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Design Strategy for Green Residential Building in Solar Decathlon
- Based on Case Study of Residential Building in Solar Decathlon

Yoon, Sung-Hoon*

** Corresponding Author, Dept. of Architecture, Cheongju Univ., South Korea (shyoon@cju.ac.kr)*

ABSTRACT

The Purpose of this study is to analyze the green design strategies in residential building, based on case study of Solar Decathlon in USA. This study could provide the basic reference data and theocratical foundation for finding new green design strategies and applicability of green design for korea. The Solar Decathlon is an green design competition that challenges collegiate teams to design, build, and operate the green residential building with optimal energy production and maximum efficiency. As a result of the analysis of this study, the green design strategy is identified and analyzed design issues related in energy, materials, and indoor/ outdoor environment. Also, it is useful to find best green design strategy with more economical and environmental benefits presented by renewable energy and design solutions. This study is based on selected 18 green housings of Solar Decathlon from 2002 to 2013. This result is helpful to understand the green design strategies for green residential building's design of modern residential building, and expect future green residential building design approach

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1. Introduction

1.1. Background and Purpose

Since the Declaration of United Nations Conference on the Environment for Environmental Sound and Sustainable Development (ESSD) in 1992, environment-friendly approach has settled down in the field of residential building construction, emphasizing sustainable development. In Particularly, environment-friendly construction has kept developing in line with residents' needs and demand for pleasant and healthy living space where they can reduce the consumption of energy and minimize environmental load remarkably. Under the circumstance in which people are more aware of the seriousness of global environment deterioration and the importance of sustainable development and management, studies have kept being conducted to save energy and reduce environmental load by adopting various planning factors of environment-friendly construction as well as such construction technologies and applying them to architectural design.[1)2)]

Based on the case studies on the green residential buildings presented in Solar Decathlon, which is U.S. environment-friendly residental building design competition, the present study is aimed to provide basic data for understanding possible approaches to applicable environment-friendly residental building design. With this effort, this study expects to overcome the limits of environment-friendly residental building design and find design strategy and its applicability necessary to develop new and suitable environment-friendly architecture design for domestic market.

1.2. Method and Scope

For research object, this study targeted the residental buildings submitted in U.S. Solar Decathlon from 2002 to 2013 and finally chosen 18 residental buildings that have been highly evaluated 6 times. With them, the present study attempted to understand the planning factors of environment-friendly construction and such construction technologies and performed case studies to find an architectural approach to environment-friendly residental building and design strategy for it. Analysis was divided to 6 areas: exterior environment, passive design planing factor, use of renewable energy, environment-friendly technology factor related to the reduction of energy load, construction material and indoor environment.[3)]

From the analyses, this study tried to derive the design strategy and architectural characteristics of environment-friendly residental construction observed in the residential buildings of Solar

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1) Kibert, C. J., Sustainable Construction: Green Building Design and Delivery, John Wiley & Sons, Hoboken, 2005
2) Vivienne Brophy and J Owen Lewis, A Green Vituvius - Principles and Practice of sustainable Architectural Design, Second Edition, Earthscan, London UK, 2011
3) 윤성훈, 현대건축에 나타난 그린빌딩 디자인의 특성 연구-미국 친환경 건축물 사례분석을 바탕으로, 청주대학교 산업과학연구소 산업과학연구 제30권 1호, 2012 // (Yoon, Sung-Hoon, "Green Building Design in Contemporary Architecture, Based on Case Study of Green Buildings in USA", Journal of Research Institute of Industrial Sciences, Vol. 30, No1, Cheongju Univ., 2012)

Decathlon. Based on the findings, the present study aimed to propose basic data with which a new method for the construction of environment-friendly residental building and an approach to and strategy for such design applicable to our society and domestic settings and has significance in that the results of this analysis can help understand the design strategies for green residential building for Korea.

