Evolution of Building Envelopes through Creating Living Characteristics

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Abstract: Building envelopes include facades and roof, which have the most interaction and exchange with outside and natural environment. In the future, meeting buildings various complicated needs with new technological advances necessitates a change and evolution in building envelopes. Controlling the energy consumption of the buildings is mostly through controlling the energy performance of the building envelopes. New technologies lead to the intelligent facades and envelopes. The envelope can be designed to be a part of the whole building’s metabolism (energy production, storage and consumption) and morphology. The envelope would be a controlled part of the building which is managed through the central control system of the building, which connects it to other parts. It caused building envelope design to be changed fundamentally, so that there is a need to interact with engineering disciplines including computer engineering, mechanical engineering, material engineering and so on. All of these caused building envelope to get closer to biological and living systems. The physical restrictions which affect buildings system and living systems are the same. So they cause the same forces to shape the structure and form of the systems and the same rules to interact with the environment. The restrictions of material and energy resources caused living systems to be energy efficient and consuming less material. But the most important difference between living systems and building systems is in maximum use of different resources. As living systems use information maximally, the building system technology is based on using maximum energy. Now, there are many reasons and restrictions that building envelopes cannot act like living systems. But technological developments and contributing more disciplines in design and construction of building envelopes caused the future way of these envelopes get close to living systems for their energy efficiency. Some of living systems characteristics which the future building envelopes would have partially or benefit for the design process or construction are self-organization, evolution principles, hierarchical levels, processing energy, reaction to environmental stimuli and self-adjustment. Self-organization is achieved in some design software and in building material production for creating formal patterns. Evolution principles provide infrastructure for soft wares for optimization purposes and form creation. Hierarchical levels refer to giving hierarchical structure to the building envelopes through layering and designing different scales. Processing energy (metabolism) would be achieved through photovoltaic and solar collectors to produce energy and in passive systems for energy storage and distribution. Controlling solar radiation absorption and transmittance would help energy transfer from outside to building and vice versa. Reaction to environmental stimuli which is one of the most important characteristics of future building envelopes would use different types of active and passive sensors to create envelope mechanical reactions through material properties or collect data for processing in the control center to determine the right reaction. The reaction would be through different strategies such as changing properties and moving. Reaction could be passive or active. Self-adjustment can be achieved by control systems and processing units. All of these mean intelligent envelopes are essential parts of future buildings. Though it is now started with new design soft wares based on biological principles to optimize different parameters affecting the envelope function or to create the most efficient form.

Key words: Intelligent envelopes, living systems, new technologies, environmentally respondent, energy consumption.

1. Introduction

To find out about the future of building envelopes (Fig. 1), we must go through the history of their evolution. Vernacular and traditional architectures which evolved through time according to environmental conditions have appropriate solutions to climatic conditions within their design which is called passive design. So they did not use energy to survive but they were dependent upon their environment resources [1].
One of the most important characteristics of passive design is to provide comfort condition as much as possible inside the building through design solutions and based on natural resources without using any more additional energy. So building envelopes which is defined as roofs, exterior walls and ground touched floor and external surfaces of building, has the most interaction with the environment and the most energy exchange with outdoor. So they have a very crucial role for providing comfort conditions in the buildings.

Understanding building envelope functions reveals that envelopes has more additional important roles than just separating inside from outside and they are influenced mostly by environmental and external factors. These factors mostly are dynamic than static. So they are the most suitable parts of buildings for innovations. Considering their exchange of energy and materials with the outside environment, building envelopes are the most crucial parts of the buildings for energy exchange and energy consumption of the building and providing comfort conditions. Also, other functions of the building envelopes can be listed as creating building image, creating message for the urban environment, symbolic values, providing natural ventilation, providing natural light, controlling energy exchange, providing visual view and finally providing shelter against environment (Fig. 2). Building envelopes can be designed somehow to be a part of building morphology and metabolism and function that is connected to other parts of building through controlling system of the building which manage the whole system and parts. This definition of building envelope caused a fundamental and basic change in its designing method which applied more collaboration between different engineering disciplines and architecture [2]. Besides that, new emerging technologies and intelligent materials and delivery systems bring forward the consideration to biological models for expanding the understanding of their behavior and designing building systems and controlling their functions. So, a comprehensive biological lexicon has been developed to explain new architectural concepts and ideas [3].

