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A Fundamental Study on the Modularization of Intelligent Skin Design

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Abstract

Modern societies are paying more and more attention to energy consumption. Nations are implementing and systemizing policies on low carbon green growth to reduce greenhouse gas emission while various studies are being conducted on eco-friendly architectures and energy reducing technologies in relation to buildings. In Korea, since 39% of the total energy consumption is accounted for by buildings, the energy consumption issues of buildings have global implications that are linked to other areas such as the growing population, enlargement of buildings and technological developments. To address issues related to the energy consumption of buildings in the modern era, the importance of building skins has been emphasized since it has the potential to make a direct impact in terms of reducing energy, and due to the developments of IT which provides a wireless network environment, intelligent technologies such as the IOT are being widely expanded, and building skins that were once regarded as fixed exteriors are now adapting to the environment in the current era. Therefore, this study aims to examine building skins that have great potential as a high value added industry in the near future and present fundamental data on intelligent skin design and the optimized types that can be adopted to intelligent skin design by ascertaining the characteristics and planning factors of each category by studying a variety of cases from home and abroad.

Keywords: *Intelligent skin, Surface design, Smart material, Intelligent technology, Ecological building*

1. Introduction

1.1. Background and Purpose of Study

1/3 of the total energy consumption worldwide can be attributed to buildings and according to the data from the United States Department of Energy (DOE), 39% of the total energy consumption of the nation is allocated to buildings [1]. Therefore, we need to devise technologies and conduct studies to achieve efficient energy reduction in the future. Also, due to many factors including the enlargement of buildings and the constructions of skyscrapers, the energy consumption of buildings has become a pressing issue. Especially, the skin of the building is where most of the energy loss occurs and the form and the composition of the skin has a significant effect on the ambience of the environment and the health of the occupants [2]. Accordingly, the importance of the

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building skin of an architecture is growing due to its direct impacts on energy reduction and the building skin is now increasingly thought of as not just a fixed exterior of a shell that surrounds an area but something that autonomously adapts to changes in the environment through intelligent technologies such as IoT with the development of IT and wireless networks. It is anticipated that intelligent skins can make a contribution to addressing global issues like reducing energy consumption.

Therefore, this study aims to research building skins that have great potential as a high value added industry in the near future and present fundamental data on intelligent skin design and the optimized types that can be adopted to intelligent skin design by learning about the characteristics and planning factors of each category by studying a range of cases from home and abroad.

1.2. Methods and Process of Study

This study is a fundamental study on intelligent building skins and will provide comprehensive results by defining the definitions and the spectrum of intelligent skins; the study also conducts researches on adapted technology factors and various architecture cases. The method of this study is shown in Figure. 1.