2. Theoretical Review of Solar Decathlon

2.1. Solar Decathlon

Solar Decathlon is an biennial occasion hosted by U.S. Department of Energy from 2002 (It has been held six times, every two years since 2002: 2002, 2005, 2007, 2009, 2011 and 2013). It is an international competition in which collegiate teams participate to design, build, and operate green residential building for themselves and their works are evaluated and awarded. Their works are evaluated for the optimal blending of environment-friendly architecture technologies, best energy efficiency and production, low cost of construction (affordability), construction feasibility and post-management. Particularly, consumer appeal is the key factor for design evaluation. After evaluation, the works are open to general public in form of exhibition, which is thus led to practical use for education, distribution and expansion of green residential buildings. Participating teams are composed mainly of experts including students, researchers and professors in line of architecture and/or engineering.

Fig. 1. Public Opening Day: Solar Decathlon by U.S. Department of Energy, USA.

Since the green residential buildings of Solar Decathlon are assessed for design, construction and operation on site, they should satisfy all aspects of economic feasibility, energy efficiency, constructability, innovative design and esthetics. Especially, this competition program places emphasis on sustainable development, so it aims to propose green residental buildings that can reduce environmental load through the minimization of the use of resources and production of construction wastes by maximizing the life cycle of a building; to suggest the architectural direction to attractive and effective green residential buildings through optimal blending of environment-friendly planning factors and technological elements of passive design factors; and to educate students approach to sustainable architecture and practical application.[4)5)] Especially, the value of this program is magnified as the green architectural education that provides students with opportunity to develop substantial on-spot skills and integrated design capability by allowing them to design green architectural environment/facility, construction structure and materials necessary to make a real residential space and construct and operate it by themselves, beyond the boundary of school curricula that largely focus on planing and design. For general public, in addition, the concept and meaning of green residential building, which have been superficially understood, can be more precisely conveyed. Furthermore, Solar Decathlon finds itself another significance that the submitted works promote and spread the functions of environment-friendly residential buildings, excellence in design, convenience, technological applicability and applicability of innovative design. In Solar Decathlon, the direction and approach to future green architecture can be predicted and a chance can be given to overcome the limitations to design for environment-friendly residential buildings. Companies related to the materials, facility and structural system for green construction are involved in Solar Decathlon as sponsor and therefore it provides useful opportunity that green architectural work can be tested for applicability, promoted and met with consumers directly. Since 2002, 112 collegiate teams have participated in this design competition and this competition became widely known to the world for as a program for a new environment-friendly architectural program. Thanks to its popularity, Solar Decathlon has expanded and newly organized from 2010. Apart form U.S. Solar Decathlon, Solar Decathlon in Europe is in operation for European countries. In 2013, Solar Decathlon China 2013 was held in China and Solar Decathlon Latin America and Caribbean is going to be added and run from 2015 for Latin America and Caribbean regions.

2.2. Work Assessment of Solar Decathlon

The participants in Solar Decathlon go through 10 evaluations by judges and a qualitative assessment with a measuring device: architectural planning and design; constructability in terms of

4) U.S. Department of Energy, Solar Decathlon 2002, 2005, 2007, 2009, 2011, 2013, <http://www.solardecathlon.gov>

5) 최영오, 안용한, Viginia Tech Lumen Haus를 통해 본 친환경 주택의 실험, 대한건축학회지, 건축, 2010 // (Choi, Young Oh, Ahn, Yong Han, "The Experiment of Sustainable House through LumemHaus in Virginia Tech", Review of Architecture and Building Science, Vol. 59 No. 1. Serial No. 428, Architectural Institute of Korea, 2010)

engineering; energy efficiency of building; energy evaluation of building; indoor comfortability of building; functional aspects of residential building; indoor communicative factors; marketability of design (design practicability); innovative design; and sustainability of building. And the scores obtained from the 10 assessment areas are averaged. Looking into specific composition of the assessment in Solar Decathlon, it consists of 1,000 score in total: judge evaluation (500) and measuring evaluation (500) by measuring instrument. Sub-items of evaluation are shown in Table 1.

