 shows the design and illustrates the different levels, following the combined models of Duffy and Brand. The interfaces between the levels of the design are demountable, thereby offering flexibility. In Figure 5, the shell (1 & 2) of the bathroom consists of the walls and floor of the building in which the bathroom will be realized. The structure of the bathroom consists of aluminium frames (3) and small blocks for the floor (4) that form a pattern. The services, such as piping and electrical wiring (5), are mounted within the aluminium frames, as well as the tubing for the floor heating (6). The scenery of the bathroom consists of wall tiles (7) and floor tiles (8 & 9). Finally, stuff (10) represents the bathroom appliances such as the toilet, shower and sink.

**Modules & interfaces**

The basis for the design is a combination of modules. This is shown in Figure 6. At the left, an exploded view of a wall module developed by an architectural firm in Amsterdam (4D Architects, 2009) and at the right a floor module that was designed during the pilot project (at the right), are shown. Again, the levels indicated in the figure.

Both modules have fixed dimensions and can be seen as building blocks out of which a bathroom can be built. In the bathroom, four wall modules and four floor modules were used (see the dotted lines in Figure 5). Every wall module has space for one appliance (indicated by the level stuff). For every bathroom appliance, a wall module is available. By using demountable piping and applying a common height for services, it is possible to create a bathroom by placing several modules next to each other. In Figure 6 (at the right) it is shown how a floor module is composed. In this particular module, space is used for the drainage (the brown pipe) at the side of the module. Also, the blocks are shown that form the structure on which the floor tiles (scenery) lie. These floor tiles are prefabricated plates and can be demounted from the structure of the module. This demountability provides the opportunity to access the services later on, but without damaging the module.

The table at the top-right in Figure 6 shows several configurations of how different levels of the modules can be connected. Two examples are given for the wall module, as well as for the floor module. These examples indicate where the interfaces occur and how they can be applied. The illustrated interfaces are examples, but can also consist of other types of connections. They illustrate the importance of interfaces. The following examples of
configurations are given:
• The Shell – Structure interface in the wall module consists of connection type IV from Figure 4. This is a direct connection with an additional fixing device such as a nut – bolt connection. Such a connection is sufficient because this interface will rarely be changed.  
• The Scenery – Stuff interface in the wall module consists of a VI connection which is an indirect connection by using an independent third component such as a clamp or click connection. This offers the facility to detach/replace an appliance easily.  
• The Structure – Scenery interface in the floor module is a VI connection which makes the floor tiles detachable from the structure. This facilitates access to the services.  
• The Services – Services interface of the floor module is a VII connection; this is an indirect connection with an additional fixing device such as a “coupling part” for the piping. It offers changing elements so they can be re-used or recycled.

**Water and energy saving**

Although the main focus of the pilot project was to improve the adaptability of the bathroom, sustainability aspects regarding water and energy saving also played an important role. Reducing the amount of water was a key objective for the local water district of Waterschap Regge en Dinkel. The sketch to the left of Figure 7 shows the design of a new product; a transparent shower wall that functions as a water-saving reservoir. At the right of Figure 7, the working of the product is shown: water coming out of the shower (1), which normally goes to waste down the drain, is filtered (2) and then saved in the shower wall reservoir (3). Next, the collected water can be re-used for flushing the toilet (4). Furthermore, the shower wall aims to make people more aware of their water use because they can see through the glass wall how much water has
been used. This increase in awareness is expected to encourage people to save water. Water is also stored in the floor underneath the shower, which further increases the water storage capacity.

As well as saving water, the reduction in the required energy plays a role in the bathroom’s design. This is acquired by applying a low-temperature floor heating system (as represented by the tubing in the floor in Figure 5). Furthermore, both water reservoirs in the shower wall and the floor will be filled with warm water from the shower. The residual heat in the water will then be transferred to the colder air in the bathroom, which leads to a further reduction in the energy required. Therefore, both water reservoirs function as a passive heating system.

CONCLUSION

The proposed PhD research described in this paper aims to design a typology of interfaces for the building industry that can be applied for IFD building and that will increase mass customization and industrialization of the building industry. If such a typology will be the result in the future, this will comply with Open and Sustainable Building by offering stability on one hand (the building consists of properly designed, strong connections) as well as change (the interfaces are flexible, so users can make alterations to the building). Furthermore, such a typology will increase the re-use and recycling of building parts, resulting in increased sustainability of the building process. The preliminary case study, in which a flexible and sustainable bathroom was designed, shows the importance of the interfaces between the various levels of the design of a structure. Also, it indicates how flexibility offers the potential to customize individual levels apart from each other; leading to improved opportunities for mass customization. In addition, the various levels can be manufactured and assembled in the factory, which makes the design industrial. Finally, the bathroom consists of systems and sub-systems that can be changed or removed with a minimum of interface difficulties due to the use of demountable connections. Undoubtedly, these properties will become increasingly important in the future of the construction industry.

FUTURE WORK

This paper has presented an overview of a PhD research project that will be executed over a four-year time span. Future work consists of conducting the research plan shown in Figure 1. Following the pilot project, future work is expected by cooperating with companies that showed an interest in the design of the bathroom. Improving the bathroom’s design by specifying the flexible interface connections will be a first step. Next, the design can be tested in an experimental project.
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INTRODUCTION

Modular construction comprises pre fabricated room sized volumetric units that are normally fully fitted out in manufacture and are installed on site as load bearing ‘building blocks’. Their primary advantages are:

- Economy of scale in manufacturing of multiple similar units.
- Speed of installation relative to site-intensive construction.
- Improved quality and accuracy in manufacture.

The current range of application of modular construction is in cellular type buildings, such as hotels, student residences, military accommodation, and social housing, where the module size is compatible with manufacturing and transportation requirements. The current application of modular construction of all types is reviewed in a recent Steel Construction Institute publication (Lawson RM, 2007). A paper (Lawson RM, Ogden RG et al, 2005, p28-35 ) describes the mixed use of modules, panels and steel frames to create more adaptable building forms.

There are two generic forms of modular construction, which affects directly their range of application:

- Load bearing modules in which loads are transferred through the side walls of the modules – see Figure 1
- Corner supported modules in which loads are transferred via edge beams to corner posts – see Figure 2

In the first case, the compression resistance of the walls (comprising light steel C sections placed at 300 to 600 mm spacing) limits the maximum height of modular buildings. Current uses of modular buildings of this type are in the 4 to 8 storey range, depending on the size and spacing of the C sections.

In the second case, the compression resistance of the corner posts is the controlling factor and for this reason, Square Hollow Sections (SHS) are often used due to their high buckling resistance. Building heights are limited only by the size of the...
SHS that may be used for a given module size (150 x 150 x 12.5 SHS is the maximum sensible size of these posts).

Resistance to horizontal forces, such as wind loads and robustness to accidental actions, become increasingly important with the scale of the building. The strategies employed to ensure adequate stability of modular assemblies, as a function of the building height, are:

- Diaphragm action of boards or bracing within the walls of the modules – suitable for 4-6 storey buildings
- Separate braced structure using hot rolled steel members located in the lifts and stair area or in the end gables – suitable for 6-10 storeys
- Reinforced concrete or steel plated core – suitable for taller buildings

Modules are tied at their corners so that they act together to transfer wind loads and provide alter-
native load paths in the event of one module being severely damaged. A paper (Lawson RM, Byfield M et al, 2008 p 3016) reviews the robustness requirements for modular construction based on ‘localisation of damage’ in which modules are removed individually to assess the ability of the rest of the modular assembly to support the applied loads at the accidental limit state.

For taller buildings, questions of compression resistance and overall stability require a deeper understanding of the behaviour of the light steel C sections in load bearing walls and of the robust performance of the inter connection between the modules. A further issue is that of installation and manufacturing tolerances, which cause eccentricities in the compression load path and also lead to additional horizontal forces applied to the modules.

HIGH RISE BUILDING FORMS USING MODULAR CONSTRUCTION

Modular construction is conventionally used for cellular buildings up to 8 storeys high. However, there is pressure to extend this technology up to 15 storeys or more. One technique is to cluster modules around a core to create high rise buildings without a separate structure in which the modules are designed to resist compression and the core provides overall stability. This concept is illustrated in Figure 3, where the modules can be accessed from the core. A called Paragon in west London, shown in Figure 4, used a concrete core to provide lateral support to modules constructed with load bearing corner posts.

An adaptation of this technology is to design a ‘podium’ or platform structure on which the modules are placed. In this way, open space is provided for retail or commercial use or car parking. Support beams should align with the walls of the modules and columns are typically arranged on a 6 to 8 m grid (7.2 m is optimum for car parking), as shown in Figure 5.

STRUCTURAL TESTS ON MODULAR WALLS

A series of tests was carried out to verify the structural action of load-bearing walls in a typical modular system using 75 mm deep x 45 mm wide x 1.6 mm thick C sections. The test arrangement is illustrated in Figure 6. Orientated strand board (OSB) was attached externally and, in some tests, cement
particle board (CPB) was included to assess the difference in restraint provided by the boards. Two layers of 15mm fire resistant plasterboard were used internally, as required for 90 minutes fire resistance. In two of the tests, this plasterboard was omitted on one face.

Additional tests were included on taller walls to examine the influence of slenderness and also on walls with eccentric loading. The boards were fixed using 2 mm diameter air driven nails at 200 mm centres, as used in production of the wall panels. The boards were attached 2 mm short of the web of the top and bottom track so that the boards were not loaded directly.

The test results are presented in Table 1. It was found that composite action due to the stiffness of the boards attached on both sides of the wall increases the buckling resistance of the C sections by over 30% in these tests. From bending tests, the effective stiffness of the C sections is increased by 62% for boards fixed on both sides but by only 2% for OSB board on one side. Calculated compression resistances are also presented in Table 1. The strip steel was S350 grade and measured strengths were in the range of 380 to 405 N/mm². The model factor is the ratio of the test failure load to the compression resistance to BS5950-5 (BSI, 2000), based on measured material strengths. This suggests that the buckling curve used for cold formed sections is conservative.

The eccentricity of load application using a plate below the wall accentuates local crushing, as well as overall buckling. The crushing resistance may be taken into account by considering a reduced compression area. It was found that a 10 mm eccentricity caused a 19% reduction in load capacity and a 20 mm eccentricity caused a 36% reduction in capacity.

**STRUCTURAL ACTION OF GROUPS OF MODULES**

The structural behaviour of an assembly of modules is complex. The key factors to be taken into account in the design of high-rise modular buildings are:

- The influence of initial eccentricities and construction tolerances on the additional forces and moments in the walls of the modules.
- Second order effects due to sway stability of the group of modules.
- Mechanism of force transfer of horizontal loads to the stabilising system.
- Robustness of modular systems to accidental
In terms of constructional tolerances, Eurocode 3-1-1 Clause 5.3.2 (EN 1993-1-1, 2004) limits the out-of-verticality of a single column to $L/200$, but this is reduced to $δ_H = L/300$ when considering the average out-of-verticality over a number of storeys. The permitted out of verticality of a whole structure is obtained by multiplying this value for a single column by a factor of $\frac{1}{m}$ for $m$ columns in a group horizontally, which tends to $δ_H = L/420$. A further requirement in the approach of Eurocode 3 is that this out-of-verticality is considered in combination with wind loading.

These tolerances may not reflect the practicalities involved in modular construction because of the difficulties in precisely positioning one module on another and in making suitable connections. It is proposed that the out of alignment of one module relative to the top of the module below is not more than 12 mm on plan, which requires careful control on site. For a vertical stack of modules, the cumulative positional error, $e$, due to installation can be partially corrected over the building height, and may be taken statistically as $e = 12\sqrt{n}$ mm, where $n$ is the number of modules in a vertical group.

Added to this positional error is the possibility of a systematic manufacturing error in the geometry of the module. For a single module, the maximum permitted tolerance in geometry may be taken as illustrated in Figure 7. However, over a large number of modules, the average out of verticality of the corner posts may be taken as half of the maximum tolerance per module, or $h/1000$, where $h$ is the module height (typically 3m). Therefore the total permitted out-of-verticality $δ_H$ over the building height, consisting of $n$ modules vertically, is a combination of out of alignment and geometric tolerances. It follows that $δ_H = 50$ mm for $n=6$ storeys, which is equivalent to an out of verticality of approximately $h/350$ per floor.

A way of assessing the sway stability of a group of modules is using the notional horizontal force approach. The second-order effects in a vertical assembly of modules takes into account the increasing eccentricity of one module is successively placed on another, combined with reducing compression forces acting at higher levels. The equivalent horizontal force leads to an over-turning moment that is the same as the second order effect of vertical load. These horizontal forces that
required for stability are transferred as shear forces in the ceiling, floors and end walls of the modules.

For modular construction, it is recommended that the notional horizontal force is taken as a minimum of 1% of the factored vertical load acting on each module. It should be combined with wind loading (although with reduced partial factors) to assess overall stability of the assembly of modules or to transfer forces to the stabilising system.

Shear forces may be transferred to braced walls or cores through the continuous corridor members. The connection of the modules to the corridor may be made by a detail of the form of Figure 8. The extended plate is screw fixed on site to the corridor members and is bolted to the re-entrant corners between the modules so that it also acts as a tie plate.

A further load case defines the ability of a group of modules to transfer loads in the event of serious damage to a module at a lower level. The loading at this accidental limit state is taken as the self weight of the module and its façade materials plus a proportion of the design imposed load (normally one-third) acting on the modules. The main design solution is to ensure sufficient tying action, in this case at the corners of the modules (Lawson RM, Byfield M et al, 2008). For simple design, it is proposed that the tie force in both horizontal directions should be taken as not less than 30% of the total vertical load applied to the module and not less than 30 kN. The same connections may be used to transfer wind loads to braced walls or cores for overall stability.