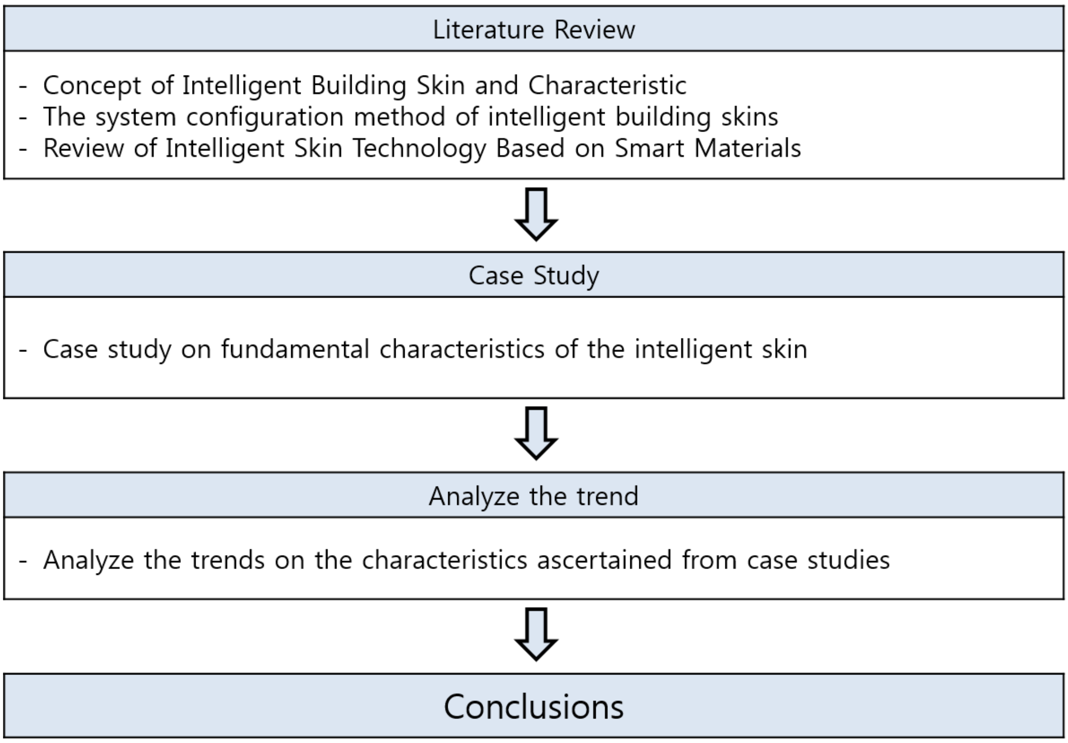

Figure 1. Study Flow Chart

2. Theory Study of Intelligent Building Skin

2.1. Concept of Building Skin and Characteristic

According to the dictionary, the building skin is a term used to describe ‘the exterior of a building that surrounds the interior volume.’ So the building skin is designed to react to outdoor environmental conditions and to meet artificial requirements such as safety and security. Therefore, the skin has to maintain the balance between indoor environment and the outdoor environment while protecting the inside from the outer environment. [3]. Also, the building skin is literally the skin of the building because it is composed of

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functional factors and their characteristics. In other words, the building skin is an installation that separates the interior and exterior while connecting the two [4].

2.2. Concept of Intelligent Building Skin and Characteristic

An intelligent building skin means the planned installation of a building skin that used to be a fixed exterior in order to mimic the intellectual abilities and the activities of a life form [5]. In addition, the intelligent building skin surrounding the interior of a building should be able to perform on the basis of its independent intelligence while controlling and managing the indoor environment such as light, heat, sound, ventilation and air conditioning through user control and the completed form of an intelligent building skin should be able to autonomously react and adjust to the changes in the external environment based on learning abilities that resemble the biological tissues of a human to maintain pleasant indoor environments and achieve energy efficiency [6]. The intelligent building skin is expected to possess differentiated effectiveness compared to existing general building skins from planning to function, design and the characteristics. The characteristics of intelligent building skins and general building skin are listed in Table. 1.

Table 1. Characteristic of Building Skin and Intelligent Building Skin

	Building skin	Intelligent building skin
Plan	Architecture specialists	Cooperation with diverse engineers
Function	manual control	auto control after initial command
Design	fixed skin	dynamic skin reacting to environmental changes
Advantages	Relatively low initial cost	High initial cost, but eventually reduces costs due to reduction of environmental burden and energy consumption

2.3. The System Configuration Method of Intelligent Building Skins

The intelligent building skin system is composed of sensor, operator, and controller. The sensor senses the environmental information and converts it into a notable signal and sends it to the controller. The operator deduces the most effective adaptation method among diverse variables. Finally, the controller performs the physical operation and prudent reaction and responds to the environment by following the command ascertained from the operator. Figure. 2 is the operating method of the intelligent building skin.

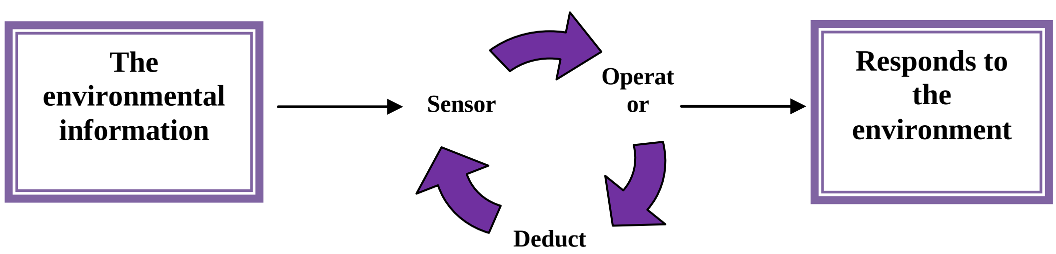


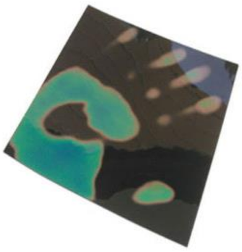
Figure 2. The Operating Method of the Intelligent Building Skin

2.4. Review of Intelligent Skin Technology based on Smart Materials

The smart material is a new material concept that responds to the surrounding environment like a living creature that is different from existing materials that need to be manually operated. A smart material has been reprocessed to react with high sensitivity to a specific stimulus so it can be significantly utilized to realize intelligent building skins with its remarkable reactivity without any help from specific software or additional installation [7]. The intellectual ability of a smart material depends on its ability to change its characteristics according to diverse conditions and flow of time, and the smart material could undergo multiple changes in its characteristics according to its performance [8]. It was adapted in the medical sector in its early stages and recently, it has been adapted in architectures, which implies that the concept of intelligent architecture is being generalized.