Table 1. Evaluation Factor for Solar Decathlon

	Evaluation Factor
Evaluation Area (Totals: 1,000pt)	· Architecture (100 Points) · Market Appeal (100 Points) · Engineering (100 Points) · Communication (100 Points) · Affordability (100 Points) · Comfort Zone (100 Points) · Appliances (100 Points) · Home Life (100 Points) (Lighting, Hot Water, Home Electronics, Dinner Party, Movie Night) · Commuting (100 Points) · Energy Balance (100 Points) (Energy Production, Energy Consumption)

3. Research Object and Analysis

3.1. Residential Building for Case Study

A total of 18 residential buildings of Solar Decathlon were selected for case study: 3 highly evaluated residential buildings from each of 6 Solar Decathlon competitions (from 2002 to 2013,every two years).

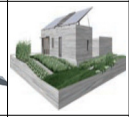
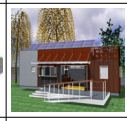
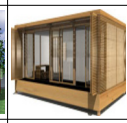
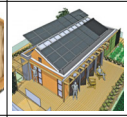
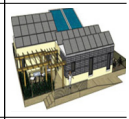
Table 2. Case Residential Buildings for Analysis

Year	Case Buildings (Total 18 Case Buildings)		
2002	U. of Colorado	U. of Virginia	Auburn Univ.
2005	U. of Colorado	Cornell Univ.	Cal. Polytechnic State Univ.
2007	Technishe Univ Darmstadt	U. of Maryland	Santa Clara Univ.
2009	Technishe Univ Darmstadt	U. of Illinois Urbana-Champaign	Santa Clara Univ.
2011	U. of Maryland	Purdue Univ.	Victoria U. of Wellington
2013	Vienna Univ. of Technology	U. of Nevada Las Vegas	Czech Technical Univ.

Table 2 shows the list of collegiate teams that submitted the residential buildings selected as case study object in this study. The method and scope of research on those cases are as describe in the previous section.

Analysis was carried out on the selected residential building focusing on 6 evaluation items: outdoor environment; passive design planning factor and use of renewable energy such as solar heat, solar light and geo-thermal heat; use of rainwater and environment-friendly technology factor to reduce the use of water; environment-friendly construction material; and indoor environment.

Table 3. Green Building Analysis I based on Case Study

		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
Team Name		Univ. of Colorado at Boulder	Univ. of Virginia	Arburn Univ.	Univ. of Colorado at Boulder	Cornell Univ.	California Polytechnic State Univ.	Technishe Universitat Darmstadt	Univ. of Maryland	Santa Clara Univ
Building Image										
Year		2002	2002	2002	2005	2005	2005	2007	2007	2007
Building Orientation/ Building Shapes		South-facing Gable Roof	Rectangle Shape Gable Roof	Trapezoid Shape, Gable Roof	Rectangle Shape	Rectangle Shape, South-facing	Rectangle Shape, South-facing	Rectangle Shape, South-facing	Rectangle Shape, South-facing	Rectangle Shape, South-facing
Outdoor Env.		·	·	·	·	Biotope	·	·	Biotope	·
Energy	Atrium	·	·	·	·	·	·	·	·	·
	Top-Lighting	○	·	·	·	·	·	·	·	·
	Lighting Shelf	·	·	·	·	·	·	·	·	·
	Shading Device	·	○	○	·	○	○	○	·	○·
	Renewable Energy	Solar E. Generation/ Solar Heat	Solar E. Generation/ Geo-thermal	Solar E. Generation/ Solar Heat	Solar E. Generation/ Solar Heat	Solar E. Generation/ Solar Heat	Solar E. Generation/ Solar Heat	Solar E. Generation/	Solar E. Generation/ Solar Heat	Solar E. Generation/ Solar Heat
Water	Rain-Water Collecting Sys.	·	·	·	·	·	·	·	○	·
	Water Saving Devices	○	○	○	○	○	○	○	○	○
Green Materials		High-Performance Insulation	Wood Materials	Reuse Materials/ Insulation Structure	BIO-SIPS Insulation Materials	·	·	Wood Material/ Double Facade	·	·
Indoor Env.	Max. Daylighting	·	·	·	·	○	·	○	○	·
	Max. Natural Ventilation	○	·	·	○	○	·	○	○	○

