Active Building Structure and Envelope

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ABSTRACT

Using the abstract idea of considering a building as a human body. For instance if we consider the structure and envelope of the building to be the skeletal system and the skin, then the technological, managerial, production and assembly systems of the building would be the nervous system and cardiovascular system. Explore: The potential of using advanced construction method and other alternative concepts to underpin new approaches in the making of future building systems. The proposal will allow buildings to adjust, interact and respond to the changes of any condition. Put simply, when we feel cold or warm, happy or sad, our body reacts according to the situation, just as a future building would. The active building system can be used for new construction project as well as be compatible with existing structures. The approach emphasizes the concept that building should not be erected as a permanent form, but should be flexible, active or even mobile; it should offer interchangeability, interaction between building elements and end-users and be adaptable throughout its entire life-cycle. Furthermore, the concept of self-diagnosis function will enable the building system to interact and respond to changing surroundings and also detect malfunctions and call for rapid repairs. Results & The proposed building system will reflect the most multi-disciplinary approach and state-of the art technologies within building design, manufacturing, on-site construction (assembly, installation), maintenance, deconstruction and recycling.

Keywords -
Active; Adaptable; Advanced construction

1 Introduction

The Industrial Revolution in the 19th century had a profound effect on many aspects of life. The construction industry benefited from growing demand due to rapid urbanization. In England, there were huge demands for affordable housing as some of the industrial cities grew. Those building had to be erected rapidly using unskilled labour. The solution was ingenious; a simple design using standardized elements as well as the use of mass produced materials such as brick and sandstone. Then the materials were transported by railways or canals to the construction sites. Millions of back-to-back terrace houses were constructed. Until now, red brick terrace houses are a stereotype in part of English towns. After the invention of the computer, there were increased uses of digital technology in many sectors, including the construction industry. Some referred to it as the Third Industrial Revolution. Architects and the construction industry started to examine the potential of computers and digital technology and to explore the opportunities of how it would enhance the way we design and build. Very quickly, Computer-Aided Design (CAD) application became the mainstream design tool used by architects. The use of digital application also enhanced the implementation of Information and Communications Technology (I.C.T) in the construction process. Furthermore, Computer-Aided Manufacturing (CAM) enables architects to fabricate or prototype building components, which have very complex geometries.

The new generation of designers may find it hard to understand the design process of architecture without the use of digital technology. At present there is another wave of the industrial revolution that carries on the legacy of the previous technological leaps: The fourth Industrial Revolution. The main characteristic of the fourth Industrial Revolution is the use of cyber-physical systems and the internet of thing to enable the creation of smart industry. This allows the industry to become flexible, adaptable and aware of the customers’ needs. Customer will be able to directly influence the design and production of a product. Assisted by automation and robotic technology, the fourth Industrial Revolution is a giant leap for manufacturing industries. The idea’s that the technology will transfer to the construction industry so it will also benefit from this wave of the industrial revolution and laying a foundation for the next generation of active building systems.

2 From Open Building to Active Building

Mass produced, prefabricated building system became a popular choice for architects and engineers. The concept of Open-Building (OB), -also known as

Support/Infill (S/I), Skeleton Housing, Supports, reconfigurable and houses that grow, etc. –now represents one of the most flexible construction principles. The building has been designed in different levels: support structure, infill system, fit-out and appliances. These have been reinterpreted and updated to harness the benefits of state-of–the–art industrial production, emerging information and digital technologies, improved logistics, changing social values and market structures.

Open Building is the predecessor of active building. It used a cross disciplinary approach to the design, finance, assembly, fit–out and long–term management processes of buildings, including mixed–use structures and teamwork. Its goal was to create varied, flexible, fine–grained and sustainable environments with the responsibility for decision making distributed to various levels. OB has emerged gradually in response to evolving social, political and market forces, to prevailing conditions and trends in residential construction and manufacturing and many other factors that demand more efficient and susceptive practices. [1] The Open building concept is no longer a novel idea but it is the backbone that will greatly support the active building concept.