The function of a smart-material-based intelligent building skin is determined by the characteristics of the smart material so its ability to respond to diverse environments is lower than that of computer systemized intelligent building skin utilizing sensors, operators and controllers. However, the smart materials have great potential with regard to the intelligent building skin industry because its growth potential is boundless, and it requires simple design routes with relatively low cost, and due to the fact that it is highly compatible with computers [5].

Table 2. A smart Material Applied to Intelligent Building Skin

Material		Picture	Characteristic
Shape memory alloy smart material			Remembers its original shape and when deformed returns to its pre-deformed shape when heated.
Electric active polymer smart material			Contracts when a voltage is applied
Photochromic smart material	**photochromic material**		Changes color under exposure to light
	thermochromic		Changes color or opacity in relation to temperature

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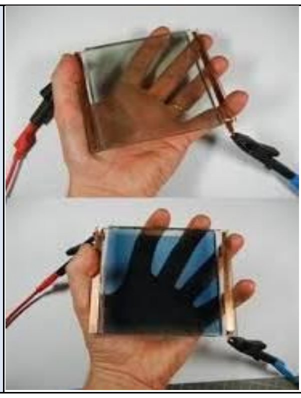
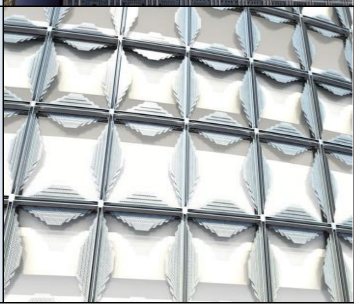
	electochromic		Changes color or opacity when a voltage is applied

A smart material changes under diverse stimulus and can be categorized under the types of stimulus and it is divided into materials that change under natural conditions and artificial stimulus as shown in Table. 2. A representative example of a smart material that changes under natural conditions is the shape-memory alloy which is an alloy that "remembers" its original shape and when deformed returns to its pre-deformed shape when heated. A piezoelectric material is a smart material that changes under artificial stimulus. A piezoelectric material contracts when a voltage is applied. And chromogenic systems change color in response to electrical, optical or thermal changes. The value of these types of smart materials will increase since they can be utilized in the intelligent building skin field.

3. Intelligent Skin of Case Studies

The analysis of intelligent skin cases shows the method of displaying intelligence with respect to the responsiveness, variation, and usefulness, which are the basic properties of an intelligent building skin. Table. 3 shows the methods of displaying intelligence analyzed from the cases of intelligent skins.

Table 3. Intelligent Skin of Case Studies [9]

Building Name	Picture	Reactivity	Variability	Utility
Institut du Monde Arabe (I.M.A), France, 1987		Response to solar radiation.	Variation of the opening area of the skin in the form of an aperture.	Saving of cooling energy consumption, amenity in indoor light environment.
Helio Trace Robotic (H.T.R), 2010		Response to solar radiation.	Combination of an aperture shape and a protrusion.	Energy saving of 42%.

Tower of wind, Japen, 1987		Response to wind and sound.	Bulbs turned on in response to wind and sound.	Mutual communicatio n effect.
Flare Shifting Facade (F.S.F), Germany, 2006		Response to solar radiation and humidity.	Variation of protrusion angle in response to solar radiation.	Utilization of solar energy, Improvement of indoor light environment.
GSW, Germany, 1999		Response to solar radiation.	Variation of the skin area by axis rotation in response to solar radiation.	Saving of heating and cooling energy. Energy saving of 50% in comparison with existing system.
City of Justice, Spain, 2011		Response to solar radiation.	Folding and unfolding of skin in response to solar radiation.	Saving of heating and cooling energy. Improvement of indoor light environment.
Al-bahr towers, Arab, 2012		Response to solar radiation.	Variation of skin opening in the shape of an aperture.	Energy saving of 20% in comparison with existing system.
CJ r&d Korea, 2012		Response to solar radiation.	Folding and unfolding of wrinkled skin.	Improvement of indoor light environment. Saving of lighting energy.