**STUDY OF HIGH-RISE BUILDING USING MODULAR CONSTRUCTION**

A high-rise modular construction project in Wolverhampton in the midlands of England was studied to evaluate the efficiency of the construction process. The project consists of 3 blocks of 8 to 25 storeys and used 824 modules. The tallest building is Block A, which is shown in Figure 9. It has various set back levels using cantilevered modules. Lightweight cladding was used on all buildings and comprises a mixture of insulated render and composite panels, which are attached directly to the external face of the modules.

The total floor area in these three buildings is 20,730 m² including a podium level. The total floor area of the modules is 16,340 m², which represents 79% of the total floor area. The average module size was 21 m², but the maximum size was as large as 37 m².

The contractor was Fleming Developments for client Victoria Hall Ltd and the architect was O’Connell East Architects. The modular manufacturer was Vision, part of the Fleming Group. The project started on site in July 2008 and was handed over to the client in August 2009 (a total of 59 weeks). Importantly, the use of off site technologies meant that the site activities and storage of materials were much less than in traditional construction, which was crucial to the planning of this project.
MANUFACTURING DATA

It was estimated that the manufacture and in–house management effort was equivalent to a productivity of 7.5 man–hours per m² module floor area (for a 21 m² module floor size). This does not take into account the design input of the architect and external consultants, which would probably add about 20% to this total effort.

The module weights varied from 10 to 25 Tonnes depending on their size, which is equivalent to approximately 5.7 kN/ m² floor area. For modules at the higher level, 14% of the module weight is in the steel components and 56% in the concrete floor slab. At the lower levels of the high rise block, the steel weight increased to 19% of the module weight. The steel usage varied from 67 to 116 kg/ m² floor area, which is greater than a typical figure of 45 to 60 kg/ m² for medium-rise modular buildings.

The total area of cladding was 10,440 m² for the 3 blocks, which included composite panels, metallic cladding and insulated render. The thermal properties of the cladding (U values) ranged from 0.18 to 0.27 W/ m² and 1.9 W/ m² for the glazing, giving an average of 0.45 W/ m² over the whole façade.

CONSTRUCTION DATA

The installation period for the 824 modules was 32 weeks and the installation team was a total of 8 plus 2 site managers. The average installation rate was 7 modules per day although the maximum achieved was as high as 15 per day. This corresponds to 14.5 man hours per module (9.5% of the manufacturing effort), or 0.7 man hours per m² of module.

The overall construction team varied from a further 40 to 110 with 3 to 4 site managers for the non modular components, and the number of personnel increased at the finishing stage of the 59 week project. The total man-hours on site work were estimated as 170,000 (or approximately 8.2 man hours per m² of the completed floor area. It was estimated that the reduction in construction period relative to site intensive concrete construction was over 50 weeks (or a saving of 45% in construction period).

The estimated breakdown of man effort with respect to the completed building was; 36% in manufacture, 9% in transport and installation, and 55% in construction of the rest of the building. The total effort in manufacturing and constructing the building was approximately 16 man–hours per m² completed floor area, which represents an estimated productivity increase of about 80% relative to site intensive construction.

ECONOMIC BENEFITS OF MODULAR CONSTRUCTION

Modular and off-site construction technologies take most of the production away from the construction site, and essentially the slow unproductive site activities are replaced by more efficient faster factory processes. However, the infrastructure for factory production requires greater investment in fixed manufacturing facilities, and repeatability of output
to achieve economy of scale in production.

An economic model for modular construction must take into account the following factors:
- Investment costs in the production facility.
- Efficiency gains in manufacture and in materials use.
- Production volume (economy of scale).
- Proportion of on-site construction (in relation to the total build cost).
- Transport and installation costs.
- Benefits in speed of installation and reduced ‘snagging’ costs.
- Savings in site infrastructure and management (preliminaries).

A comparison of the breakdown in the costs of a building constructed using site-intensive processes and fully modular construction is shown in Figure 9. Materials use and wastage are reduced and productivity is increased, but conversely, the fixed costs of the manufacturing facility can be as high a proportion as 20% of the total build cost.

Background data may be taken from a recent report by the UK’s National Audit Office, 2004. In this report, the typical as-built cost of a fully modular residential building is stated as £1000/m² (1200 Euros/m²) in relation to a cost-median of £800 to £850/m² (950 to 1020 Euros/m²) for traditional housing. However, savings of 7-8% when using modular construction are readily identified in the NAO Report, which offset this cost premium. The economic arguments are presented below.

**INVESTMENT COSTS IN MANUFACTURING**

The investment in factory production of modules takes into account the following fixed costs:
- Manufacturing machinery and infrastructure.
- Storage, materials handling and distribution facilities.
- Heating, lighting and running costs of the factory.
- Skilled personnel involved in manufacture.
- Management and administration overheads.
- Design personnel and CAD/CAM facilities.
- Testing and system approvals.

A typical advanced production facility for modular construction would require an investment of £8 to 10 million (10 to 12 million Euros) and running costs could be as high as £4 to 5 million (5 to 6 million Euros) per year, including the costs of 80 to 100 personnel. Such a capital investment would
be amortized over 5 years and would require a minimum output of 1500 modules per annum to achieve its ‘pay back’.

It follows that the manufacturing cost per modular unit is approximately £5,000 (6,000 Euros) excluding materials (or £200/ m² (250 Euros/ m²) for a typical 25 m² modular unit). This is a very significant investment, and must be balanced against other tangible savings, as identified below.

The efficiency gains may be summarised as:

- More efficient materials use and ordering of materials.
- Less wastage and more recycling of materials.
- Higher productivity in factory production.
- Less work on site in difficult conditions.
- More reliable performance of the completed building.

It may be estimated that off-site production leads to at least 15% saving in materials and wastage. Given that materials cost is about 30% of the total building cost, this is equivalent to about 4% overall saving in build cost.

Productivity benefits are significant, and it may be estimated from the above case study that the labour costs in production are reduced by at least 30% relative to on-site work, and the number of site personnel is reduced by over 70%. This means that overall productivity is increased by about 50% relative to site-intensive building.

An annual production of 1,500 units may be broken down into 10 to 20 individual projects, with some opportunity for repeatability of components. A typical modular project may be as small as 30 modules, although the median is close to 100, and the largest maybe 300 for a high-rise modular building.

Design and production costs will decrease depending on the number of modules in any production run. A nominal 10% increase on production costs for internal design and management costs may be assumed for a typical modular project. Background testing can also lead to efficiency gains by optimising performance and removing unnecessary waste in the design and manufacturing process.

The cost of external consultants is also reduced from typically 6 – 8% in traditional design and tender projects to 3 – 5% in modular projects, as more design work is carried out in-house by the modular supplier. Furthermore, these costs will reduce if repeated over a number of projects.

**PROPORTION OF WORK ON-SITE**

Even in a highly modular project, a significant proportion of additional work is done on-site, due to:

- Foundations.
- Service connections.
- Cladding and roofing.
- Finishing.
- External works.

The NAO report estimates that this proportion is approximately 30% in cost terms for a fully modular building, and may be broken down approximately into Foundations (4%), Services (7%), Cladding (13%) and Finishing etc (6%). However, in many modular projects, the proportion of on-site work can be as high as 55% - see case study. Modular construction also saves on commissioning and ‘snagging’ costs that can be as high as 2% in traditional construction.

Some efficiency gains may be achieved by pre-attaching cladding to the modules. Lifts and stairs and air conditioning service units may also be produced as modular components.

**TRANSPORT AND INSTALLATION COSTS**

Transport costs are relatively independent of module size and may be taken as £600 (720 Euros) per module for a 200 mile (320km) travel distance (each way to the site). A large mobile crane would normally be required at a cost of up to £2,000 (2500 Euros) per day, and an average installation rate of 6 to 8 modules per day can be achieved. The combined transport and installation cost is therefore approximately £900 (1080 Euros) per module, which for a 25 m² module is £36/ m² (45 Euros m²) or approximately 4% of the overall construction cost.
BENEFITS IN SPEED OF INSTALLATION

Overall construction periods are reduced by 30 to 50% relative to site intensive building techniques. The financial benefits of speed of installation may be considered to be:

• Reduced interest charges by the client.
• Early ‘start-up’ of business or rental income.
• Reduced disruption to the locality or existing business.

These business-related benefits are clearly affected by the size and type of the business. The tangible benefits due to reduced interest charges can be 2 to 3% over the shorter building cycle. The NATIONAL AUDIT OFFICE (NAO) 2004 report estimates that the total financial savings are as high as 5.5%.

In traditional construction, site preliminaries may represent 12-15% of the total cost and take into account:

• Management costs.
• Site facilities, storage and accommodation.
• Equipment and craneage.

Savings can be achieved due to the reduced number of site personnel (and hence costs) over the reduced construction programme. The site preliminary costs may be taken as 5% for fully modular buildings, leading to a saving of 7 to 10% in comparison to traditional building.

CONCLUSIONS

The structural design of modular building systems should take into account the influence of constructional tolerances which increase the eccentricity of loading on the walls of the modules. Tests on light steel walls used in the modules showed that the compression resistance was 97 kN per C section, which is 455% higher than predicted by design standards, due to composite action with the boards on both sides of the walls.

A case study on a high-rise modular building presents manufacturing and constructional data. The economic benefit for modular construction may be as high as 15% in comparison to site intensive construction, depending on the speed of construction and economic of scale in manufacture. However, it is recognised that a cost premium for modular construction in smaller projects is due to the significant investment in manufacturing infrastructure.

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Industrial Flexible Demountable (IFD) building has recently been a subject of debate in the Dutch construction sector. This is a special type of construction involving experimental projects, experimentation being the first step in optimising a renewed production process or product. The building process is currently subject to various construction-related and organisational obstacles. This means that, in some cases, the objectives (which are focused on consumer-oriented building practices) were not being achieved. It was necessary to identify the problem areas and to consider the available opportunities for optimising the building process in future IFD house-building projects. The results of this study have been incorporated into guidelines containing a step-by-step plan. This plan sets out practical recommendations for market actors who wish to initiate an IFD house-building project. This study’s conclusions and recommendations form the basis for the seven stages that such parties will need to complete before starting on such a project.

Keywords: Industrial, Flexible, Demountable, Sustainable, Housing.
Lack of familiarity with the IFD concept
It appears that relatively few people are familiar with IFD building. The major clients are well informed in this regard, however. In addition, the limited use of IFD building makes its acceptance more difficult, especially among small businesses and construction companies. IFD building is a “generic term involving many and varied solutions, lines of development and manifestations” (Desicio 2006).

Technical aspects of building
The choice of smart construction techniques was an important aspect of the experimental IFD house-building projects. A search was conducted for refined building techniques and systems capable of achieving the desired degree of flexibility. This was not restricted simply to product or building-component level, it also addressed the level at which products, components and activities were coordinated. Obstacles arose because, in some cases, innovative systems at building component level were still insufficiently mature (floor-, wall-, installation-, and façade systems) or because there was a lack of innovation at the level of the overall concept. “Nevertheless, these obstacles to IFD building and to innovations in construction also represent challenges for the future” (Decisio 2006).

Structure and organisation of the building process
While building technology itself is undoubtedly an essential element in achieving a flexible dwelling that is capable of meeting the needs and demands of the user, the associated organisational aspects are no less important. Consumer-oriented construction and the use of innovative construction sys-
tems affected the structure of the building process itself. Exploratory talks (Gunst 2008) revealed that the organisational aspects of IFD building had a major influence on the final result. Both project-based thinking and process-based thinking are important here. How do you keep a grip on cost, quality and time in an IFD building project? This required a different approach to the process.

PROBLEM DEFINITION AND RESEARCH AIM

IFD house-building projects are still in the experimental stages. Existing obstacles to the building process mean that the aim – to build in a consumer-focused manner – is not being achieved. How can one create optimal conditions for a building process involving an IFD house-building project such that the aims – focused on consumer-oriented building and specified at the start of the IFD house-building project – can be achieved? The aim of the study was to provide insight into ways of optimising the building process in IFD house-building projects, by removing as many obstacles as possible and by exploiting all available opportunities. The results are intended for real estate developers, architects, builders, materials suppliers and end-users who wish to create flexible homes the IFD way.

A questionnaire was sent to real estate developers, architects and construction companies involved in twelve IFD house-building projects. The purpose was to obtain an insight into the aims specified for IFD house-building projects, and to discover which of these aims are not being achieved, and why. This survey formed the basis for the case studies. Five IFD house-building projects were studied in detail and the parties involved were interviewed (figure 5).

Objectives at the start of IFD projects

At the start of IFD house-building projects, various objectives are established in relation to Consumer-oriented building, Industrial building, Flexible building, and Demountable building (see also figure 1). The main objective of these IFD house-building projects was consumer-oriented building. The IFD concept was seen as a strategy that enabled consumers to influence projects in an efficient and manageable way. Various aspects of the flexibility objectives were developed on a project-by-project basis. Most of the objectives with regard to flexibility were at the level of the dwelling’s volume, layout, built-in facilities, and appearance. The individual projects each interpreted these objectives in their own way, in addition to setting objectives of their

![Number of IFD Projects](image)

**Figure 4. Number and nature of IFD projects (by Crone 2007)**

![The five detailed cases: Smarthouse (Rotterdam), De Zeven Hemels (Rotterdam), A+ dwellings (Etten-Leur), Het Masker (Veenendaal), Terbregse.nl (Rotterdam) - (by Crone 2007)](image)
own. The agreement was that each project would draw a distinction between freedom of choice for the initial user (concerning the dwelling’s size, layout, built-in facilities, finishing and appearance) and adaptability in the later stages of use (adjusting the size of the dwelling by adding or removing various parts, changing the floor plan, façade elements, extensions), through the use of detachable building components.