One of the examples is the application of the word “skin” for building envelope, which has a deeper meaning than its just metaphoric naming usage [4]. This means that building skin can be a very complicated membrane with the capability of exchanging energy, material and data with the environment in a controlled and managed way according to building needs [5]. The idea of creating natural skin characteristics in building envelopes which has been proposed by some researches and designers is more considered as self-healing, processed reaction, passive reactions, and multi-functionality of envelopes. Though its thermodynamics and heat transfer characteristics have been less noticed. Studies on finding a biological solution for natural ventilation lead to solution that are sought in the patterns of natural breathing skins in living organisms. This suggests the idea of natural ventilation through controlled pores in envelopes. Transformation of conventional facades and
Evolution of Building Envelopes through Creating Living Characteristics

1. Emulating Living Systems

Converting roofs into skins which control and adjust the temperature and energy flow of building can be achieved by emulating living systems physical characteristics, behavioral reactions and mechanisms for temperature regulations [6].

2. Comparing Building System with Living Systems

There exists the same physical restrictions both for buildings and living systems. There is a determined proportion between space and the surface which surrounds it as a system boundary to exchange the resources. Gravity and environmental forces make constrains for the formation and shaping of the structure and forms. The limitation of resources as material and energy in the environment leads to the effective and intelligent use of them in living systems. The most important difference between building and living systems lies on energy usage. Though in the technological systems, the energy consumption is maximum in the living systems, it is the information that counts for the most. There exists a difference comparing minimum energy consumption between living and engineering systems. This is because that living systems in a competition for surviving have evolved methods for minimum usage of resources and
energy which applies both for metabolism and optimizing the allocation of energy to different activities [7]. Comparisons between building system and living systems are briefed in Table 1.

Though some principles and rules of living system functions have been applied now in generation of some designing soft-ware, the application of the living criteria in buildings is still the most in temporary and trial structures [8].

There are many reasons for non-realization of the living criteria in building systems. Apart from some technical and industrial problem, the building industry is based on conservative views with low paced evolution, the dilemma of controlling over building system and the environment is very crucial for the impacts and intermediate effects. And there are some reasons for pursuing the realization of living characteristics in building envelopes as introduced in Fig. 3.

It seems that some living criteria have more importance in comparing and matching the architectural and biological disciplines. It seems order, growth, energy application; sensing and reaction, metabolism, self-regulation and evolutionary development are the most suitable criteria to transfer from biology to architecture. Evolution process, adaptability and making reactions are among living characteristics which have been realized somehow with some degrees in architecture field till now. Passive response to environmental stimuli had been existed in vernacular architecture from the past. Energy transformation and self-regulation have been recently achieved in some architectural aspects and evolutionary process is a new trend in architectural design [9].

3. Realization of Living System Characteristics in Building Envelopes

What the technological achievements of the modern world offered to the envelope architecture was the

<table>
<thead>
<tr>
<th>Building system</th>
<th>Living system</th>
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<tbody>
<tr>
<td>Linear process;</td>
<td>Cyclic process;</td>
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<tr>
<td>Dependency on synthetic and far-reached resources</td>
<td>Natural available resources</td>
</tr>
<tr>
<td>Maximum use of energy;</td>
<td>Maximum use of information;</td>
</tr>
<tr>
<td>Minimum use of information;</td>
<td>Minimum use of energy;</td>
</tr>
<tr>
<td>Energy consumption;</td>
<td>Energy process (production, storage, distribution);</td>
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<tr>
<td>Centralized production</td>
<td>Distributed metabolism</td>
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<tr>
<td>Similar physical restriction</td>
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A determined proportion between space and the surface surrounded it;
Constraints by environmental forces for the formation and shaping of the structure and forms;
The limitation of resources as material and energy in the environment;
Multi-functionality