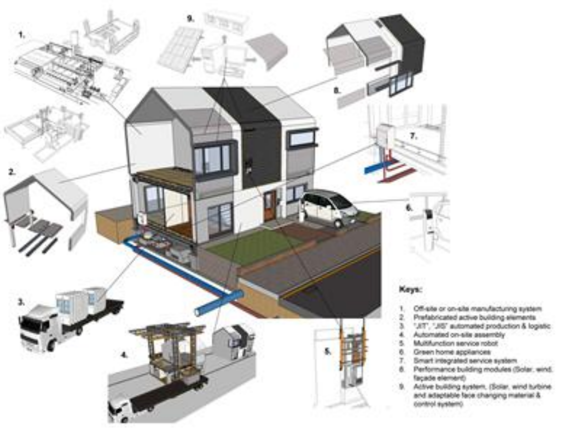

Figure 1. Overall composition of the concept

In general, active buildings are divided into four levels: support structure, infill, façade and information cluster. Let's imagine an active building to be a human body. If we consider the structure and envelope of the building to be the skeletal system and the skin respectively, then the technological, managerial, production and assembly systems of the building would be the nervous system and cardiovascular system. Every level is aware of any changes that will to happen, happening or has already happened among each other in terms of configuration, maintenance, customer demand and function. This level of awareness will be demonstrated throughout the entire building process; design, construction, use phase, maintenance and recycle. In this sense, everything can be customised, relocated and optimized for personal preferences. In order to achieve this robotics and automation in architecture will play a significant role. The embedded robotic system or intelligent building system will not simply respond but actively participate according to various conditions of the environment while also interacting with other systems when necessary.

3 Design for Active Building System

As aforementioned, an active building is highly interactive, intelligent, and adaptive. The design process of such a system will be dramatically different from any conventional method. Traditionally, buildings are designed to meet existing client's specifications and requirements and then later adapt to current social, economic and demographic situations. Openness is one of the key concepts when designing an active building system. The building system must be designed as a group of interrelated components that act together to accomplish a specific task. It must be able to exchange information about external impacts. External impacts do not just refer to environment impact but also include transformation triggered by social and economic impacts. The levels of openness are surmised as below:

- Open for manufacturing
- Open for individual design
- Open for alternative assembly
- Open for competition between suppliers
- Open for alteration and maintenance
- Open for integration of modules and subsystems
- Open for recycling

The importance of decision about intensity and degrees of activeness on an individual building system levels cannot be underestimated. At the initial design stage the designer has to define the complexity of the building platform, components and diversity of the interactive networks which are acting as the nervous system. The building platform will serve as the base of the structure which has the flexibility that enables various building processes, structural configuration and function alteration during the lifespan of the building. Once the buildings armed with this level of flexibility any social, economic and user changes, both expected and unexpected, can easily be addressed. [2]