Prior agreements concerning such things as standard dimensions, details, and fixed prices per product or per m² make it possible to provide guarantees concerning the end product. Efforts to accelerate the building process focus on making the maximum use of the available production technology, involving fixed agreements on dimensions, suppliers and implementation, all of which make it possible for industrially prefabricated products to be assembled and fitted on site. The use of factory-like production processes under controlled conditions makes builders independent of weather conditions, while providing a more comfortable working environment.

OBJECTIVES NOT ACHIEVED - AND THE REASONS WHY

The various parties involved indicated that, in practice, some objectives are not achieved (Gunst 2008). The principle causes put forward to account for this were: impediments in the development and construction process, projects that folded before they could be realised, lack of scope for creating a more efficient building process, product innovation that was mainly at component level rather than at the level of an overall concept, inability to provide guarantees due to a lack of coordination and cooperation between the various parties involved. The three most common reasons for failing to achieve objectives were technical, financial or organisational in nature (see figure 7). On the basis

![Figure 6. Flexibility in dwelling layout (left: A+ homes) and in the volume of the dwelling (right: Smarthouse); (by www.slimbouwen.nl May 2010)](image)

![Figure 7. Reasons for erosion of original objectives, segregated into five clusters (by Gunst 2008)](image)
of five projects, a further analysis was carried out to identify the objectives formulated at the start of the project, those that were ultimately achieved, and the reasons why the remaining objectives were not achieved.

**Smarthouse**
The Smarthouse concept was aimed at a very specific target group, to wit private buyers with their own plot of land and an interest in specifically tailored architecture. However, there was very little demand for dwellings of this kind. While the Smarthouse had been developed for a clearly defined target group, a deteriorating housing market caused demand to ebb away before the concept could be realised. Smarthouse combined the extensive freedom of choice that is normally associated with an individual construction contract with the advantages of a dwelling selected from a catalogue: a sleek design and a streamlined building process involving serial construction. In this way, it was possible to develop products with a fixed construction time, cost, and quality.

**Seven Heavens**
The Seven Heavens (Zeven Hemels) concept involved some very extreme aspects of design and construction, virtually all of which were highly innovative in nature. This was an entirely new concept, IFD building. This involved novel aspects such as a building system based on a steel-skeleton that had never before been used in practice, an unknown end product in the form of a flexible apartment block with eight different façades, unknown buyers (no potential clients had yet signed up), a new form of cooperation (a single basic-frame architect and seven different architects specialising in built-in facilities or in the finish of dwellings).

Market research carried out in the initial stage revealed that the project was excessively ambitious, both in view of the assigned site and of the new concept of IFD building. There was a lack of coordination between the principal on the one hand and the architects (basic-frame architect and seven architects specialising in built-in facilities or in the finish of dwellings) on the other. This meant that the project was not viable, and that it ultimately had to be abandoned.

**A+ dwellings**
The A+ building system concept was already in place prior to the start of the IFD programme. However, its application in housing construction was an innovative aspect. The A+ building system makes it possible to implement a range of different housing plans and to adapt these plans to fit...
changing housing needs. However, the users (tenants and buyers) did not become involved until after completion. Accordingly, any design modifications to meet the needs and demands of future occupants could not be fleshed out in the construction stage. Inevitably, traditional ways of thinking and working had to make way for more innovative approaches. While innovative construction systems were used, there was no coordination with those involved in the associated organisational and building work.

The Mask
Not only has The Mask (Het Masker) project been completed but it also achieved the flexibility objectives. The choice of building system substantially influenced the building process. The result was a totally different process. The preparation stage was much more intensive than had been expected, which meant that coordination between the various disciplines involved was crucial. However, the various parties failed to contribute and coordinate their expertise. The residents made full use of their freedom of choice during the construction process, at the levels of dwelling volume and layout. As the dwellings in question are rental properties that are managed by a housing association, future adjustments to changing housing needs are expected.

Terbregse.nl
The Terbregse.nl project was completed as a direct result of previous flexibility projects by the same developer. Previous in-house experience in building flexible homes in an industrial and demountable way was harnessed in this project. The nature of the approach to consumers contributes to the freedom of choice and degree of adaptability of the dwellings. The first step, involving the registration of future residents, is followed by a ‘Dream House’ day, after which general wishes are translated into

Figure 10. The objective of the IFD project A+ dwellings was to create homes that are adaptable to the composition of families and to changing housing needs. The Infra+ floor contributed to this flexibility (by www.slimbouwen.nl May 2010)

Figure 11. The scope of The Mask was the development of housing within the housing benefit limit while giving users the freedom to design their own home (by Het Houtblad April 2010)

Figure 12. Nijhuis (a developer and building contractor) had been building in accordance with the IFD concept for some time before the SEV came up with the IFD innovation programme. They had already come up with solutions to problems that they had encountered in previous projects (by www.terbregse.nl May 2010)
specific design features. Next, comes the layout of the house, plot selection, the exchange of contracts, and construction. Integrated design was the most important stage in the construction process, and was already well developed. This made it possible to achieve a good rapport between the parties involved, as a result of which the implementation stage went very smoothly indeed. The only issue was that some users were too late in making their views known, which meant that the flooring system could not be adapted to individual requirements.

CONCLUSIONS AND RECOMMENDATIONS

The study has shown that some predetermined goals for the experimental IFD projects were not achieved during implementation. This is mainly due to the building and organisational aspects of the building process associated with IFD house-building projects. The production of flexible housing that allows initial users the freedom of choice to design the dwelling to suit their own requirements and that guarantees adaptability to changing housing needs as time goes by, calls for a new approach to building processes. The use of industrially manufactured, removable building elements allows dwellings to be completed in much less time than is possible using traditional building processes. The preparatory stage, however, is much more intensive. Furthermore, the design work and the technical implementation are fully integrated, and run concurrently. When attempting to optimize the construction process, it is vital that the following aspects be addressed:

• Defining the target group for whom dwellings are being constructed is the basis of a successful project. This involves market research and an understanding of the needs and requirements of the target group in question.
• The premise and the objectives are formulated on the basis of the selected target group and the agreed definition of the “IFD building” concept. These will have to be monitored throughout the entire process.
• Consumers tend to have traditional views. They want to know what the end product will look like. Given the extreme flexibility of these dwellings, there are few standard aspects that can be used to show what the final product will look like. Accordingly, buyers often prefer a traditionally built house. The development of a demonstration home, or prototype, can help to address these concerns.

• Before all aspects of the building process have been determined, the degree of user involvement should be determined. This might relate to their ability to influence the end-result, for example, or to the process of drafting the schedule of requirements, the design process, and choice of building system.
• Many problems arise due to inexperience (and a lack of familiarity) with innovative products and processes on the part of those involved.
• The expertise of each of the various parties should be deployed at the appropriate stage. Traditional ways of thinking and working will have to make way for an integrated approach.
• Integrated design offers the opportunity to achieve an optimal end product. The expertise of the various parties involved is deployed as part of a joint effort to achieve a design and to work out the relevant technical details. This requires close coordination and harmonisation between the various disciplines.
• The intended degree of flexibility will have to be translated into a design. This presents opportunities with regard to the technical aspects of building. For example, the design of a load-bearing construction that can be divided into lots, integrating flexible floor and wall systems into the design, or the creation of over-capacity.
• The shift of intensity from the implementation stage to the preparation stage means that coordination of the various market actors is crucial. It is preferable to work with fixed co-makers, in order to optimise the coordination and cooperation of the various parties. Fixed agreements can be made with them at an early stage of the building process, concerning price, quality, logistics and the supply of products.
• The full potential of product flexibility can be employed to cater for changing housing needs while the dwelling is in use. However, these
need to be monitored and supervised to avoid the erosion of knowledge over time, concerning what is and is not possible.

SEVEN STEPS IN THE GUIDELINE FOR IFD HOUSE-BUILDING PROJECTS

The study’s conclusions and recommendations form the basis of the IFD House-building Project Guidelines (Gunst 2008). These consist of seven steps that must be completed before the development of an IFD house-building project can commence.

**Step 1: Market research**
Launch market research in the initiation stage. On the basis of the results obtained, select the appropriate target group and the associated living requirements for which the flexible dwelling is to be built. This provides a better guarantee that the new homes will be sold.

**Step 2: Draft the initial guiding principles**
The principles to be drawn up involve generating a definition for the concept of IFD building, the development concept of flexible housing (e.g. private contractor, catalogue-style construction, or a concept involving a specific building system), and the approach to future users (for the user, with the user and/or by user).

**Step 3: Formulate objectives**
Formulate objectives in the initiation stage that can be subdivided into a central or general objective of creating value (or added value) for the user, and peripheral objectives specifically aimed at industrial, flexible, and demountable building. Monitor and check these objectives throughout the remaining stages of the process.

**Step 4: Select method**
In the initiation stage, select the method to be used during the development and building process. Allowance should be made for the amount of freedom of choice available to the residents during the development stage and for the degree of adaptability while the dwelling is in use. Choose an innovative building system that is best able to provide the desired flexibility. Suppliers’ expertise may be useful in this regard. Determine an organisational structure and identify the parties involved and their individual responsibilities within the process and in terms of the end result.

**Step 5: Monitoring flexibility in the design stage**
Structure the design stage such that the principles and objectives are translated into a design. From the point of view of market research, the identification of user needs and the schedule of requirements, guarantees must be given during the design stage concerning the freedom of choice available with regard to house size, house layout, installation, built-in facilities, and finishing. Adaptability while the dwelling is in use should also be monitored, such as adding or removing various parts of the house, or making changes to its layout or appearance.

**Step 6: Structuring implementation stage**
Structure the implementation stage such that the flexible dwelling can be completed quickly, without encountering any obstacles. This might involve implementation logistics, on-site assembly techniques for industrially manufactured prefabricated building components, and working with fixed co-makers. This involves cooperation between the contractor and specialist subcontractors and suppliers. The advantage of established teams is that the representatives of the various disciplines are used to working with one another. Each other’s knowledge and expertise are utilised to the full.

**Step 7: Monitoring flexibility options**
Create flexibility options while the dwelling is in use and ensure that these can actually be implemented should the need arise. If a dwelling remains in the ownership of a corporation, then the latter is responsible for making the options for adaptation or change as clear as possible. When the user owns a dwelling, the latter must be provided with a logbook in which the various modification options are described and explained.

A final important recommendation relates to experimenting with innovations, both at building-component level and at the level of an overall concept. This offers an opportunity to identify potential
obstacles at an early stage. Experimentation involves learning from experience, optimising, and perfecting. Setting up a demonstration home can be part of this procedure.

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INTRODUCTION

The design of KUBIK is based on an industrialised approach to achieve a flexible and adaptable experimental facility, an open building-system, to evaluate and optimise new construction components and solutions, systems and services for the improvement of building energy efficiency.

The Open Building concept is not new and the main principles have been established by Habraken (Habraken, 1998):

- Distinct Levels of intervention in the built environment, such as those represented by ‘support’ and ‘infill’, or by urban design and architecture.
- Users / inhabitants may make design decisions as well.
- Designing is a process with multiple participants also including different kinds of professionals.
- The interface between technical systems allows the replacement of one system with another performing the same function.
- The built environment is in constant transformation and change.
- The built environment is the product of an ongoing, never ending, design process in which environment transforms part by part.

However, there is still a need to disseminate and to train the stakeholders of the construction sector to fully understand and to implement the Open building concept in our buildings and built environment (Open House International, 2006), (Kendall, 2008).

On other hand, one key innovation regarding the implementation of the Open Building concept is the industrialisation of it. The industrialisation of the open building concept has been dealt at concept level and the state of the art introduced by the CIB (International Council for Research and Innovation in Building and Construction) (Sarja, 1998). And, more recently, has been a hot topic for R&D in Europe (Manubuild, 2009).

To finalise this introduction of the issues that have influenced the design of the research facility, KUBIK, it is compulsory to address the current envi-
Environmental concern that affects the building industry, mainly driven by the energy performance of the built environment and the new European Energy Performance Directive in force (EPBD, 2008) and the R&D initiative lead by the European construction sector to meet this challenge, the Energy Efficient building Joint Technology Initiative (E2B JTI, 2010).

As summary, KUBIK provides the needed support to improve the energy performance at building level, as requested by the EPBD, and in a comprehensive way, the envelop, the demand and energy generation, and based on industrialised construction systems.

KUBIK AIMS AND DESCRIPTION

The “openness” of KUBIK

Although it is necessary to acknowledge that does exist a previous similar facility by the Fraunhofer Institute of Building Physics in Germany (VERU, 2005), whose team has collaborated with Tecnalia in KUBIK, KUBIK offers new characteristics that make it a distinctive and unique world-class experimental R&D infrastructure designed for the evaluation and optimization of new construction components and solutions, systems and services for the improvement of building energy efficiency under real conditions.

The main distinctive feature of KUBIK is its capacity to create realistic scenarios, its “openness”, to perform experimental research with regard the building energy efficiency resulting from the interaction of the constructive solutions, the intelligent management of air-conditioning and lighting systems and the non-renewable and renewable combinations of energy supplies. And, in addition, is focused in the development of industrialised components for the implementation of the open building concept, see Fig. 1.

The infrastructure encloses a maximum of 500 m2 distributed over a basement, a ground floor and a further two floor levels; the main dimensions are 10,00 m. width x 10,00 m. length x 10,00 meter high (plus and underground floor 3,00 m. depth). The supply of energy is based on the combination of conventional and renewable energies (geothermic, solar and wind power). Finally, the building is equipped with a monitoring and control system that provides the necessary information for the development of R&D. The build-
ing is totally demountable and allows reconfiguration of the scenarios at construction level, by exchanging the components of the envelope, the roof, the floors and the partitions. The “openness” of KUBIK has been implemented in all the sub-systems of the building:

- the structure,
- the envelope,
- the partitions, actually, only dry construction systems are used,
- the services, energy and IT related, and
- the equipment, mainly climatisation and energy intelligent management

The “openness” of all these sub-system will be shown in the following sections of this paper.