Realization of living characteristics

- Integration of various functions into building envelope
- Application of new materials
- Designing envelopes as systems
- Regulating the inside through controlling systems
- Solutions for environmental and energy crisis
- Movement toward imitating living systems

Fig. 3 The aims of realization of living characteristics in building envelopes.
Evolution of Building Envelopes through Creating Living Characteristics

removal of the structural function of the outer walls of the barrier, which made it possible to make walls of lesser and lighter thickness with non-load materials. Although this technical and structural change made significant changes in terms of visual, symbolic and functional capabilities, it also disrupted the original functioning of the walls as moderators of the external environment. In such a way, mechanical facilities were needed to compensate for the inefficiency of the envelopes [10]. Also, the use of thermal insulators in the envelopes and increased air sealing in the openings subsequently caused problems in ventilation and condensation, and again the need for mechanical installations requiring energy consumption was felt more. In addition, contemporary life required more comfort for residents in the buildings, and this also highlighted the importance of providing the proper temperature in the interior, which made this thermal comfort more applicable to mechanical installations. Thus, it can be said that solving the problems of envelopes caused new problems, from the system point of views from envelopes to the whole building system.

Over the last decade, a pattern that takes the shift from linear thinking to system thinking, has been developed and has accepted the environment as a dynamic system that treats resources and feedbacks and boundaries [8]. This is important because human-made environments affect ecosystems in different ways. In this view buildings can be seen as a whole system which are connected to the environment by the envelopes as their boundaries. Envelope functions as a boundary for building system is illustrated in Fig. 4.

The necessity of using mechanical installations for the heating, cooling and ventilation of buildings to compensate for the inadequacies of walls whose energy was often supplied from fossil fuels, along with the development of urbanization and modern construction around the world, as well as the growing population and increased construction, led to untapped consumption of fossil fuels. The use of fossil fuels worldwide over decades has led to a rapid increase in carbon dioxide gas, which is a greenhouse gas, in the atmosphere, which has a gradual global warming and relatively rapid climate change around the world. The

Fig. 4 Building envelope as building system boundary.
cause is: this climate change has affected environmental equilibrium around the globe. The consumption of fossil fuels has also caused environmental pollution and air pollution, which has had a negative impact on the quality of life of humans and living organisms. Another issue with regard to fossil fuels is their non-renewable resources, which are currently under construction or are not reliable for a long time due to the increasing consumption of energy in the modern world and their long-term consumption [11, 12]. For this reason, reducing energy consumption and shifting energy sources from fossil sources to renewable sources such as solar energy, wind, geothermal, and so forth are the requirements of the present. The most important factor in the future of building developments and building layers in the future, is the energy factor in terms of availability of its resources, production and consumption. Another important factor in the environment is the interaction of the building with which in the future will be more important. Demonstration technology and architecture have already worked with the climate factor as a design necessity, and considering environmental and energy issues in design are expanding. Ultimately, performance is another important factor that should be introduced into the design process, which is only related to saving energy and financial economics, but also effective design solutions for combining functions and capacities and organization [13]. Building performance can be expressed with indicators such as primary energy consumption, environmental burden or indoor quality. The issues that building envelope arise are illustrated in Fig. 5.

Future skins will integrate all the functional and mechanical functions needed for the building. The combination of mechanical equipment in the envelope has been tested in some buildings. The combination of building envelopes with mechanical appliances is due to the fact that two systems, both interfaces between the interior space and the external environment, are integrated together so that an integrated control system can be used for both systems and pre-fabricated industrial production. This high-tech compilation can have a positive impact on building performance.

Such solutions are available in intelligent surface technology, membranes (structural skins) and even in nanotechnology. Recent advances have been on two sides, one of which is the development of link views and the other merging views. Linked views are a combination of common views with fixed awnings and double-glazed windows and the addition of mechanical and engineering units to the facade [13]. Integrating

![Diagram](image)

**Fig. 5** Issues on the envelope impacts.
views, in fact, integrate all the service components of the building, including mechanical cooling and heating installations, ventilation and artificial light, etc. in the envelope of the building. The most innovative and promising strategy for future building chains is the dynamic, active, and integrated solutions based on renewable energy sources. The behavior of envelopes should be dynamic and moving [14].