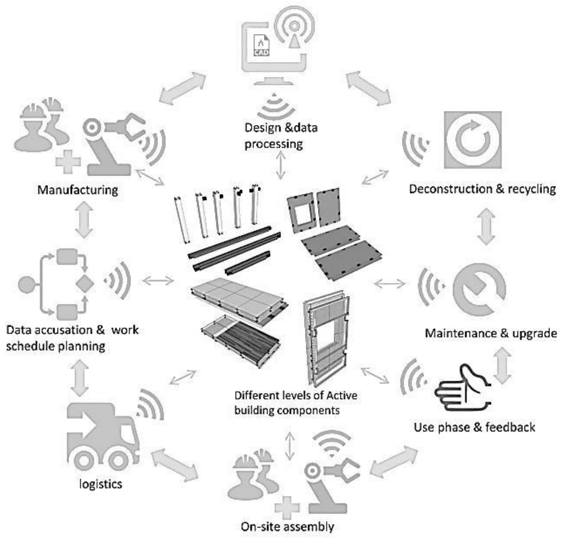

Figure 2. Openness of the active building concept

3.1 Digital Design

Considering technology implementation, it is important to mention the impact of information technologies and computer-aided design on the construction sector. Computer Aided Design (CAD) has had a huge influence on accuracy and efficiency within the construction industry. The developments of the latest software, such as Autodesk's Revit Architecture and SolidWorks are an upgrade of traditional CAD-based software. Building Information Management (BIM), which enables designers and engineers to analyse each stage of the building's lifecycle, from its concept to demolition and recycling, monitors the entire building process. The sharing of information and resources between key players within the company, such as design data, financial data, legal data and service layout, lead to the important of team communication and increased efficiency, constructability and, ultimately, predictability of all projects.

Unlike a conventional architectural designer, responsibility of an industrialized building production designer will extend and cover aspects throughout production, assembly, storage, disassembly, distribution and market gain. Therefore, from the conceptual design stage, designers will have to take into consideration how each building component is produced, handled and assembled and then disassembled and recycled at the end of its life-cycle.

A wide range of building components will form the various designs of building systems. Building systems will be designed rather than entire buildings. Building systems will become part of the design tool that will allow architects to arrange them accordingly and fulfil the design requirements. Computer software will be used not only to produce building drawings but will also be designed to analyse the performance of different designs of building systems and whether they are compatible with one another; this is similar to BIM systems but with more specific functions. All design data will be shared throughout the life cycle of the building and feedback from the use phase can be used for system optimization.

4 Production for Active Building

In terms of production, the use of a computerised system has shown its potential in increasing productivity. In the past two decades, the Automobile Industry has benefited from using Computer Integrated Manufacturing (CIM). The system has not only changed the productivity of automobile production but also defined the concept of customer oriented product. Traditional building design methods will be challenged by automated design methods. The success of other manufacturing industries has shown the benefits of using automated production methods. Design data passed on from the design stage can be sorted automatically and used in the prefabrication process. By using computer software specifically designed for the construction industry, cost, design, material usage and assembling requirements of the project can be generated automatically.

Active building requires innovation in the production methods, automation in production facilities and technology implementation from other disciplines in order to increase productivity, improve quality and save labour cost. The "Design for X" concept, e.g. design for production or design for assembly, has been implemented in many other manufacturing sectors addressing the fact that before the production phase the product has to be designed with consideration to its operational features. However, between manufacturing processes, they may share many similarities, but the construction process still bears many unique circumstances. The active building designer has to understand the entire construction process in order to design an effective building system that will be adopted for automated manufacturing method, customization, coordination with other building systems and final automated assembly, disassembly and maintenance on-site. [3]

4.1 Flexible Manufacturing

Active building assumes a degree of flexibility in the manufacturing stage that allows a manufacturer to change production method, material and achieve customisation as well as low level of alteration on the existing manufacturing setup. Especially in the prefabrication industry, for example, a production facility designed to produce a single range of products, such as a precast concrete facility, will only produce concrete building components. However, when there is low demand for such products, the business will find itself struggling to adjust or adopt its production facility to produce something more desirable. [4] Conventionally, it is very costly to shift from one manufacturing type to another. To complete such a task involves changing many existing structures of the business, including production, operation, marketing and management aspects. [5] Therefore, the requirements for a flexible manufacturing facility consist of:

Basic level flexibilities:

- Machine flexibility - machines need to be able to handle multitask roles, for instance, in the wood prefabrication industry, machines could perform cutting, drilling and placing tasks with minimal adjustment
- Material handling flexibility – within the factory, materials and parts can be flexibly delivered and fed through to the next station
- Operation flexibility – alternative operation sequences can be easily implemented

System level flexibilities:

- Volume flexibility – the system can operate profitably at different volumes without alteration on existing parts.
- Expansion flexibility – the production system can be expanded when required
- Process flexibility – without replacement of the workstations, the production sequences can be altered
- Product flexibility – more than one kind of product can be produced by using the same production line