3.2. Environment-Friendly Architecture Design Strategy of Solar Decathlon

As described above, 18 entry works in Solar Decathlon were examined for case study and the results are summarized in Table 3 and 4 as follows. According to the operational procedure of Solar Decathlon, the entire participants plan and design a work and construct its parts in advance and assemble them during the occasion on a designated site for completion. Therefore, constructability on site is more important than other buildings. The strategies for environment-friendly residential design are as follows.

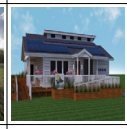
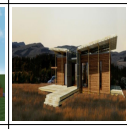
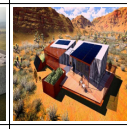
First, as mentioned earlier, The design of Solar Decathlon building is materialize, placed and shaped in consideration of constructability and exterior environment on site, rather than with a combination of a simple idea of green architecture and related technology. Second, it is active introduction of passive design and active use of renewable energy. Because energy should be generated to operate the building within the space as much as it can be, the building is designed so that it can use energy most efficiently and reduce environment load. Third, various green construction materials are actively used. A variety of new or materials completed or still in development are employed for the building construction. Especially, wooden materials are more used for its excellent on-site constructability and environment-friendly property as interior and exterior finish.

Fourth, various attempts and efforts are made not only to create comfortable and pleasant indoor environment by focusing on thermal, auditory, light and indoor air environment, which increase the satisfaction and functions of residence, but also on energy generation and energy efficiency. Fifth, the green residential buildings are attempted to avoid existing uniformity and be innovatively designed. Each of those design strategies derived from the cases is presented as follows.

3.3. Building Arrangement and Shape Suitable for Constructability and Outdoor Environment

Due to the characteristic of Solar Decathlon competition, buildings are constructed on the site of exhibition but they are designed to minimize the destruction of peripheral environment. Most of the research objects (buildings) are designed to maximize energy generation within a building and face south to take advantage of sunshine/solar radiation and natural ventilation. In addition, they are designed in square shape and their roof are various and masses are overlapped on eastern and western axis to avoid uniformity and monotony. Solar-cell panels attached with PV Cell are used as main design factor which are materialized through gable roof or saw-tooth roof that is better for the production of solar energy than flat roof. Besides, landscaping is also an important factor to create more comfortable and pleasant outdoor space and

Table 4. Green Building Analysis II based on Case Study

		Case 10	Case 11	Case 12	Case 13	Case 14	Case 15	Case 16	Case 17	Case 18
Team Name		Technishe Universitat Darmstadt	UIUC	Santa Clara Univ./ California. College of Art	Univ. of Maryland	Purdue Univ.	Victoria Univ. of Wellington	Vienna Univ. of Technology	U of Nevada, Las Vegas	Czech Technical Univ.
Building Image										
Year		2009	2009	2009	2011	2011	2011	2013	2013	2013
Building Shapes		South-facing Cube Shape	Rectangle Shape, Gable Roof	Bended Shape, South-facing	Butterfly Roof, Rectangle Shape	South-facing Gable Roof	Butterfly Roof, South-facing	Rectangle Shape	Rectangle Shape	Rectangle Shape
Outdoor Env.		·	·	Biotope	·	·	·	·	·	·
Energy	Atrium	·	·	·	·	·	·	·	·	○
	Top-Lighting	·	·	·	·	·	·	·	·	○
	Lighting Shelf	·	·	·	○	·	·	○	·	○
	Shading Device	○	·	·	○	○	○	·	○	·
	Renewable Energy	Solar E. Generation/	Solar E. Generation/	Solar E. Generation/ Solar Heat	Solar E. Generation/ Solar Heat	Solar E. Generation/ Geo-thermal	Solar E. Generation/	Solar E. Generation/	Solar E. Generation/ Solar Heat	Solar E. Generation/ Solar Heat
	Rain-Water Collecting Sys.	·	○	·	○	·	·	·	·	·
	Water Saving Devices	○	○	○	○	○	○	○	○	○
Green Materials		Vacuum Insulation	Wood, Bamboo	Wood	Wood	Biowall, Recycle wood	Wood	Fiber Shading	Insulational Structure System	Wood, Wood-fiber Insulation
Indoor Env.	Daylighting	○	·	○	○	·	○	○	·	·
	Natural Ventilation	·	○	○	○	·	○	○	○	·