The increasing complexity of the human environment requires the use of various specialties for designing buildings. This specialization has led the manufacturing process to become a scattered practice, with the increasing collaboration of professionals from various disciplines [15]. Currently, building skins are the only elements of the building that are important in architectural design and engineering design. The envelopes have different functions (thermal, energy consumption, static, light supply, etc.) [16].

Envelopes are the most effective part of building for technical innovations that existing technologies can not meet their developing needs. Therefore, the need for new strategies, techniques, and techniques in this field is essential to make fundamental changes. When a type of technology reaches its limits, experience has shown that it is necessary to look for unusual solutions to break the existing boundaries. The evolution of envelopes has been accompanied by advances in envelope engineering and building knowledge, computer engineering, artificial intelligence and cybernetics. New technologies and smart materials and new distribution systems have introduced the bio-models to understand the behavior and design of building systems and their performance control.

Investigating future skins should lead to the development of design methodology, the elements and components of the envelope, and the integration of facilities and services in the crust with regard to energy, environmental and performance requirements as key elements [17].

The envelope can be designed to act as part of the overall morphology and metabolism of the building system and be linked to other elements of the building through the building management system (the overall control system). This view to the envelope of the building has fundamentally changed its design style [2].

Living systems are very efficient, which can adapt to environmental conditions and overcome various challenges. Some of the living features and characteristics that can be realized in the building envelopes are listed as; self-organization, evolution rules, hierarchical levels, energy processing, responsiveness, self-regulation.

3.1 Self-organization

Through self-organization, the order would be transferred from lower levels to higher levels, which means achieving more order that is in contradiction with hierarchical systems. Local interactions of system components (units which have less complexity in comparison to the whole system) lead to creation of universal properties and behaviors [18, 19]. Though the overall behavior may be very complicated, the local interactions follow simple rules. Regulation mechanisms lead to internal balance of the system and system preservation instead of system disruption and disturbance. Simulation of the simple interaction between complex system components especially in living systems has been possible by developing multi-agent models that can predict the whole system behavior. The self-organization rule has been realized in architectural design through applying some new soft-wares that work based on this rule. The physical self-organization process can be integrated into building materials production industry. In this case, it helps formal patterning of materials in manufacturing process that is especially crucial for new manufacturing and production techniques for variety of diverisive materials and functions (Figs. 6 and 7) of building envelopes in the future [20, 21].
Evolution of Building Envelopes through Creating Living Characteristics

Fig. 6 Using materials with self-organizing features in the envelopes according to the needed characteristics.

Fig. 7 Smart materials change their properties, with changing their structures.

3.2 Evolution Rules

Findings derived from biology lead to new inspiration in technology which one of them is natural evolution. In architectural field, softwares with evolutionary process for calculating are used for complicated and time consuming problems (Fig. 8). These design processes apply principles emulated from evolutionary process in living systems such as production, combination, change and selection to create new design which includes the whole evolutionary algorithms. One of the examples is genetic algorithms that are used to evaluate different solutions produced based on important parameters introduced by designer and search for optimized solutions among them. The optimized solutions have the most effectiveness according to the introduced parameters. John Holland was the father of genetic algorithms. He mimicked various types of genetic algorithms by abstracting them from adaptive processes in living systems to be used in soft-wares to create new artificial systems [22].

Genetic algorithms are used to solve complicated problems in forms and functions used in architectural designs with dual functionalities. These algorithms are used as tools to create forms and to optimize functionality
of building components. Limited application of these tools is in some parts of design process and in virtual space [23]. So optimization of building envelope functions and creating innovative and diverse forms which are in compliance with the functions are now possible through using these softwares.