Combined level flexibilities:

- Program flexibility – the system program can remain for long running times without major adjustment
- Production flexibility – production set up can be reconfigured to increase volumes of products
- Market flexibility – the production system can be effectively adapted to produce various types of products based on the market demand

Recently, the use of computers and robotic technology in the manufacturing industry has improved productivity as well as flexibility. Production facilities equipped with industrial robots can be reconfigured easily by relocating the robots within the plant or simply replacing the end-effector of the robot allowing changes in terms of factory layout, production sequence and production output. With combined technology, a business could easily alter its manufacturing facility and adapt to the changes of market demand. [6] In order to adjust to changes in market demand, future construction industry must change from passive operation to active operation. To achieve this goal, the construction industry must adopt new technology and concepts, and implement in every phase of the construction phase.

4.2 Digital Fabrication

Active building should be able to be manufactured by a variety of materials and means. In the digital age, as part of the aforementioned flexible manufacturing process, there are various methods available to produce active building components. Many of these methods can be implemented on-site, in situ or even mobile. Here are a number of projects that were influential on the development of active building systems.

"Wiki house" is a concept which offers an open source construction system, because it is based on an open source platform, meaning the system is continuingly improved by the user. The components are freely accessible and customisable. The 3D model of the building can be printed by Computerized Numerical Control (CNC) machines or 3D prints. Those components can achieve very high standard of quality due to the high precision of the manufacturing process. Components are designed to be easily assembled on-site by using only basic tools. The workers do not require special training yet can operate the assembly task safely and efficiently. The concept also reflects on the concept of open building in which a reserved space is kept for a later service; piping installation.

Another project is called "CasaMobile", is a European Union funded project. The concept of the project is to offer an alternative method to providing local, flexible and highly customised products on-the-go. The mobile factory, which consisted of additive manufacturing module, CNC – milling module, automated assembly module, was embedded in a standard 20ft ISO container. The materials and equipment are transportable enabling the concept to produce products while on the move.

Active building system can adapt some of the concepts mentioned above, while enhancing its own performance. An open source concept will enable customers to be involved and influence, in the building design stage. The data collected during this stage will be beneficial in later maintenance, product improvement and remanufacturing phases. Furthermore, a 3D printed house is no longer a novel concept. Armed with these technologies active building can potentially be fabricated and printed by a mobile factory using in situ materials. The availability of the local materials can be provided via a ubiquitous computing system that interacts with the location of the mobile factory. [7]

5 ROD and Automation in Construction

Robot oriented design (ROD) was a ground breaking concept suggested by Professor Thomas Bock in 1988. [8] The concept suggested that building components could be designed and erected with the use of construction robots. In terms of active building, despite the consideration of structural aspects, there are also other perspectives which differ from conventional building; manufacturability, productivity, assemble-ability, storage, transportation, on-site assembly, maintenance, after-sale, relocatability, deconstruction, recycling, upgradeability and lifecycle management. It is impossible to achieve above points without the implementation of the ROD concept. [9]

In the late 1980's, Japanese construction contractors explored the use of single-task robots. However, applying single-task robots did not improve the overall productivity as expected because of preparation procedure and high research and development (R&D) costs. The complete potential of robotics cannot be realised until the construction process is automated and building components are designed and adapted to robotic on-site operations. The main reason for this difficulty is the complexity and variety of the buildings themselves, the engineer and manual labor organizations, and the environment in which buildings are constructed. This trend also reinforced the importance of the ROD concept. [10]

In order to offer the flexibility that active building promises. It is necessary to introduce high degree of automation level throughout the entire construction process. The production facility, building products, workers and robotic application will not only transfer information to one another but also interact with each other. The uses of sensors and feedback systems will be ubiquitous in providing awareness throughout the lifecycle of the building.