minimize radiant heat from neighboring land. Therefore, the buildings are assigned so that they can well agree with peripheral environment, which is meant to convey the meaningfulness of environment-friendly residence.

Fig. 2. Butterfly Roof for Daylighting and Ventilation, Team University of Maryland (Left), Flexible Shading System with Oak, Team Technische Universitat Darmstadt (Right)

3.4. Active Use of Passive Design and Renewable Energy

Although the buildings are designed in a simple arrangement along eastern and eastern axis, which enables to actively cope with the thermal load inside and outside of buildings and facilitates natural ventilation in consideration of external environment, such passive design planning factors as BIPV system connected to the building shape and the roof to use solar light and heat easily available around, various shading devices including light shelf, ceiling and louver for building facade are employed.

In particularly, as seen in Figure 2, the residential building of Team University of Maryland is characterized with a butterfly swing-shaped roof of which both sides are lifted to maximize the ventilation and natural lighting of the residential building. Team Technishe Universitat Darmstadt uses oak wood to introduce the shading device of flexible dual skin. It has also a function to protect privacy and block external solar heat that increases the thermal load of the building. In such efforts, we can sense both functional and beautiful facade of the building.

Fig. 3. Solar Energy Generation System with PV Cell, Team Cornell University (Left), Gable Roof with BIPV System, Team University of Illinois, Urbana-Champaign (Right)

In the buildings, renewable energy facility and high efficiency facility are integrated and embodied. Since the competition weighs importance on the use of renewable energy, solar energy generator and solar heat-based hot water supply facility, which use solar energy actively, are more used. As a result, green roof system using rain water or rain water system are not much considered but recycling water treatment system and irrigation water system using used water generated from the buildings are actively introduced for irrigation and lavatory water.

3.5. Introduction and Application of New Environment-Friendly Materials

Another characteristic of the residential buildings on display in Solar Decathlon is to develop various environment-friendly materials for interior/exterior finish, high-efficiency windows and doors and structures as well as various environment-friendly technology and new design method and to actively apply them to the residential buildings.

Fig. 4. Double Building Envelope with Wood Materials, Team Czech Technical University (Left), Bio-BIPS Insulation Materials, Team University of Illinois, Urbana-Champaign (Right)

Green, recycled and renewable construction materials are mainly used. A variety of insulating materials using insulating structures made from polystyrene and high-performance insulating materials like vacuum insulator are employed. Especially, as seen in Figure, Team Czech Technical University uses dual skin system of wood to minimize the indoor and outdoor environment load of the building. The residential building of Team University of Illinois, Urbana-Champaign draws a great attention by employing Bio-SIPS, which is an environment-friendly insulation and finish materials made from bean extract and bamboo interior material that is popular as interior finish. It also uses green wall panels to reduce external solar radiation and increase familiarity in esthetic point of view. The interior materials and furniture are made of recycled wood and recycled construction materials in an effort to realize sustainable residence. Like this, Solar Decathlon takes advantage of the occasion as an opportunity to apply and test new environment-friendly construction materials directly to a real residential building and promote and distribute new and green and superior construction materials and products to general public who visit the competition.

3.6. Approach to Realizing Healthy and Pleasant Indoor Environment

What is emphasized in Solar Decathlon is to realize healthy and pleasant indoor environment as well as energy generation and innovative reduction of energy consumption in the building. As mentioned above, the residential building try to provide high performance windows and doors, insulation and green indoor finish materials, natural ventilation and lighting through optimal shape of building and design of openings to improve the quality of heat environment, sound environment, light environment and indoor air environment, which will eventually improves the satisfaction and function of residence from the viewpoint of residents.