**Experimental capabilities of KUBIK**

KUBIK enables the evaluation of energy performance, acoustic performance and air tightness evaluation of the scenarios built, see Fig. 2, taking into account the holistic interaction of the constructive solution for the envelope, the intelligent management of the climatisation and lighting systems and the supply from non-renewable and renewable energy sources.

The main aim of KUBIK is to provide a better understanding of the performance at room or at building level, acknowledging the traditional laboratories as the better for the characterisation at component level according international agreed standards.

KUBIK has an advanced monitoring system, equipped with over 400 sensors that records conditions inside and outside the experimental facility, climatic conditions. Researchers and customers have access via the Internet to measurements being taken in the scenarios where the performance of the products and systems under development are evaluated. In addition, the monitoring system is integrated into an Intelligent Energy Management System which optimises the energy consumption of the building. The experimentally-obtained results enable diagnoses and proposals for potential product improvements to be made.

It is important to note the contribution of KUBIK for the activities related to the new product development for buildings. Currently, the technical
development of a product begins with the numerical analysis and simulation of the product, carried out in a virtual scenario. The product is then tested in a laboratory in accordance with standardised procedures, and is finally launched on the market.

KUBIK offers an intermediate step that allows to evaluate the products performance in realistic conditions. This speeds up the product development and reduces the risk of malfunction of highly innovative products or products without previous experiences on the market place.

The aim of this experimental facility is to offer a flexible infrastructure able to build realistic scenarios with different building components and systems, for that is compulsory to make possible the assembly and disassembly of them. This permits not only in service performance assessment but also help to develop and to evaluate assembly and erection procedures.

**STRUCTURAL SYSTEM, SUPPORT STRUCTURE**

**Foundation and underground floor**

The foundation, an underground slab and walls, and hereby the resulting underground floor are really the unique “not-open” sub-system of the building. The foundation is made of on-site reinforce concrete but with the innovation of the substitution of the stone aggregates by slag from electric arc furnace for steel manufacturing.

Although “not-open”, the slab foundation provides the needed flexibility, “openness”, to allow any lay-out of the steel structure columns. In addition, the underground floor is in concept a “plug” where the building takes the energy supplies, renewable and non-renewable, to run the scenarios as well as the data connectivity for the IT systems and intelligent management, see Fig. 3.

**Steel structure and precast concrete floors**

The steel structure is made of standardised sections for the columns and fabricated sections for the beams; this special section allows the integration of the floor system and the building services.

The joints of steel structure are bolted and the bracing system includes “X” bracings in the floor to allow the use of demountable precast concrete slabs. The structure, columns, beams and floors allows its de-construction floor by floor level, see Fig 4.

As it is shown in the Figure 4, the service installations are integrated in the floor slabs, so they are accessible for repair and upgrading. Thanks to a complete demountable timber finishing, the accessibility is accomplished from the all the space being served by those installations, the room or
combination of rooms for the analysed scenario.

ENVELOPE AND PARTITIONS, INFILL COMPONENTS

The special focus on the R&D activities on the improvement of the energy performance of buildings makes necessary the development of optimised solutions for the envelope taking a special attention, in the case of prefabricated or industrialised components, to the joints and connections to avoid thermal bridges, lost of continuity of the insulation of the envelope...

Currently, in KUBIK there are several solutions under study, see Fig. 5. This variety of solutions for envelopes allows analysing the real compatibility between components made of different materials, with different fabrication tolerances and different erection and joining technologies.

In fact, the keystone for a real open building implementation might be the possibility of having industrialised components available in the market with several “joining or interface standardised options” that could make possible the use of components from a variety of manufacturers, materials...And, in addition, the joints are really important to deal in detail how to assess the thermal and acoustic performance of the building but on other hand, they must allow the easy disassembly.

The roof and the façade of KUBIK are made of prefabricated and demountable components. So we refer them as infill systems because they can change when the rest of the infill or fit-out changes, e.g. the scenario (room surface, occupancy, partition walls and the envelope components), following the example of the NEXT 21 project. On other hand, the façade might acts as a support system to include several types of windows, glassing systems, finishing...

Regarding the internal partitions, light steel frames and timber frames it have been used to arrange the different rooms in each floor to create the “volume control” of each scenario in terms of energy and acoustic performance.

HEATING, VENTILATING AND AIR CONDITIONING SYSTEM (HVAC SYSTEM)

The primary function of the HVAC installation of KUBIK is to provide the energy necessary to keep the different measurement rooms, scenarios, of the infrastructure under controlled indoor conditions (temperature and humidity), as well as measuring the energy delivered to each measurement room to obtain the results to carry out the research regarding the components and/or systems under analysis.

Since the building has been conceived to enable the possibility of modifying the envelope...
and its floor layout, the HVAC system has been designed to support this feature:
- ability to satisfy thermal loads which may vary (especially for the cooling regime) within a wide range (25 -50 kW), and
- maximizing the ability of the distribution and the diffusion systems to adapt to variable floor layout.

Each of the 3 floors of the building can be divided into a maximum of 6 thermal zones, and if necessary, those zones can provide independent temperature setpoints and measured energy supply, see Fig. 6.

In addition, the entire HVAC installation have been designed so that its expansion through the integration of additional elements will be possible without the need to modify none of the main sub-systems of the facility (generation, distribution, measurement and diffusion), beyond the minimum required adjustments.

For research purposes, KUBIK sums up to the conventional generation systems and air conditioning elements:
- Distributed electricity generation from renewable sources (photovoltaic and wind).
- A ground source heat pump, coupled to a heat exchanger with the surrounding ground (superficial) for water.
- A Canadian well, formed by a heat exchanger with the surrounding ground (superficial) to provide outdoor air for ventilation when the difference of outside air and ground temperatures is adequate.

The HVAC installation of air conditioning of KUBIK consists of an hydronic system, see Fig. 7, and a Variable Air Volume system (VAV), see Fig. 8. Both systems, will have independent distribution, measurement and diffusion subsystems. And for thermal energy generation, both systems will be fed by a common generation sub-system based on natural gas.

The air handling unit has been dimensioned to carry out the ventilation of the whole building or alternatively to reproduce on a single floor, the conditions of a building conditioned by a variable air volume system. It is possible to supply ventilation air...
up to 3 independent thermal zones per floor. The location of diffusers is optimized to maximize the capacity of the air system to accommodate changes in the thermal zoning of the different floors.

Summarizing, the HVAC system is in the Support or Base Building and the diffusers and other services such as electrical power, water... are placed integrated in the floor and ceiling of each room so we can consider that from this point the parts become infill elements...

Figure 7. Hydronic systems for the HVAC installation. Scheme(left), distribution pipes and equipments (right) related to thermal energy: natural gas micro CHP (12.5 kW of thermal power and 5.5 kW of electrical power), storage tank, condensing boiler and 2 air-condensed chillers 22 kW each.

Figure 8. Variable Air Volumen System (VAV) for the HVAC installation. Scheme(left); Variable flow air handling unit (right) (maximum flow of 2,500 m³ / h)
MONITORING AND MANAGEMENT SYSTEM

At the end, all the flexibility required to KUBIK aims to provide a R&D infrastructure able to perform diverse scenarios and to capture the necessary information to carry out the analysis and assessments.

The infrastructure has up to seven individual measurement rooms; one control room and one service room per each of the three floors, see Fig. 9. It provides the possibility to combine some individual rooms into a unique measurement room if it is required by the experiment and also allows to have all the three floors as a unique building, for example an specific office, school, etc… This flexibility is possible thanks to the structural design and to the services design: each individual measurement room has the climatisation, power and data network that needs to build an scenario.

The Figure 9 shows the nine rooms of each floor with the electrical and data network: the individual measurement rooms are: N1, M1, M2, M3, S1, S2 and S3; the control room is N3 and the service room is N2. Figure 6 shows too an example of a possible layout of one floor: three individual measurement rooms (N1, M1 y S1) and one combined measurement room (a combination of M2, M3, S2, and S3) and their respective HVAC system.

The monitoring and management system is integrated in an intelligent energy system (IES) which optimizes the energy consumption of the building satisfying each measurement room needs. This system is in charge of data gathering and management tasks and to provide comprehensive information necessary for the analysis along. It collects data from the: measurement system; building automation system, HVAC control system and external meteorological conditions.

The monitoring system is equipped with over 400 sensors that records conditions inside and outside, weather conditions, the experimental facility. Researchers have access via the Internet to measurements being taken. The test measurement system includes the following sensors: indoor air temperature, surface temperature, radiant temperature, humidity, air velocity, heat flux, solar irradiance, luminance, CO2 concentration, sound level meter …

The building automation system includes sensors for: shading control, blind control, lighting control, open/close window control, open/close
openings control,... The HVAC control system includes the following sensors: air temperature, relative humidity, air velocity, air/water temperature, air/water flow, air/water temperature flows, energy consumption of auxiliary equipment (fans, pumps). The external meteorological conditions are defined by: air temperature, humidity, solar irradiance, wind direction, wind velocity, precipitation and atmospheric pressure.

The experimentally-obtained results enable diagnoses and proposals for potential product/concept design improvements to be made and the thermal/energy performance.

The chosen measuring and management system is based on a PLC platform with Windows Embedded technology allows simultaneous scenarios analysis as well as with different requirements, boundary conditions.... The PLC layer of the control system is in charge of gathering data from the sensors and writing commands into the remote actuators, not only this but the PLC layer processes update the central database with the sensor and actuator values.

On the other hand, the Windows layer hosts the developments done in order to analyse different energy efficiency policies, e.g. will be dedicated to energy efficiency developments from a holistic approach, this means taking into account not only the potential energy demand reduction but considering, too, the storage and generation capabilities deployed in the KUBIK.

The technology used to build the energy efficiency algorithms is based on expert systems development platforms as Jess (Java Expert System Shell) and Hybrid Finite State Machines (Hybrid FSM). Both technologies are in the domain of the intelligent agent development field. The background for both technologies is that they are based on the skills to simulate complex scenarios and not only simple state transitions. Those skills are used to model scenarios in which user behaviour and preferences, outdoor and indoor conditions, altogether, are factors in order to take a decision.

CONCLUSIONS

KUBIK provides the needed support to improve the energy performance at building level, as requested by the EPBD, and in a comprehensive way, the envelope, the demand and energy generation, and based on industrialised construction systems.

The aim of this experimental facility is to offer a flexible infrastructure able to build realistic scenarios with different building components and systems, for that is compulsory to make possible the assembly and disassembly of them. This permits not only in service performance assessment but also help to develop and to evaluate assembly and erection procedures. In addition the service installations are integrated in the floor slabs, so they are accessible for repair and upgrading.

The roof and the façade of KUBIK are made of prefabricated and demountable components and can be considered as infill systems because they can change when the rest of the infill or fit-out changes, e.g. the scenario (room surface, occupancy, partition walls and the envelope components). Even though the façade might acts as a support system to include several types of windows, glazing systems, finishing...

With regard the services, the HVAC system has a clearly identified part on the support or base building, and the diffusers and other services plugging such as electrical power, water services... have a complete flexibility to be located in all the available floor lay-out and can be considered as “infill”.

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INTRODUCTION

The majority of buildings are designed and constructed to suit a particular purpose at a certain time, with relatively little thought for their future use or adaptation. The Adaptable Futures research group (AF) is investigating the development of adaptable buildings in the UK that can better accommodate uncertain futures (Gibb et al, 2007, Schmidt III et al, 2009a). The investigation seeks to operationalize adaptability as a definable design characteristic, stressing the significance of “time” and “layers” as key design constructs (e.g. Duffy, 1990, Brand, 1994, Schneider and Till, 2007). Our current definition of adaptability reflects our accrued journey, namely “the capacity of a building to accommodate effectively the evolving demands of its context, thus maximizing value through life” (Schmidt III et al, 2010). “Time” as a design consideration suggests buildings as dynamic systems that interact with a set of evolving endogenous and exogenous demands requiring a capacity to accommodate change spatially and functionally through life (e.g. Till, 2009, Venturi and Scott Brown, 2004, Douglas, 2006). Achieving greater adaptability arguably demands a shift away from the current emphasis on form and function in response to immediate priorities towards this time-based view of design. Layers concern the organization of, and interfaces between, components of varying life spans and functions (e.g. Rush, 1985, Leupen et al, 2005, Slaughter, 2001). They provide a convenient way of decomposing the building based on rates of change, and establish a system for understanding a building’s technical capacity to accommodate change (Schmidt III et al, 2009b).

The aim of the paper is to illustrate the cultivation of adaptability in Japan by revealing a maturing of design concepts into technical innovations, trends, priorities, and obstacles to realizing...
adaptable designs. The findings are then reflected upon and augmented through further work in preparation for a second stage of interviews.

**Japanese context**

Historically the life expectancy of Japanese buildings is much shorter than that of western countries (see Figure 1) and the ratio of maintenance and renovation to the total investment lower (e.g. In 2005, only 24% of Japanese building work was maintenance and renovation compared to approximately 50% in France, Netherlands and UK, Figure 2).

This implies that Japanese buildings are rebuilt within a short period and new construction dominates the market. On the other hand, adaptability as a design feature has long been associated with Japanese housing. Whilst the approach to office design has begun to shift in recent years due to changing market conditions and priorities aligning more with the emerging sustainability agenda, the Japanese construction industry has begun to realize the advantages adaptability can provide in reducing environmental impact, increasing cost-effectiveness, and satisfying client desires. The emergence of design considerations for adaptability under two disparate building typologies (housing and office design) render Japan an interesting context within which to explore the development of such buildings.