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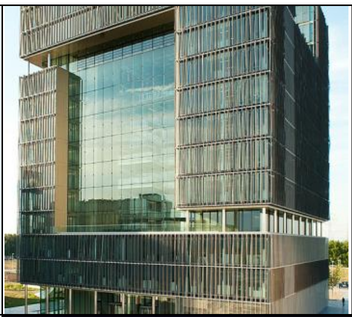
Thyssen Krupp Quarter Q1 Germany, 2010		Response to solar radiation.	Transformation to a shade by axis rotation in response to solar radiation.	Improvement of indoor light environment. Saving of heating and cooling energy.
Torre Agbar, Spain, 2007		Response to temperature change.	Variation of horizontal louver by axis rotation.	Improvement of indoor light environment. Saving of lighting energy
Milwaukee Art museum, USA, 2001		Response to climate change	Transformation to a shade by axis rotation in response to solar radiation.	Improvement of indoor light environment. Saving of heating and cooling energy

The changes of the skin depend on the formation of the subject and the system. For example, the skins that have reactivity to sunrays will respond to exterior stimulus that will create changes in the form of apertures or rotational positions. These changes will induce the diverse variability of the building skin and also affect the indoor environment.

Through the analysis of intelligent building skin cases we will deduce an analysis standard in types of intelligent building skin and observe trends by analyzing the distribution of such intelligent building skins through the evaluation table.

Table 4. Trend Analysis of Intelligent Skin

●: Apply

Building Name	**Reactivity**				
	Reacting type		**Sensor recognition**		
	Physical reaction	**Chemical reaction**	**Sun**	**Temperature**	**etc.**
IMA	●		●		
HTR	●		●		
Tower of Wind	●				●
FSF	●		●		●
GSW	●		●		
City of Justice	●		●		
Al-bahr tower	●		●		

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Cj R&D Center	●		●		
Thyssen Krupp Quarter Q1	●		●		
Torre Agbar	●		●		
Milwaukee Art museum	●		●		●

Name	Variability			
	Rotational position	Contraction/expansion		None
		Sliding	Apertures	etc.
IMA			●	
HTR		●	●	
Tower of Wind				●
FSF		●		
GSW	●	●		
City of Justice			●	
Al-bahr tower			●	
Cj R&D Center			●	
Thyssen Krupp Quarter Q1	●			
Torre Agbar	●			
Milwaukee Art museum	●			

Name	Utility					
	Indoor environment			Reduce energy		
	Light	Heat	Air condition	Light	Cooling	Renewable
IMA	●	●			●	
HTR	●	●			●	
Tower of Wind						
FSF	●	●	●			●
GSW	●	●			●	
City of Justice	●	●			●	
Al-bahr tower	●	●			●	
Cj R&D Center	●	●			●	
Thyssen Krupp Quarter Q1	●	●		●	●	

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Torre Agbar	●	●		●	●	
Milwaukee Art museum	●	●			●	

As shown in Table .4, most physical reactions due to sunrays are in regard to reactivity and apertures in variability, indoor environment, light and heating conditions and reduction of cooling energy, so we can conclude that since the purpose of intelligent building skin is to reduce indoor energy consumption by adapting to the outdoor environment as a composition factor of intelligent building skins, many of them were designed for environments that have great effects on indoor energy consumption such as light, heating, and reduction of cooling energy.

4. Conclusions

There is increasing interest about energy consumption in the modern era which automatically leads to greater interest in CO_2 emission. Among forms of energy consumption, 39% of energy consumption is attributable to buildings. Therefore, we need to devise technologies and conduct studies to effectively address the matter of reducing energy consumption. The building skin is responsible for most of the energy loss and its formation and composition is responsible for energy reduction and the pleasantness of the indoor environment. Therefore, the importance of the building skin will be increasingly recognized in the future. Also the development of IT and wireless networks, intelligent technologies such as IOT is expanding and building skins that were once merely thought of as a fixed exterior are now regarded as intelligent and able to adapt and respond to the environment. It is anticipated that the intelligent building skins will make a great contribution to maintaining pleasant conditions indoors and reducing energy consumption unlike current building skins.

Therefore, we conducted a case analysis and examined the trends of intelligent building skins by reviewing preceding studies and the result of this study shows that sunrays induced the greatest physical reaction in terms of reactivity and the most changes in formation occurred in apertures in terms of variability, and in terms of utility, its purpose being to improve light and heating conditions while reducing cooling energy consumption. Therefore, we can conclude that the trend of intelligent building skins is to effectively control the amount of sunlight with awning technology and improve indoor light and heating conditions and the chief goal is to reduce cooling energy consumption.

In upcoming studies that utilize this study as fundamental data regarding intelligent building skin design module to realize intelligent building skins, we must review the validity of the proposal and the system of intelligent building skins designed to control light as outlined in the case studies presented in this study.

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