Fig. 5. Interior Space with Daylighting and Natural Ventilation, University of Nevada, Las Vegas (Left), Team Santa Clara University+California College of Art (Right)

That is, environment-friendly residential buildings put weights more on the realization of pleasant indoor environment for resident' s pleasant and healthy life as well as reduction of energy consumption. As seen in Figure 5, the residential building by the collaborated team of University of Nevada and Santa Clara University+California College of Art designs its indoor space with clerestory on the northern indoor walls and large skylight on the south to induce natural ventilation using cross ventilation principle. Thanks to it, indoor pollutants can circulate out and indoor space can remain bright without separate lighting system, which creates bright and pleasant residential environment. To improve IEQ (Indoor Environmental Quality), the team makes integrated consideration of light, sound, indoor air and thermal conditions by actively applying more efficient, healthier and green cooling/heating conditioning system, multi-purpose space that comforts diverse life of a resident, optimized lighting system by natural indoor lighting system and harmless green construction materials.

3.7. Innovative Green Construction Design

As time goes, Solar Decathlon expands its existence to America, Europe, China and Latin America. Such progression is explained by the distinctions of the program in which the participants make utmost efforts for creative design of green residential buildings, their effective education and openness of the works to the general public that had not experienced the potentiality and practicability of environment-friendly residential buildings in person.

Fig. 6. Butterfly Roof and Shading Device, Team Victoria University of Technology (Left), Fabric Curtain at Exterior Space , Team Vienna University of Technology (Right)

Examining the research objects, we come to know that, as seen in Figure 6, the residential building designed by Team Victoria University of Technology uses shading device and roof as design factor while Team Vienna University of Technology uses fabric curtains in the outside of its residential building to give the facade flexibility to function as shading effect and privacy, which is an attempt to make outdoor space into indoor space. That is, this building tries to avoid the existing uniform and monotonous images of green residential building and uses newly fabricated structure materials and wooden and fabric insulations as new environment-friendly interior and exterior material. Furthermore, it actively employs shading devices made of wood, steel and plant; roof of a new form in consideration of ventilation and lighting; all-automated louver running on the level of solar light; dual skin of the building; renewable energy including solar heat, solar light, geo-thermal heat and wind force; and new indoor cooling/heating control system. This integration of advanced green architectural technologies and design planning factors presents the possibility and applicability of green residential building to the reality and also the possibility to overcome the limitations of existing environment-friendly residential design.

4. Conclusion

Based on the case study of the residential building introduced in the Solar Decathlon, which is U.S. environment-friendly residential building design competition, the present study tried to derive the design strategies for green residential buildings. This competition program is an occasion of significance in that we can understand the design trend of the world environment-friendly architecture and related technologies. With this beneficial opportunity, we

could have time to think harder of green residential building design. what we learned here is that we need to take advantage of this program as a valuable opportunity to figure out, improve and overcome the problems and limitations that green residential buildings may have, which are found in these real cases as well as learn how to convey the exterior images of the buildings. Particularly, the Korean residential architecture needs to avoid existing biased approach largely to function and technology and develop green residential building architecture customized to our natural environments and actual conditions in order to create pleasant and healthy residence. In addition, like U.S. Solar Decathlon, we needs to have a program, not heavily relying on certain experts for research and design, that architects, related exports and students actively participate in, have substantial understanding on overall building system and operation, learn integrated green architecture and widely distribute it. Through this program open wide to the general public, we can expect that the public have better awareness and change existing notion of environment-friendly architecture; green construction materials can be more promoted; thus eventually environment-friendly architecture market will be expanded.

That is, there should be catalyst in Korea to stimulate the development of construction industry and public promotion as well as related education. In addition, continuous research is required upon an a new approach to green design, construction and management of economic and energy-efficient residential buildings suitable for domestic environment. Along with it, institutional an administrative support are also asked including the revision of green construction related laws and administrative procedures.

Acknowledgements

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