This part of the AF research explores the attitudes and mindsets of designers to understand how current processes/projects either impede or enable adaptability to manifest. There are clear linkages here extending adaptability beyond the physical artefact to the distributed control concept – a central principle of Open Building (Kendall et al 1999).

**JAPANESE ‘LONG LASTING’ HOUSING**

The move away from traditional house construction was originally driven by an effort to produce a large amount of houses due to the severe shortage in the middle of the 20th Century following WWII. In a 1968 census, the number of total residential units was greater than the total number of households. At this time, Japanese housing policies moved from quantity to quality (Building Center of Japan 2008) with a focus on adaptability.

**Traditional Japanese Houses**

Originating from Chinese temple construction, the entire house is based on a single philosophy of measurement - the distance between column centres known as a ken - making it easy to change and extend. Both the widths and depths of all spaces are multiples of this standard unit and form the frame of reference for the remaining components – timber structure, tatami mats (2 mats = 3.3m² = 1 tsubo), doors, and furniture (Hirai, 1998). The house contains no load bearing walls and uses a system of thin columns (width 12-15cm: fits within outer wall), beams, and trusses (wagoya) that can be removed or extended in a straightforward manner. Rooms
are separated and connected to the exterior with light double sliding windows and partitions (fusuma) allowing them to be shifted or stored easily. Traditional Japanese rooms bore no functional labels, rather as multi-functional spaces or wa-shitsu meaning a largely empty stage deriving its identity from its temporary occupants (Nute 2004).

KEP: Kodan-Experimental housing Project (1973-)
In the 1970s, the housing industry shifted to respond to the demand of various types of housing and their quality. KEP was an experimental project conducted by the Japanese Housing Corporation in order to incorporate flexibility and adaptability into housing from 1973. They categorized the building into structural frame and four subcategories of components - exterior, interior, kitchen & bath and other devices (piping, wiring etc.). The intention was to identify interface details between each category and facilitate the use of “open” components.

Century housing system (1980-)
This system divides the building parts into five categories to prolong life expectancy, based on experience and estimated life expectancy: 1) the main structural members, which are the most difficult to replace lasting 50 to 100 years; 2) roofs, exterior doors and windows lasting 25-50 years; 3) partitions and furniture lasting 12-25 years; 4) home appliances, piping and wiring lasting 6-12 years; and 5) light bulbs and sealants, lasting 3-6 years. The central philosophy is that buildings need to be designed so that parts with long life spans are not damaged when parts with short life spans are replaced (Utida 2002). This system facilitates the future maintenance and exchange of parts as a response to changes in residents or residents’ life styles.

SI: Skeleton Infill (1990s)
This system supplies buildings in two steps; first “S” (skeleton) which signifies the long-lasting part and social property and second “I” (Infill/fit-out) which represents the short-lasting part and private property (NEXT21 editorial committee 2005). However, in general, most of the Japanese construction industry tends to recognize this system as a physical issue, such as “S” means structural frame and “I” means interior and services. This is despite its origins deriving from the open building approach of John Habraken, which incorporates more of the softer issues such as decision making levels in the management of residential areas. The NEXT 21 project by Osaka Gas in 1993 is the most famous project in Japan and both public and private sectors were brought together to develop SI technologies in experimental and practical projects (Kendall et al 1999). The Japanese government still uses SI in their policies helping this concept gain widespread dissemination in Japan.

200-year Housing (2006-)
In 2006, the Basic Plan for Housing (National Plan) indicated a transition to a stock-based housing policy leading to the promotion of the “200-year Housing” initiative which aims to extend the useful life of housing (Minami 2009). This concept involves the construction of houses that boast excellent durability and are easy to manage and maintain (MLIT Japan et al. 2008). This most recent policy incorporates SI thinking, but is diffused through nine chapters focused on minimizing operational consumption and the promotion of ‘good’ building principles and ‘routine’ actions to prolong the life of the building.

Each policy and practice iteration has produced more explicit and refined considerations towards time and layers as a way of communicating adaptability. Through the years, an experience-based progression has added clarity, simplifications, priorities and knowledge about how buildings change through life, developing a matured understanding.

LEARNING FROM JAPAN

While the number of projects constructed around these policy initiatives represents a small percentage of total construction in Japan, the concepts have pervaded the industry (Utida 2002). All of the interview participants had excellent prior knowledge about the initiatives and often used them as a basis of which to discuss how they addressed adaptability outside of the housing market. It was clear that policies had affected designers’ attitudes, whilst a wider dissemination did not occur due to a lack of
demand in the market and society as a whole. As
mindsets in Japan (and across the world) have
begun to amalgamate along the sustainability
agenda, a more accepting market and tenable cul-
ture has arisen bolstering a renewed interest in
implementing these concepts in industry. While the
interviews provide a mixture of positive and nega-
tive perspectives, the non-domestic case studies
suggest clear evolutions of the housing culture in
Japan.

It should also be noted that many reports on
Japan’s construction industry have drawn lessons
from the management process(es) and technolo-
gies associated with the industrialized housing sec-
tor (e.g. Gann 1996, Barlow et al. 2003, Barlow et
al. 2005, Bottom et al. 1996) which makes up
approximately 25% of the housing market in Japan
(a small percentage of the total construction mar-
ket). While aspects of these technologies and
processes have been applied outside this small por-
tion of the industry, what makes the learning from
Japan intriguing stems not from these technical
fetishes but from fundamental differences in culture
and mindsets yielding different possibilities.

Buntrock (2002) makes lucid all of the small fun-
damental differences in culture which promote a
much more collaborative and integrated process
which often is facilitated through much of the same
technologies used in western cultures.

Thus, this is not meant to be a series of
lessons extrapolated from Japan and recontextual-
ized for UK implementation, but a narrative pre-
senting a slow transition of attitudes towards a more
adaptable future. It illustrates the gap between ide-
alistic principles (mindset) and the volatile contin-
gences of practice (built construct) and demonstra-
tes how concepts, while potentially premature
for implementation, can pervade thinking and
slowly permeate through tactical shifts towards a
better way of operating, as the evolution of policies
are not iterations of radical thinking, but grounded
in a constant refinement/ modernization of tradi-
tional Japanese housing. Within this context, the
paper offers a look at how different practice typolo-
gies have adapted these concepts through three
non-domestic case studies and how physical and
social variables play a contingent role.

METHODOLOGY

Qualitative data was collected for this exploratory
exercise through semi-structured interviews with
thirteen high-level personnel from six architectural
practices. Japanese practices fall into three distinct
categories: large general contractors, large archi-
tectural design firms and small design ateliers.
Large general contractors offer a complete pack-
age, ranging from property acquisition, design,
construction, maintenance, R&D and so on. Accord-
ing to company profiles as of 2009, the top
five companies have more than 2000 licensed
architectural designers in house. Large architectu-
ral design firms deal mainly with the design stage of
relatively large projects (e.g. more than 10,000 m2
total floor area office buildings). They will also get
involved with Construction Management (CM) and
Project Management (PM) businesses as well. The
larger companies have about 300-700 licensed
architectural designers. Small design ateliers typi-
cally consist of a few dozen people and deal with
relatively small projects, such as private housing.
World-famous architects’ offices are included in this
category. Two design practices were interviewed
from each of the three categories.

A series of questions regarding adaptability
were developed and emailed to interviewees prior
to the interviews directed at exploring a high-level
understanding from a practice and professional
perspective (e.g. as a company, do you tend to
think about future changes?; as an architect, how
do you design for adaptability?), and a more spe-
cific understanding espoused at a project level (e.g.
what enabled or impeded adaptability to manifest
in this project?). The aim was to understand the
practice as an arena for change and the architec-
tural profession as a facilitator for such change.
They were then asked to use specific projects as
vehicles to articulate how their practice and profes-
sional perspectives are operationalized through
specific factors that influenced the adaptability of
the design. In the email, the questions were pre-
ceded by our definition of adaptability (time and
layers) and illustrated through six high-level strate-
gies for adaptability (e.g. available, flexible,
refitatable) that together formed part of our AF
Framework (Figure 3). In addition, a building layer
diagram (Brand 1994) was adopted to visually
convey how the strategies could be related to different areas of the building.

Data from the interviews were tabulated (generating three A3 size pages) mapping the responses of each practice typology to each question. A thematic content analysis was conducted through a systematic comparison of each cell revealing several themes (e.g. spatial, functional, componentry). We present a description of three projects as case studies (one from each practice typology) followed by a discussion of the key themes that emerged across the six interviews.

CASE STUDIES

**Takenaka Corporation Tokyo Main Office (large general contractor)**

Takenaka Corporation constructed its Tokyo headquarters in 2004 (33,000m² and 7 stories) with three major themes: 1) high efficiency (a high quality work place for employees); 2) green building; and 3) low cost solution (initial and total life cycle cost) (Figure 4). The implementation and convergence of these three aspirations turned the conventional office layout inside out by positioning more static core spaces along the periphery and opening the center up for communication and interaction, allowing the design to accommodate ongoing changes in office operations and environment (Figures 5-6). A key tactic was shifting to a 10.8m uniform-grid offering a low cost solution, which is typically used for shopping centres and parking - in contrast to the typical office span of 16-18m. The reduced column spacing is accompanied by external lateral bracing that creates a rigid shell and allows for a free internal space that was envisioned to incorporate future changes in use (e.g. a hotel or shopping centre). The openness of the space is complimented by a storey height of 4.1m with an open and protruding ceiling ranging from a minimum of 3.1m in height to a maximum of 3.8m providing a good acoustical environment.

The convertibility of the solution is augmented by the decentralization of mechanical and electrical services into 10 modules along the east and...
The dispersing of the centralized core created an open solution allowing for continuity (visual connection and access) between floors, spaces and nature through large light wells. The dynamic central zone provides a diverse range of open meeting spaces adopting eye-catching colours and shapes (e.g. diverse angles, shell-shaped partitions) not found in other areas. The furniture is movable and adjustable to stimulate diverse forms of communication. Previously, a wide-range of desk types were used to articulate an employee’s position and division, but in this case desks were standardized into two workstations reflecting the types of tasks to be carried out (Takenaka 2005).

Mokuzai Kaikan (large architectural design practice)
Mokuzai Kaikan (Wood Wholesalers Union, MK) was designed as an innovative prototype for urban wooden offices, based upon earlier traditional structures of Japanese housing and buildings such as temples and shrines, which aimed to revive this culture in Japanese architecture (Figure 7). Traditionally, the structure is made only by timber without steel, concrete, or wet connections (e.g. glue) and is based on a single module - to ease changing layouts and componentry. In MK they use some structural steel parts, but they are removable, being fastened through dry connections. In general, there are strict regulations regarding fire resistance in Japan, so to use timber as a component in...
an urbanized area, especially more than three storeys high, is extremely rare. Wooden components are used on the façade, interior and some parts of the structure - all of which are made with standard sizes - providing easy availability in the future. While the lifespan of wood is shorter than of concrete, only two ‘generic’ types of wooden parts were used and are assembled with dry joints (screws) increasing their refitability in the future. This innovative solution of steel and timber ameliorate conventional applications of glue-laminated timber which does not lend itself to adaptability. State-of-the-art computer modelling and manufacturing technology was needed to develop the low tolerances for such a precise solution for both structure and façade (Figure 8).

The designers of MK utilized the external periphery of the office space to create a strip of more casual and semi-open air spaces connecting the office space to the outside environment (Figure 8). Like Takenaka headquarters, the building also decentralizes services to the outside which help allow for distributed control of the services amongst different tenants. However, contrary to Takenaka’s non-uniform plan, MK utilizes a ‘universal space’ which they signify through a column-free work space.

c-MA1 (small design atelier)
This project involved the conversion of an 18-year old office building in central Tokyo, formerly a photo studio, into three residential units and an office suite. At the time of the project in 2003, the market for conversions in Tokyo was small, however the developer realized a potentially emerging market with several similar office buildings that were vacant in the city. The developer planned to create a prototype business model for the conver-
The architect and contractor had no experience in converting a building to a new use. The architect’s design approach was to enhance the characteristics of the original building (e.g. provide a higher floor height for residential use). The designer perceived the building as part of the existing site which allowed the building to become integrated into his method of working and proposed solution. The team attempted to drive market value by emphasizing the uniqueness offered by the original characteristics - taller floor heights of rooms (4.5m and 3.8m) and split floor levels with small stairs linking the spaces (Figures 11 and 12).
Exposing the features of the original building was also intended to enhance users’ experience – blending the new with the old.

Their lack of experience became evident with the difficulties encountered through the construction process (e.g. limited space for construction and elevator capacity). They had to think creatively in order to accomplish the design desires by carefully considering what parts of the building to dismantle to allow construction work and how to use existing components in combination with new parts (e.g. the canopy). In the end, due to the novelty of conversion work, a new and more integrated design approach was needed by both the architect and contractor utilizing innovative construction techniques at the component and building scale, for both new construction and the reuse of the existing building.

**CRITICAL DEPENDENCIES**

The following discussion expands the black box of adaptability which is often poorly defined, either in terms of requirements or solutions. It probes design criteria, obstacles and mindsets to establish links between the stereotypical understanding of adaptability and perceived external factors. It is also of interest that some comments cut across the practice typologies (universal) while others were only held by one, alluding to a particular perspective or approach. The section is organized into two dimensions: physical variables – critical design parameters associated with the physical object (e.g. storey height, plan depth, structural grid); and social variables - critical design contingencies conditioned by human factors (e.g. mindsets, policies, practice protocols).
**Physical variables**
The physical variables construct the building’s design structure – what it is, how it is constituted. Here, designers’ responses are both direct (when asked what are the most critical physical parameters) and indirect (extrapolated from comments about projects). Floor to floor height was found to be the most critical design parameter and, on average, ranged from 2.5m to 2.8m. A typical concern was with older office buildings (1960s) where the structural floor height is not large enough due to the demand for raised flooring to equip the latest service devices, making them difficult to renew. This however may change in the future with the increased use of wireless technologies; furthermore as illustrated in the case of c-MA1, conversion to residential use may be a viable option with typically lower storey heights being the industry norm. A second explicit and common parameter was the structural frame - as one designer commented, “If the building has a good enough structural frame, including large open spaces, there are no obstacles to realize adaptability”.