6 Advanced Software Architecture

A multitude of different Building Information Modeling (BIM) software programs are available to designers, and selections often come from company preference and the nature of the product. In general, BIM can be defined as a modelling and management tool which processes and analyses sets of information carried by building models. However there is not a standard BIM application or definition. Active building designers have to tailor-make software that is compatible with existing BIM application but also introduce new agents. For example, designing an active BIM system that can predict the correct work schedule and estimating the time and budgeting of using on-site automation. In addition, the building elements will be able to interact with the software and assist it with data acquisition, evaluate the assembly task, process collected data, plan working processes, distribute and calibrate with other on-board smart algorithms and record and coordinate the task in real-time. [11]

6.1 Sensor Technology and Self-diagnose

The self-diagnose concept can be elaborated upon by using various sensors and embedded context sensitive devices like Radio-Frequency Identification (RFID), Near Field Communication (NFC), Bluetooth that enables each level of the building to proactively respond to any changes that will happen, are happening or have already happened. Auspiciously, this approach will comprise an alternative approach in how a building will respond to its surrounding environment. The responsive environment can be physical, geographic, demographic and economic. The responsive activity can be distributed into different building levels: component level, production level, assembly level, maintenance level and recycling or re-condition level. [12] Here is an example of how sensor technolog would change the way that a building performs. Based on the use of fiber-optic sensors or active-passive RFID tags, the building could detect the early signs of landslide risk in the surrounding location. Potentially, the sensor network modules could be embedded into the building structure. The fiber tube would connect the building components. In this sense, the fiber-optic-sensors would be acting as the nervous system of the building. This concept can be applied to prevent and predict potential structural failures. [13]

7 Lifecycle Management

Based on the principle of product oriented design and armed with BIM system and sensor technology, the future of active buildings will forever be independent and aware of any changes that might occur. From the design stage to the production stage all the way to the end of the building life span the date acquisition process will be constant, seamless and ubiquitous. At the early stage of the design phase, the design specifications will be defined with the involvement of the architects, engineers, manufacturers and most importantly the stakeholders. The embedded data will be shared later at the repair, maintenance and upgrade stages. For instance, in a repairing scenario when the building maintenance system detects malfunctions of a building part, a report with the location and specification of the parts will be sent to the engineer automatically. According to the shared data with the manufacturer, the reported parts can easily be allocated and ordered in advance.

8 Business Model for Active Building System

The construction industry is rapidly changing. There is an increasing demand for efficiency, shorter delivery times, and higher quality buildings. This is pushing owners and contractors to adopt new business models and technologies which will give them a competitive advantage. There is a significant difference between constructing an automobile and a building. Automobiles are unfixed; parts can be upgraded and the auto itself can travel from one place to another. Buildings however, are stationary; renovation is often costly and the building cannot be relocated once erected. In contrast an active building will offer maximum flexibility to the designer, manufacturer and the end user.

The active building will emphasize that a building should not only be permanent but should also offer flexibility and interchangeability throughout its lifespan. The building system is highly standardized and customized. It will be able to implement various configurations and specifications to match the client's requirements. [14] In conjunction with the open source platform concept, the business model will corroborate with customer's and individual designer's personal input, therefore, embracing the mass customisation of the building design. Last but not least, active building concept will offer highly flexible market segments. The building component will not only be applied to new build projects but also be compatible with existing buildings. Hence, the system has a huge potential to be promoted as a successful hybrid construction product in the current competitive market in order to attract developers and contractors.

9 Future Development

The active building concept provides a huge potential for dealing with the issues of promoting construction industrialization and customisation. However, it also faces many challenges in terms of design, production, construction, government policy and marketing. The conventional construction industry still feels reluctant to consider the integration with other sectors. As the first step, the future development will focus on the integration of the construction industry with other industries such as the manufacturing and automobile industries. This would be the first step for the construction industry to step into the fourth Industrial Revolution.

10 Conclusion

This paper has given an overview of the concept of the active building in an abstract way. The concept has the potential to solve larger issues, such as the shortage of skilled labour and the low efficiency of land use, material waste and sustainability. However further research and development is still essential to bring the concept to reality.

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