3.3 Hierarchical Levels

Hierarchy actually is a grading and organizing system for components which shows which component follows the other component (Fig. 9). A combination of components relations creates patterns which lead to emergence of new properties and characteristics [24]. In architecture, the hierarchy can include structural, functional and material hierarchies (Fig. 9). Structural hierarchy is different in various structural systems and the more structural system has levels of hierarchy, the more it has structural components and surfaces and load transfers with more components in more levels [25]. Creating a structural hierarchy is possible through layering. Building materials are not structured in different levels such as living textures. Adding structural levels to building materials would enhance their physical and chemical characteristics. Designing and manufacturing of building materials in different scales from Nano to bigger dimensions can increase the structural level of the materials. In future, the materials that will be used in building envelopes have layering structures and different scales to achieve different functions and characteristics which are needed.

3.4 Energy Processing

Energy saving in building industry is an important issue which became a criterion for quality evaluation of the buildings. Using the envelope components to produce energy caused the possibility to collect energy in a decentralized way to omit the centralized provision of energy resources. The decentralization way of energy production is a biological strategy to save energy in distribution and loss of energy in transformations. Buildings can be energy self-sufficient using solar free energy as what organisms do. Heating and cooling are the most energy consuming applications in buildings considering continuous changing environmental conditions outside the building during the building life [26]. The most applicable forms of energy for building’s usage are electricity and heat. Solar cells can generate electricity from solar radiations, by integrating these cells into envelopes. Also solar collectors can provide heat from solar radiation, through air or water conveyors for heating or for provision of warm water for usage [27]. These collectors can also be integrated into building envelopes as one of their components. Depending on
the source of energy, energy transformation into applicable ones in buildings can be done through different processes and methods which would cause high loss of energy. In comparison to living systems which have high efficiency in energy conversions, buildings are very inefficient. To increase energy efficiency of buildings, passive systems must be applied as much as possible which do not consume energy or using low energy systems. Also energy sources should be shifted to renewable and free sources of energy which are available in the environment besides finding the most efficient ways of energy resources exploitation.

Building system as living systems has energy exchange with the outside environment. To preserve the indoor thermal conditions in a constant range, the energy flow between building and the environment should be controlled. The methods of controlling the energy flow depends on the type of energy and can be a passive or active method itself which means it would be energy consuming or not. Controlling energy flow would include the material flows as ventilation and moisture that transfer heat between inside and outside and thus have influence on energy flows of the building.

Heat energy can be conveyed and transferred through radiation, convection and phase change of materials. Buildings absorb solar radiation in days and have constant energy exchange with their environment. Energy gain and loss through envelopes should be controlled using energy management systems in the building that operate through processing data which is gathered from the environment. These systems would manage the inputs and outputs in a centralized way. The energy processing is introduced in Fig. 10.

Some of the nature solutions for energy collection and savings have been emulated. Intelligent façades or envelopes achieved more optimized way of using solar energy through adaptive and responsive behavior according to environmental changes [28].

3.5 Responsiveness

Responsiveness which means giving response to environmental forces and changes, is recognized as one of the living characteristics. A building can response to environmental changes and stimuli in different ways. Some of these responses can be described as opening and closing envelope to the outside environment to control energy and material exchange, mobility, changing
material properties, changing space features and qualities, changing structure and form [29, 30].

Making reactions to environmental changes is through using sensors and signals to gather data and diagnose the changes and make the system to response in a passive or active way. Responses to environmental changes and stimuli can happen in different scales and in different time frames with different speeds. The scale of responses can differ from envelope components to the whole building and even to number of buildings. These responses can be classified in different categories as displacement, mobility, intelligence and learning and transformation, which can be summarized in two main groups as dynamic and static. Dynamic group creates responses through dynamic behavior as movement, rotation and so on. While static responses are through material characteristics and transformation in material properties. Comparing these two main categories, they can be called as active and passive responses as well. Static group basically has passive behavior, but dynamic behavior is active and energy consuming. Another factor which makes a difference between these two main groups is the controlling factor. Dynamic systems mostly have a controlled reaction and response, but in static one, there can be no controlling over the behavior of the system. Responses to environmental changes can be through mobility and transformation and in different ways as illustrated in Fig. 11.