While the most explicit parameters were floor to floor height and structural grid, all six practices mentioned the importance of services and the capacity (and cost) to be able to subdivide services to a minimum floor area due to greater demand to partition larger spaces/buildings for more individual control. This is the case in both the Takenaka building and Mokuzai Kaikan above; whereas for c-MA1 services needed to be subdivided for each individual residential unit (opposed to the centralized unit that serviced the building prior). Other inferred parameters arose from common trends shaping office design reflected through changing user expectations including lower overall building heights and larger floor plates (mega floor) – e.g. Takenaka’s headquarters. Enlarged personal space has increased the floor module as well from 3.0m to 3.2-3.6m. Linking inside and outside through visual connection, inclusion and access of natural elements was a common point. Takenaka’s office exhibited this characteristic through the central zone while Mokuzai Kaikan created a buffered zone along the periphery. Interestingly in a similar desire in c-MA1, it was the idiosyncrasies of the existing structure beyond the ubiquitous frame that the ‘new’ designer wanted to capture. A final aspect considered by two of the practices (e.g. Mokuzai Kaikan) was the standardization and reuse of materials allowing for more efficient resource management and improved future availability.

**Social variables**
The capacity for architecture to change is not simply limited to the artefact itself, but is contingent to a process of design, construction and use; and is conditioned by a market, regulated by policies, and subject to stakeholder values. The social circumstance of greatest precedence resides in both supply and demand mindsets about adaptability. It was clear that while designers’ admitted the need to design adaptable buildings, they presented clear reservations (e.g. possible reduction in work, a loss of character and identity in the building, scepticism to its realistic implementation). Designers also perceived that adaptable features would cost more which was reflected in the clients’ reluctance to pay for additional initial capital costs; however, it was noted that government bodies were more amenable because they could invest more initially in an effort to reduce CO2 emissions through-life. Some of the designers attempted to rationalize the argument to clients through easier maintenance and response to changing tenant needs (whole life costs), but found it difficult to prove against short-term gains. In all of the case studies presented above, the client or developer drove the demand for adaptability which was interpreted and facilitated through different design approaches resulting in a variety of solutions. At the same time, this revealed the designers’ unanimous perception that the biggest individual benefactor and controller of adaptability is society – through a long-lasting and sustainable built environment. Without shifting attitudes and behaviours, a demand for adaptability would need to be driven from a higher level through government policies or from the bottom through user requirements. As one designer mentioned, “the easiest way to make a client do something is to point to a law or regulation.”

Current regulations were seen primarily as an obstacle to adaptability including planning permission, fire resistance, safety regulations and seismic codes. However, in some cases, it was reflected on as being positive. In c-MA1, the demand for housing in the area created a government incentive
to accommodate an increase in the floor area ratio calculation (FAR) allowing the developer to increase the scale of lettable space (by changing use). Additionally, in the case of Mokuzai Kaikan, the National Government changed the law regarding design requirements from specification to quality allowing easier compliance for wooden components. The ways in which regulations or incentives are operationalized in the design process can play a significant role in adaptability. A developer can receive incentives allowing them to exclude an amount of area from the FAR increasing their net lettable space (e.g. c-MA1) or to include more of a particular use (e.g. retail) by providing undersupplied space (e.g. affordable housing) increasing their overall profitability. These incentives, along with the reality that commercial buildings tend to be driven to maximize profitable space allowances, lock buildings into specific uses, making change of use difficult and reliant on shifts in government regulations.

Other points arose concerning the design process and how certain shifts have impeded or enabled adaptability to manifest. An obvious, but elusive shift was establishing early relationships with manufacturers. Good communication with the manufacturers at an early stage enabled the latest digital manufacturing technology to be applied resulting in a reduced number of components with a unified standard. A good relationship between contractor and architect in c-MA1 proved imperative when tackling the complications of new construction within an existing building. Along a similar line of thinking, another designer stressed the power of sharing motivation within the design team and client through creating a common goal as an incentive, such as an award for the design of their building.

The demand and cycle of the market was another significant factor mentioned by all the practices. The larger practices (general contractors and architectural design firms) saw the inclusion of adaptability as a reaction to clients’ needs (a selling tool). Whereas, the design ateliers saw it more as a social responsibility beyond the clients’ demand for specificity. A clear difference in perspectives emerged, reflecting the type of clients, scale of buildings, and perceived architectural roles and values. The ateliers found themselves more bound to their own design freedom pulled by their social role as designers; whereas, the larger, more business orientated, practices were shaped by the client or project specifics.

LEARNING FROM/ MOVING FORWARD

The analysis of these exploratory interviews in Japan have not only produced these insights into critical dependencies, but have also informed the development of the research through the refinement and expansion of the AF framework and shaping of the questions and format of future interviews. With regards to the framework, some interviewees had difficulty pinpointing what we meant by adaptability. It was clear that amongst the six interviews there were broader interpretations of adaptability and how it could be applied in industry either through the ‘adaptability’ of process, product or people. This was made evident from their responses including communication, technologies, regulations, and experiences - alluding to a wide range of sources. Whilst the design strategies (Figure 3) were comprehensible, their links to other factors discussed were not explicit and left to interpretation. All were capable of talking about adaptability; however, it was clear a finer degree of articulation would augment the discussion concerning future changes and the affects they might have on their proposed designs.

The experience clearly demonstrated the limits of the existing framework and led to the revision of our definition of adaptability (Schmidt III et al. 2010) along with the creation of additional diagrams illustrating key dimensions (Schmidt III et al. 2009a). The lessons accumulated had a direct impact on five of the consequential diagrams (strategies, sources, design perspectives, linking table, and project pull). One example is the creation of the ‘sources’ diagram which took our six strategies for adaptability and placed them in a broader contextual spectrum including design intelligence (e.g. philosophy, experiences,), rules (e.g. services, structure), policy (e.g. planning and building regulations, taxes), and products (e.g. standard details, iso standards). This allowed us to contextualize the array of responses, and emphase
size their relationship to time by organizing them ranging from more timeless aspects (intelligence, culture) to more time bound (products, market).

With respect to our ongoing design practice investigation, the revised definitions and diagrams were summarized on an A4 sheet, distilling the core concepts as an invaluable tool for clarification and reference throughout the second stage of interviews. Questions have been posed to elucidate the role of the practice as an arena for adaptability. This tactical shift is captured and conveyed through the use of the ‘project pull’ and ‘practice disposition’ diagrams that have enabled conversations around the practice and served as a convenient method for characterizing practice typologies. The research reported here has thus enabled a richer conversation to take place within stage two.

CONCLUDING REMARKS

The cultivation of adaptability in Japan has a long history from traditional construction to more recent government led initiatives to promote the longevity of their housing stock. Historically, the adaptable attributes found in traditional designs were primarily driven as methods to accommodate the diversity of everyday life at the scale of the component (change of task, space or performance), as opposed to increasing the longevity of the building - through additional types of changes at a building scale (change of scale, use or location). The sustainability agenda has brought new interest in the latter, and many of the principles established by Japan’s traditional housing design provide an interesting starting point for other contexts. Its revival has been brought about by a top-down approach of reinstating adaptable principles into the quality of construction, but will need to be matched with a shift in the mindsets of professionals or a customer-driven demand of the market by society.

Whilst historical efforts in Japan have embedded an understanding in both the architectural profession and practice of important concepts around adaptability, implementation has been a slow journey. As a profession, one of the questions the research raises is to what extent does a designer have control over adaptability? The design, manufacture and operation of buildings present a highly complicated process and slowly evolving product where control is inevitably distributed - it relies on the owners’ willingness, government agendas, the capacity of constructors and manufacturers, society’s appreciation, and most importantly the users’ appropriation. As a practice, perceived roles and values, types of clients and scales of buildings will inevitably influence the perception and application of adaptability, as shown through the three case studies offering distinct solutions in the context of modern office facilities - illustrating there is no one solution for adaptability. Further unpacking of the ‘static’ building into the design and use processes – moving architecture - is imperative to understand the influence of design practice culture in shaping the evolving solution.

Research into adaptability requires the effective communication of sufficiently sophisticated descriptions of key concepts to allow an informed conversation between professionals and with clients and users. Expanding the ‘black box’ of adaptability and unfolding the critical dependencies that link adaptability to a multitude of contextual dimensions - placing architecture in context and time - is essential for its successful manifestation. Like many other philosophical design concepts in complex processes, adaptability benefits from a mutual understanding, good relationships, communication, integration, and shared goals amongst team members. Whilst economic and regulatory obstacles are commonly cited, we should not underestimate the sociological impact of professional and practice attitudes and mindsets – shifting architectural dictums from form follows function to form accommodates change.

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INTRODUCTION

Personalization in housing is not new. Families have always personalized their dwelling places, independent of wealth, climate or culture. In rented flats, people bring in furniture, cabinets and appliances, paint the walls and put flowers on their balconies. In owned flats, families upgrade kitchens and bathrooms and rearrange spaces with new equipment even before the old equipment is obsolete.

Considered in the aggregate, this is a massive economic reality. In a development or building of identical dwelling units, a visit to the same place in 10 – 20 years will reveal customization and personalization – no two dwellings will be the same for long. The evidence for this is ubiquitous, in all countries. In the United States alone, more money is spent each year by families at home project “do-it-yourself” centers and in hiring contractors to upgrade and modify houses, apartments and condominium units than is spent on new housing construction. While cyclical, the fact remains that remodeling market is massive and will not go away as incentives increasingly encourage continuous use of the existing building stock.

Thousands upon thousands of companies offer products and services in response to the demand for personalization. These companies are constantly improving their products and services to maintain a competitive advantage. The national show organized in the United States each year by the National Association of Home Builders is a remarkable display of this phenomenon. The equivalent showcases occur everywhere if not at the same scale.

Since personalization is ubiquitous, and the worldwide building industry is deeply committed to it, investing heavily to develop new products, tools, and methods, what, then, might be the next steps for an industry already deeply involved in personal-
BALANCE

Because personalization never occurs in a social vacuum, there are important constraints that must be spelled out. Most importantly – especially in the context of multi-family buildings, where the difficulties of personalization are most pronounced - there is always the reality of the other family next door, upstairs or downstairs exercising the same initiative. And there is the larger social system, i.e. the “community” involving building codes and standards, legal and financing regulations, as well as more local constraints such as home owner association or condominium rules.

To be specific, an electrical appliance attaches to an outlet and cable in a wall, which connects to a cable in the building and then to a cable in the street. Similarly, a toilet connects to a drain line in the wall, which connects to the building’s drain line, which connects to the city sewage system. When such resource systems cross the boundaries of territories (legal jurisdictions) under the control of various parties, potentially complex and disruptive conditions of entanglement arise. These must be sorted out and resolved, particularly at the building level. Legal disputes and quality-control problems are well known in residential buildings due in large measure to these entanglements.

Because of these physical / technical / territorial issues, consumer electronics and the automobile – both suggested as exemplary models of innovation and all seeing extraordinary advances in mass-customization - are poor models for the building industry. This is because these products are known not by their place in the larger fabric of the built environment but exactly by their fundamental detachment from any place.

Further advances in personalization and customization for the individual in respect to the built environment – and housing in particular - cannot ignore the inevitable territorial and technical dialectic between the individual and the group. Since neither a detached house or a unit in a multifamily building can exist in contemporary society without action by both the individual and the community, it is futile to expect further evolution of mass-customization and personalization in support of physical environment improvement processes without recognizing both forces.

In what follows, trends in the building products and services sectors are discussed, indicating a new understanding of how to release the tensions so often found between the individual and the group in the realization of personal preferences in housing. The release of such tensions will inevitably release new energy to solve the problems that have heretofore hampered the full application of mass-customization and personalization to the built field.

TRENDS

To survive in the competitive global market place, manufacturers and suppliers have to develop new ways to sell their products. One trend is to package core products, developing a combination of products and services, which makes the sale more attractive to customers. Consumers no longer look only for physical products, but rather focus on the benefits enabled through a value-adding service. Thus, by shifting into the provision of benefits rather than simply manufacturing products, companies might become more competitive.

Companies are facing the challenge to align their production systems with emergent complex demand patterns (Morelli 2002). The same author also argues that there must be an understanding of costumers’ needs to enable the provision of knowledge-intensive systemic solutions, or product service systems (PSS). PSS can be defined as a service-led competitive strategy, which addresses the issues of environmental sustainability, and is the basis to differentiate from competitors who simply offer lower priced products (Baines et al. 2007). According to the same authors, by considering product’s life cycle, companies increase value in use for consumers by taking the risks, responsibilities, and costs traditionally associated with ownership, while still retaining asset ownership that can enhance utilization, reliability, design, and protection.

The importance of considering all stages of products’ life cycle, as well as the connections with other products and services, has led to the emergence of the concept of “through-life manage-
ment” (Koskela et al., 2008). Through-life management should encompass designing and producing artifacts, producing services through those artifacts, and planning for deconstruction (or disposal) of those artifacts. According to the same authors, the central idea of introducing through-life management is to create an understanding of all those stages as one unit of analysis and as one integral object of management.

PRODUCT BUNDLING

Homebuilders watching service-oriented business trends will undoubtedly notice a development called “product bundling” or “kitting”, a version of PPS. This means that product manufacturers and service providers are “adding value” and gaining profit in the supply channels by preparing certain packages of building parts off-site, for easy on-site installation. Sometimes this is called “prefabrication” or “kitting”, for example when an electrical contractor pre-wires all the boxes and terminations in his shop, packs all the cable whips and associated parts needed for the entire wiring installation in boxes, and brings them to the site for installation. In these instances, no “new” products are needed, only a new way of organizing the work.

The term product bundling can have several meanings. One is characterized by the legal battle involving Microsoft, charged with monopolistic practices by its “bundling” several discrete pieces of software into a unified package the parts of which cannot be purchased separately. The business literature concentrates on this definition.

In the context of the building industry, bundling refers to bringing together a number of discrete products (made or purchased) into a coordinated (integrated) package by a single company. Normally, this process occurs at a distance from the site of final installation, signifying that value is added both off-site (in preparing the bundle or kit) and on-site (in installing it).

Product bundling is similar to prefabrication, which means assembling elements – ordered by the user rather than initiated by the producer – in an off-site location, to be installed as a whole when it reaches the construction site it was prepared for. But there is a difference. Product bundling or kitting focuses on the delivery of packages of generally small parts ready to assemble, connoting the idea of boxes of parts small enough to get in a pick-up truck and through the front door or window of the house.

This is not particularly new. Examples of “product bundles” include a kitchen from IKEA (Norman, 1993) or even a plastic-wrapped toilet bowl valve-replacement kit. Often, these products are not made entirely by the company doing the bundling (although they can be), but may be products brought together from a variety of manufacturers or suppliers. The “bundler” is an intermediate service company.

It is characteristic of a product bundle or kit that it arrives at the site ready for assembly, rather than pre-assembled. This means that further value must be added at the site, but that the on-site assembly work is facilitated by the bundling together of just the right parts designed for assembly and sometimes also the tools for the job. The on-site work is a form of construction.

KINDS OF BUNDLES

There are two kinds of product bundles. One is project independent. This kind of bundled product is made off-site, but in this case, the product is not made specifically for the project but for ANY project – that is, it is made at the initiative of the producer, for a particular market segment. This kind of product is often called manufactured. Examples of this are a Velux roof window kit; a lighting fixture with all the cables, hangers, fasteners, etc in the box; a passage door hardware kit with a variety of strikes and other parts to fit a variety of door installation conditions; a faucet/ drain/ overflow kit; and so on.

The other kind of product bundle is project dependent. This kind of bundled product is also made at a distance from the building site and is prepared to facilitate on-site assembly with increased speed and quality with reduced dependence on site labor. This is the kind of production that is initiated for the project at hand. Again, the bundle is ready-to-assemble when it reaches the site it is intended for. Such project bound bundles can and usually do use manufactured parts made for the market, and brought together (cut, bent,
shaped) for the particular installation. Examples include a sunroom extension from a local window/patio enclosure company; a set of kitchen cabinets the selection of which is specific to the job at hand including the countertop; and so on.

The key distinction is a business distinction - the locus of initiative. In the former case the producer takes the initiative and risk. In the latter case, the user takes initiative and assumes the risk.

BRIEF HISTORY OF WHOLE BUILDING PRODUCT BUNDLES OR KITS

The housing industry in the US has experienced a number of efforts during the past 50 years at whole house kitting. Some have failed because they were out of touch with the market and because they tried to introduce too many product substitutions out of the ordinary.

Sears Catalog Houses
Sears Catalog Homes (sold as Sears Modern Homes) were ready-to-assemble houses sold through mail order by Sears Roebuck and Company, an American retailer. Over 70,000 of these were sold in North America between 1908 and 1940. Shipped via railroad boxcars, these kits included all the materials needed to build a house. Sears offered the latest technology available to house buyers including central heating, indoor plumbing, and electricity. As demand increased, Sears expanded the product line to feature houses that varied in expense to meet the budgets of various buyers. Sears began offering financing plans in the 1920s. However, the company experienced steadily rising payment defaults throughout the Great Depression, resulting in increasing strain for the catalog house program. Over the program’s 32-year history, 447 different house models were offered. The mortgage portion of the program was discontinued in 1934; the entire program ceased altogether in 1940. (Stevenson, K.C. and Jandl, H.W. 1986)

Lustron House
Another case is the Lustron House, only several thousands of which were built after massive private
and public sector investments in the late ’40’s and early ’50’s.

In 1947, the Lustron Corporation received a U.S. government $12.5-million Reconstruction Finance Corporation loan to manufacture “mass-produced prefabricated” homes (a contradiction in terms – author’s note) featuring enamel-coated steel panels. The Lustron Corporation set out to construct 15,000 homes in 1947 and 30,000 in 1948. From its plant in Columbus, Ohio the corporation eventually constructed around 3,000 Lustron homes between 1948 and 1950. The Lustron Corporation declared bankruptcy in 1950.” (Herbert, 1986)

Techbuilt

Designed by architect Carl Koch, the Techbuilt house was – in the 1950’s and 60’s - a “prefabricated” house using ordinary wood framing in 4’-0” panel modules for the exterior walls and roof, and a post and beam interior structure with panelized floor elements. Each house was designed for the specific customer on a 4ft-planning grid, but the

![Image of Lustron house kit spread out on an airport runway to demonstrate the extensive contents of a Lustron House kit of parts. (ca 1950)](image1)

![Image of Techbuilt panels arriving by truck](image2)
stayed on-site only until the shell was erected and enclosed. (Koch, 1958)

DEVELOPMENTS IN INTERIOR INFILL SYSTEMS

Matura
Between 1990 - 95, Infill Systems BV in the Netherlands introduced an integrated interior fit-out product for the European market called Matura®. It was based on a decade of research at the Delft University of Technology and was designed for new construction and the renovation of older buildings. It offered fully customized residential interiors just-in-time. Two new products were developed to organize the assembly of off-the-shelf products used commonly in the European market. With newly developed software that provided seamless IT management from design through installation – with pricing, fabrication, packaging and installation information and drawings – the two new products make a proprietary system that had patents in seven countries including Japan, the US and Canada.

It was one of the most advanced product bundling or kitting products for the multi-family (apartment or condominium) residential market. It focused only on the interior. The base building and main service / utility access (shown at the bottom of Figure 5) in which these packages are installed is...
the responsibility of a development company. The Matura lower system is shown in the diagram as the more technical layer containing the horizontal pipes, ducts and cables. The upper level contains the more consumer-oriented products such as cabinets, fixtures, finishes, lighting, and so on. That initiative produced a number of completed dwellings but eventually went out of business. (Kendall, 1996)

Matura 2
Now, the developers of Matura are introducing a new set of products, one of which, CABLESTUD, is in the market in Europe introduced by GYPROC.

Whereas in the early Matura Infill System the partition and the matrix tile were technically interdependent, the new products keep them separate, as the drawing at the right shows. (intellectual property rights belong to Infill Systems BV)

Next Infill
Originating in Japan as a product innovation initiative of Sekisui Heim, in response to the emerging demand for efficient and consumer-oriented renovation of obsolete but still useful large housing blocks, Next Infill was a product bundle including a thin raised floor under which pumped drainage and water supply piping would be placed. It also included a partitioning system within which electrical and data cabling would be placed, and dropped ceilings to accommodate other cabling, light fixtures, air conditioning pipes and the variable beams of many of the concrete buildings needing renewal. Later, the concept was taken outside of Sekisui Heim and now operates as an independent company successfully selling product bundles in the
Figure 7. Matura 2 matrix tile for horizontal pipe routing
The number of newly built private housing units for sale has been decreasing for the last five years in metropolitan areas of Japan. At the same time, the stock of second hand houses is increasing. In this context, the business practice of “buy, refurbish and sell” is growing rapidly. “Intellex” is one company serving this new market. They have already sold 8,000 units over the last few years, with 1,000 - 1,500 units sold each year. Their share of the stock renovation market is 5.2% in metropolitan areas. They call their commodity “Renovex Mansion.” The period from buy to sell is under 120 days including 20 days of design and 30 days of work. They always remove all existing infill parts (including plumbing and wiring) and fill in with new infill. They call this way of refurbishing “Full Skeleton Reform.” They have their own design firm and have developed their original design – build system. Their business practice is completely different from that of apartment building developers, because their work sites are scattered across vast metropolitan areas and each site has only one unit under renovation at one time. Their system is similar to house builders.

The ‘Next Infill’ system is a supplier to Intellex. Two systems are delivered. One is the wooden (under layer) frame system without surface panels, applied to walls, ceilings and floors. The second system is the equipment system of plumbing and wiring. They call this the “infra” of the infill.

Another distinguishing movement of the stock renovation market in Japan is “full body renovation of one building”. “Revita” is the leading company. They are one of the subsidiary companies of Tokyo Electric Power Company. They buy company-owned (apartment) houses for employees that are not so old but which the company wishes to sell for economical reasons. They renovate and refurbish the entire common area and associated piping and electrical equipment. Then they sell each unit to the people who want to live there, with each unit having its old, existing infill. Then the inhabitants (to be) order the renovation of their units to a builder of their choice, according to “Revita’s” coordination guidelines. Revita is paid a coordination fee. “Intellex” and “Revita” are two typical business styles of the Japanese infill Industry today. (Chikazumi, 2010)

CONCLUSION

With the passage of new laws in Japan encouraging 200-year housing; with the trend in Warsaw, Poland toward open building as the “Warsaw Standard”; with the initiative of the Sato Development Company in Finland; and with the continued “adaptive reuse” of obsolete office and warehouse buildings world-wide into housing, it is only a matter of time before new companies discover the pent-up demand for “product service systems” and enter the market with residential fit-out. A well-developed consumer market is, however, a prerequisite, supported by sensible financial and regulatory reforms.

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INTRODUCTION: THE CONTEXT FOR CHANGE

A growing demand for more adaptable buildings. The adaptation of buildings once designed for a specific use in a specific time to a different use in a different time, is not new. The European urban landscape of the end of the 20th century holds numerous examples of an industrial, merchant, and military age which, having fallen into disuse, have become available architectures that have adapted to the most unlikely projects, lending themselves readily for modification (Bordage 2002). Industrial, commercial, and military buildings are now cultural centers, concert halls, and museums, among others. The Reina Sofia Museum, in Madrid, is an example of a former military hospital converted into a museum. In Bilbao, a 1600s baroque church now hosts a popular concert hall, Bilborock. While the natural lighting and acoustics may make these types of buildings ideal for certain activities, it is the great structures and absence of partitions what enables a physical polyvalence to host a variety of uses.

Besides singular buildings, the demand for adaptability has reached the wider building stock, triggered by constant change in market and social conditions. The most widespread need today for adaptability is either within or between residential and tertiary uses. For instance, large dwelling units are being split and turned into smaller units, as the average household size has decreased and smaller units result more marketable due to high real estate values. At the same time, many municipalities in the Basque Country are currently modifying their bylaws to allow residential uses in street-level floors formerly planned for tertiary uses, mainly office and commercial. Again, a combination of new market and social demands, as these spaces, under their former land use designation, remain undeveloped. This situation has its opposite in many residential buildings, in which dwelling units are often used as offices for a certain period of time. The capacity to assume and accommodate change has thus become a new requirement for buildings, which must adapt to different uses and situations throughout their lifespan.

The current building industry fails to achieve...
such goal. Most buildings in the Basque Country are built with post and beam concrete structures, where interior partitions have no significant structural role, and could therefore allow for change in the floor plan layout. However, the extended use of brick for interior partitions makes adaptation a complex process that involves time and user discomfort, as well as a significant generation of waste material. The recent use of lighter solutions for interior partitions, such as plaster boards or dry walls, contributes to adaptability. According to Pladur, the most popular plaster board company in Spain, their system has been used for over 20 years in over 250,000 dwellings and hundreds of office, hospital, hotel, cultural buildings, etc.

The need for a more environmentally conscious building industry
Buildings have a significant impact on the environment, both as great consumers of resources (e.g. energy, water, materials) and as generators of waste (e.g. CO2, waste materials).

**Energy consumption**
In Europe, buildings (represented by the housing/services sector) are the greatest consumers of energy (41%), ahead of industry (28%) and transportation (31%) (European Communities 2008). In Spain the impact of buildings in the total energy consumption is somewhat lower (27%). The Basque Country presents a different picture, with a housing/services sector energy consumption share of 19%, behind those of industry and transportation (46% and 33%, respectively). However, while transportation consumption has dropped in the last year by 5%, housing has increased by 10% and services by 8%, positioning the housing-services sector as the fastest growing one per year in terms of energy consumption (EVE 2009).

**Water consumption**
Buildings in the Basque Country, again represented by the housing and services sector, are by far the highest water consumers. They represent almost 70% of the urban demand, and 45% of the region’s total water consumption demand (Ihobe 2009). Within the sector, domestic consumption is 5 times greater than the services one, making residential buildings a key player to reduce the region’s overall water consumption.

**Waste generation**
Buildings directly generate waste materials during the building phase, renovation, and demolition. In this sense, the building sector in the Basque Country generates around 1.8 million tons of waste per year, representing 15% of the region’s total waste (Ihobe 2009).

**Building codes and certification standards**
The negative impact of the current buildings stock in the environment has generated a trend of environmental consciousness in both the public and the private realms. In Spain, the new recent building code (Código Técnico de la Edificación, CTE) includes specific energy consumption considerations, as well as the use of energy efficient utilities and renewable energy production in buildings. Apart from legislation, the government has set up the incentive-based Spanish Energy Efficiency Saving Plan, which in the Basque Country is carried out by EVE (Ente Vasco de la Energía). On the other hand, the private sector is slowly beginning to specifically include environmental benefits in its projects, as “green” becomes trendy for the market. Certification systems and standards, such as Passivehaus, LEED, BREEM, etc. are still underway in both Spain and the Basque Country. LEED is perhaps one of the most popular ones, applied in few specific outstanding buildings, such as the Iberdrola Tower in Bilbao. There are around 15 buildings in process of LEED certification in Spain, and up to now, none are residential developments.