Mobility and movement is one of the natural reactions of organisms to environmental stimuli and changing conditions. For buildings, some elements of envelopes can be designed to be dynamic through movement as a response to changing conditions of the environment, such as louvers, canopies, retractable and moving roofs and walls. Kinetic façades are other examples of applying dynamic components in the envelopes, though a whole building motion is rare in real projects [30, 31]. The Heliotrope House in early 90s designed by German architect Ralph Disch, is a moving house which rotates according to Sun direction in the sky. Also, the project of Cambridge arcade which was designed by Arup and association using biomimetic consultations in 2003, can create movements in the roof by using air flows.
Transformation can be another response to environmental changes through changing material characteristics such as transparency, color, phase and visibility. Phase change materials response to thermal changes by transforming their phase from liquid to solid or vice versa and smart glass transforms from transparent to opaque through changing its material nanostructure using electricity.

A common way to change the transparency of facades is to add a semi-transparent or opaque layer to them. Another strategy is to use thermo chromic glass which darkens when applying a voltage to it. Aero Dimm project is a pneumatic façade which has the ability to change its color inspiring from octopus changing color skin. Its mechanism is so that between two layers of façade, the elastic membrane changes its volume and distance of layers according to inside air pressure and the changing distance between two layers cause a change in façade color. Ventilation pipes can be integrated into internal membrane. Phase change materials react to temperature changes. Also shape-memory alloys, flexible ceramics and polymers react to temperature changes. These alloys in low temperature are amorphous and rigid while in high temperatures transform to their original form in the state of maximum carbon solubility. Piezoelectric materials would change shape by imposing stress and impact. These materials would create electric potential under mechanical stresses. Chemical actuators transform through chemical reactions. Optical fibers benefit from electromagnetic wave properties to measure quantities like temperature, pressure and so on which are good sensors in this case [32]. Thermo-elastic materials and electro-active polymers act as muscle nerve actuators. Artificial protein stretches in low temperatures and shortens in higher temperatures so they can change the shape and can do work and create movement. Smart materials have many advantages for enhancing thermal efficiency of building envelopes, but their functions are limited to a specified range of climatic conditions and restricted reactions. Thermo-bimetal materials which can convert heat to mechanical movement are being examined in south California University by Doris Song to create self-loading envelopes which can open the pores for natural ventilation without depending on external
source of energy. This system is based on a laminated surface from different metals which have different thermal expansion coefficients. When the surface exposes to heat, it causes tension and transformation in it because of different expansion length of various metals. If the temperature decreases and heat source is omitted, the surface will go back to its original form [33]. Applying electro-active polymers in dynamic building envelopes provides high potential for their transformations and their rapid elastic ability. These polymers change size and shape when they are influenced by electric field. Manuel Kreutzer in Zurich Poly-Technique University has designed a prototype of a kinetic envelope using software. The prototype consists of a unit of self bearing multilayer from elastomeres that transforms when connecting to electricity. Architects, Soo-in Yang and David Benjamin developed a transparent smart material that is named living glass and is built from polymer arrays as gills connected with sensors. The system reacts according to human presence and carbon dioxide in the environment and through opening and closure and facilitates air penetration into indoor to control the air quality inside building.

Most of the present reactive systems in buildings are based on simple physical sensors. Sensors typically can be classified into active and passive sensors. Active sensors consume energy for their function and they are used in many technological instruments. Sensors can gather all the data about temperature, humidity, air pressure, light intensity, movement and so on. Most of the sensors in the buildings are passive sensors which gather data in a passive way without consuming energy and just for transforming the gathered data to electric signals they behave in an active way. Passive sensors do not need regulative processes and they do not process the data, but the changes in physical conditions cause them to response autonomously. These sensors use their material properties for making responses, through changing properties according to environmental changes and making reactions.

Decentralized sensors need to integrate the sensing elements into structural system of envelopes. One of the disadvantages of passive sensors is that their reactions to environmental changes cannot be controlled and their degree and time of reactions can not be adjusted. Actually, their responses depend on physical parameters with a specific threshold. Hybrid systems take the advantage of low energy consuming characteristic of passive systems with controlling benefit of active systems. Active systems act according to the data that is received and process it to decide the suitable response. Responsiveness can be categorized based on different factors, as shown in Fig.12.

Though most of these systems are in research and development phase, there are some rare built samples, such as intelligent façade of Media-Tic building in Barcelona, Spain. The façade consists of a pneumatic covering system made from heat resistant plastics (ethylene tetra fluoro ethylene). Its pneumatic mechanism is activated by optical sensors that react automatically to solar radiation. The envelope is made from three transparent layers with air gaps between layers. Blowing air into gaps would increase its thermal insulation and with exhausting air through suction the layers would attach to each other and provides shade and opaque layer.

3.6 Self-regulation

Self-regulation in living systems is the ability to moderate and preserve physiologic balance inside a system against the external disturbance and changing conditions. The interpretation of this characteristic in buildings can be through passive or active self regulations. Building envelope is a part of the whole building system which is connected to other building subsystems and elements so that the sensors are connected to each other and all of them are controlled by the management system of building which is the same as brain. Self-regulation can be achieved through controlled responses to changing environmental conditions. The main components of a responsive system
is introduced in Fig. 13. Also, the relationships between these components are illustrated in Fig. 14. For a controlled reaction, there is a need for control systems which process the data. A real responsive building would react to a wide range of environmental changes with various types of reactions, as what living systems do in nature [34]. In the virtual world of computer softwares, new designs introduce a large number of different reactions which a building can have to environmental changes but in real world few
buildings have responsive characteristics. For a responsive building, having control over environmental changes is very important so physical sensors are needed to gather data from the environment and a processor unit is necessary to detect the changes from the data gathered by sensors. The processor unit would define the type of response and its amount. So the basic condition to have reaction is to have the ability to sense and sensibility. A hierarchical controlling system or controlling in several levels is used more in complex and complicated systems. Most of the complex systems include many interactive subsystems. The central controlling system should be divided and decentralized to ensure more effective function of it. Hierarchical controlling systems contain several controlling subsystems which connect to each other and function in a hierarchical way [35].

Adaptability to environmental changes and making changes according to user needs, caused buildings to move more towards living systems. The application of the words “smart building” and “smart envelopes” mainly refers to buildings with static response behavior in its systems [36]. But intelligent building envelope is used for the buildings with ability to understand the environment and can decide how to respond to environment on time [37]. Responding on time is important for an intelligent building.

4. Conclusion

Intelligent envelopes would be essential parts of future buildings. Building envelope can be designed somehow to be a part of the metabolism and morphology of the whole building system and connects to other parts through management system of the building. This way of looking at building envelope would lead to change in design views and methods fundamentally so that it necessitates interaction and collaboration of architects with other engineering fields such as mechanic engineering, computer and electrical engineering and so on [2]. Also, application of new materials in building envelopes would lead to enhance their functionality. Manufacturing technologies also should be developed to achieve high performance systems with lowest costs. Energy generative elements can be integrated into envelopes to generate and convert the energy needed [38].

The strategy of integration of various functions into building envelope with application of new materials also designing buildings as systems which have interaction and exchange with the environment caused a basic change in the definition of building envelopes as subsystems of the whole building system and its boundary to the surrounding environment. Considering building envelope as a subsystem of the whole building
system, puts more emphasis on its important role for exchanging energy and material and information with the environment. As buildings are third cover for human, they must help creating comfort conditions inside the building which need to regulate their inside conditions for different user needs and desires. This has led to more adaptive, responsive and controlled behavior for building envelopes. Future envelopes can be categorized into two main types as smart and intelligent as shown in Fig. 15. Both of them have some characteristics as living systems. Also, environmental problems and energy crisis create a movement toward imitating living systems and realization of more living characteristics in the future envelopes to be more energy efficient and have more optimized functionality.

References


Evolution of Building Envelopes through Creating Living Characteristics

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