Perhaps the flaw in current public efforts is putting all the eggs in the energy basket. That is, concentrating most of the new legislation and incentives towards saving energy and cutting down emissions, leaving buildings’ responsibility on water and materials aside. Bioclimatic and ecological practices and certification standards such as LEED, Living Building Challenge, HQE, provide a more holistic approach towards sustainability and buildings’ environmental performance.

**The context for change**
Either market, socially, or environmentally driven, there is a growing demand for an adaptable and more environmentally conscious building stock. These concerns, related to the way buildings perform over time, are generating a context in which a
substantial change in the building industry is needed. At the same time, the economic crisis, while it is significantly affecting both the Spanish and Basque building sectors, represents an opportunity for innovation in new building models. Increased efficiency in terms of time, labor, and material consumption are key to reduce cost guaranteeing, and even improving, quality. It is worth mentioning that, in order to accomplish significant change, these new models should look beyond new construction and over to existing buildings.

THE CONCEPT OF MODULAR ECOTECHNOLOGICAL ARCHITECTURE

This paper proposes the concept of modular ecotechnological architecture as a response to the demands for adaptability and environmental friendliness in buildings. The basis is an integrated design that looks at energy, water, and materials’ efficiency altogether, combined with a modular industrialized building system.

Integrating design and technology to enhance environmental performance

Ecotechnological architecture is understood by this paper’s authors as the integration of design and technology to significantly improve buildings’ environmental performance. The concept considers three key areas due to buildings’ high impact on them: energy, water, and materials. The first two are mainly related to consumption, while the latter to waste generation. These three areas of buildings’ impact represent a starting point, acknowledging there are other ones within environmental sustainability to be considered (e.g. site, biodiversity, air quality).

In order to significantly improve a building’s environmental performance, this paper proposes three ambitious goals, based on the application of the concept of zero energy buildings, beyond energy, and on to water and materials.

Zero energy goal

Although the term “zero energy building” (ZEB) has recently become quite popular, there is a lack of a common definition and understanding of what it means. There are different variants, such as net-zero site energy, net-zero source energy, net-zero energy costs, or net-zero energy emissions. Defining the zero energy goal affects design choices and whether one can claim success (Torcellini et al, 2006).

In this context, this paper uses the net zero site energy goal, which can be easily verified through on-site measurements. A site ZEB produces as much energy as it uses, when accounted for at the site (Torcellini et al, 2006). In order to achieve this goal, design and technology come together to first, reduce the building’s energy demand, second, maximize the efficiency of its utilities, and third, generate the energy it needs.

Zero water goal

This goal applies the zero energy site concept to water (again, to provide a simple way to measure performance). The concept of net zero water, defined by the Living Building Challenge, proposes 100% of occupants’ water use must come from captured precipitation or closed loop water systems that account for downstream ecosystem impacts and that are appropriately purified without the use of chemicals (International Living Building Institute, 2009). As in energy, the first step towards achieving the goal is minimizing demand, through low consumption devices, and secondly capturing rainwater and treating grey water.

At the site level, it is also important to achieve zero storm water runoff generation. That is, taking care the building’s site run off within it. This maintains the site’s original hydrological balance, contributing to overall water and waterways’ quality, reducing flood risk and the need for expansion of municipal infrastructure.

Zero waste goal

This paper proposes the zero waste goal applying the cradle to cradle concept to building materials: To eliminate the concept of waste means to design things from the very beginning on the understanding that waste does not exist (McDonough and Braungart, 2002). The aim is to use building materials wisely; not only to reduce resource consumption during the construction phase, but mostly to guarantee their recuperation, either for reuse or for recycling, when the building’s useful life is over,
reducing waste by demolition. Ideally, no building materials should end up in landfills.

**Modularity and industrialization, a consequence of environmental consciousness**

The “modular” in modular ecotechnological architecture is a consequence from the concern to reduce consumption of building materials and generation of waste (materials) throughout a building’s lifespan; during construction, renovation, and deconstruction processes. On the one hand, industry and thus industrialized systems have always been more material-efficient than the construction industry. On the other hand, reducing waste in renovation and demolition basically entails the use of “dry” systems that can be recuperated at a certain point in time. Traditional use of concrete and brick on-site would therefore not meet the goal, as the materials used are not able to be recuperated, ending up in landfills.

Modularity and industrialization through open building systems are ideal to accomplish the zero waste goal. These systems are constituted by elements or components from different precedence; are able to be collocated in different types of buildings (industrialized or not) and in different contexts; usually make use of pretentiously universal joints, delimited modular ranges, offering an almost total project flexibility (Salas 2008).

According to J. Salas, the development of these systems, particularly between 1990 and 2000, has been the germ for a new building philosophy, a term he has coined as “subtle industrialization”.

Research findings indicate significant construction waste can be cut down through open building manufacturing techniques: Reductions of 100% of waste can be achieved in plastering; from 74% to 87% for timber formwork; from 50% to 60% for concrete, and from 35% to 55% for reinforcement bars (Tam and Tam, 2007).

**Enabling adaptability and, hence, contributing to sustainability**

The use of off-site industrialized systems, either from different precedence or having been assembled in one specific off-site location, allows buildings to grow or reduce in size according to their needs, with little impact for their inhabitants. At a smaller scale, the “subtle industrialization” of open building systems entails an elasticity of construction solutions based on components which has made possible the compliance of new energy saving legislation and responses to demands for other types of architecture (Salas 2008). Modularity in these components facilitates the design and construction / assembly process (and thus, time and money), while at the same time offers a vast range of end-user solutions.

Within the different structural solutions of open building systems, those with less structural elements in plan provide the maximum adaptability to different user-activities. Providing a clear plan with few master partitions enables versatility for a variety of uses (e.g. residential, office, educational), within the same space and over time. This is a critical aspect for adaptability and flexibility of use.

**A word on adaptability and sustainability**

Modular ecotechnological architecture intends to enhance adaptability and environmental performance through the integration of design and technology, using modular open building industrialized systems. The concept is intrinsically sustainable, as it contributes socially, environmentally, and economically. Socially, it responds to changing social demands (e.g. smaller household size, related to need for space, and housing size, related to affordability). Environmentally, it reduces buildings’ energy, water, and material consumption and waste generation. Last, economically, it responds to changing market conditions, enabling different economic activities, and reducing cost (through increased time, labor, and materials efficiency).

**CASE STUDY: EXPERIMENTAL PROJECT FOR SINGLE FAMILY HOUSING**

The following case study is an experimental project for single family housing applying the concept of modular ecotechnological architecture. The south-facing rectangular site is located in a rural environment in the Basque Country, on a relatively steep East-West slope, with views down to the valley on the East.

From the beginning, the project program required adaptability of use over time. The program is proposed for a household of four (2 adults and 2
children), with an annex for hobbies, guests, or the children as they grow up. However, in the first years, the annex would be used by a close relative, as an independent apartment (Figure 1). The annex thus required a specific distribution in the short term that could at one point become one single open space. At the same time, the overall program required independence between the two units, and spatial coherence as well, as, in the end, it is one single dwelling. At one point a new adaptability requirement came up, due to affordability reasons: the possibility to build the house in phases (the main unit first and the annex later).

The client was interested in modular ecotechnological architecture for several reasons: program adaptability, shorter building time, lower overall cost, and a strong belief in ecological friendliness and technological innovation.

**Technical aspects and challenges encountered**
Below is a compilation of the technical aspects and challenges encountered throughout the project, divided into four key areas: structure, envelopes, interior partitions, and utilities.

**Structural system**
The structural system consists of 9 rectangular tridimensional modules. Each one is made up of four tubular steel posts and a prefabricated concrete slab. Modules attach to one another through a joint specifically designed for this structural system. The system and choice of materials responds to the zero waste goal, in that the building can be taken apart into its modules, and the modules can be taken apart into their components, ready for reuse or recycling.

The choice of modules only consisting of the minimum number of pillars is the cornerstone to provide an adaptable space. The combination of modules positioned contiguously on their long side provides a clear open plan (Figure 2).

Module dimensions are 2.5 m wide, 7.5 m long and 3.1 m high. One of the first challenges encountered in the design were dimensional and weight limitations. The modules were to be built off-site, so transportation and on-site assembly capacity were key aspects.

**Building envelopes**
Building façades respond to site attributes,
such as valley views, and orientation, to optimize solar gain and reduce energy demand. The building is mainly open to the South, with glazing and solar protection (Figure 3). To the North and West, prefabricated wood panel ventilated façades with few openings and extra insulation, as the North West winds are the coldest in the area. Openings on opposite façades allow for cross ventilation. Façade panels and openings respond to the modular system (Figures 1 and 3).

Green roofs provide a horizontal garden for the dwelling; an outdoors usable space in a site with a steep slope. The roofs include a shallow water deposit that covers the whole roof. The system not only reduces heat gain in the summertime, but also retains rain water in periods of heavy rain, and most importantly stores water for toilet use. Thermal panels on the roof provide energy for heating and
domestic hot water use.

**Interior partitions**

Interior partitions are made up of industrialized plaster boards that offer a simple assembly and are able to be taken entirely apart. This is relevant for the waste goal as well as for the adaptability demand. The modular system allows flexibility of plan distribution (Figures 1 and 4), although partitions do have to follow the modules to a certain degree. This can be considered a design limitation.

**Utilities**

As mentioned, the building contains thermal panels for heating (radiant floor) and hot water production. Default energy supply is natural gas. Lighting is through low consumption light bulbs and LEDs. Bathroom elements, taps with air pressure devices, and the roof deposit for toilet use, minimize the buildings’ water consumption towards the zero water goal.

The main challenge in this sense is technological innovation, and the cost related to it. Some of the proposed systems are out there on the market, although not quite meeting all the project requirements (e.g. few radiant floors meet the zero waste goal). Others are just not there, either in development or yet to be developed. Another challenge encountered is the modular system requires bathrooms to be included within a single module (Figure 4). This poses a certain design limitation, as, once built, these elements prevail throughout the different plan distributions.

**Normative aspects and challenges encountered**

As with many technological innovations, the challenge with legislation is either it directly does not consider certain systems, or it penalizes others. For instance, the new Spanish building code (CTE) does not include open building manufacturing, and the new stricter acoustics section makes design with light interior partitions relatively difficult to comply. At the same time, Spain requires a 10-year structural responsibility for the developer, for which a technical control office must approve the project. These offices have little knowledge on open building systems, and require specific certifications (DITE) to give their ok.

**Economic aspects and challenges encountered**

The project is currently on standby for reasons beyond the project’s control, so the real economics are based on a forecast. According to the manufacturers consulted, the building could be complet-
ed within 4 to 6 months, whereas the average time in conventional building would be 18 months. Indirectly, this means cost reduction. On the other hand, the project budget resulted in 10% below a previous project for a similar dwelling. The biggest challenge, nevertheless, was the cost of specific ecotechnologies in order to meet a cost objective to fit the market. Finally, although this project was not the case, there is a generalized market perception that prefab is low cost and low quality, and it applies to modular industrialized systems. This is a major challenge.

CONCLUSION

The concept of modular ecotechnological architecture intends to respond to recent demands for adaptability and improved environmental performance in buildings, contributing to the expansion of the Sustainable Open Building knowledge. The concept sets ambitious goals in the areas where buildings significantly impact the environment: energy, water, and waste. Such goals are meant to be objectives towards which to work and be able to measure performance and (hopefully) progress. Lessons learned from the case study presented suggest key elements to provide adaptability are modularity, structural system, and interior partitions. For environmental performance, envelopes and utilities are key for the energy and water goals, while structure, envelopes, and interior partitions are key for the waste goal. Ultimately, modular ecotechnological architecture is based on the integration of design and technology, and requires substantial imagination and innovation in order to meet the proposed goals and overcome the diverse design, technical, technological, normative, and economic challenges.

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The objective of Nabeel Hamdi in writing “The Placemaker’s Guide to Building Community” was to share his experiences about making and sustaining the quality of settlements of poor and to share his knowledge about social responsibility of architects. The introduction of the book contains a criticism of the World Bank and housing applications in general and this part can easily be related to the criticisms in Mike Davis’s “Planet of Slums.” The first part derives lessons from existing examples of human settlements and explains the concept of vulnerability. The second part explains Action Planning methods and toolkits to improve a poor urban area through participation of people. Part three explains the relationship between Community Action Plans (CADs) and Strategic Action Planning (SAP). Part four focuses on architectural education and explains Hamdi’s experiences about bringing the issue of place making practice into the classroom. The last part contains a code of conduct for placemakers. The author has achieved his objective especially because of the details given in the book and the strong sense of truth the book gives.

The book contains a large reference list as well as an index. It has fifty six photos, drawings or schemas, which help a lot to clarify the subject.

“The Placemakers’s Guide” is useful for architects, who work in the field of urban design or who are interested in social responsibility of architects. The book can also be useful for sociologists. It is one of the rare books about social responsibility in architecture. Thus, it can also be useful for architects who undertake research about architectural theory.

Dr. Yonca Hürol
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Ashraf M. Salama & Nicholas Wilkinson (editors).

This groundbreaking book is a new comprehensive round of debate developed in response to the lack of research on design pedagogy. It provides thoughts, ideas, and experiments of design educators of different generations, different academic backgrounds, who are teaching and conducting research in different cultural contexts. It probes future universal visions within which the needs of future shapers of the built environment can be conceptualized and the design pedagogy that satisfies those needs can be debated.

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