Deployable structure as architectural active structure on sports building in Bandung

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Abstract. Buildings not only can be resilient from environmental changing by passive design, but also have ability to adapt the environment by active system. By using deployable structure, this system can be provided by changing multiple form based on its purpose to cover the building. To provide these conditions, deployable structure need to be explored and analyzed to develop compatible structure in the building. Case of study in this research is Pajajaran sports building in Bandung. The research method is exploration of form and movement based on limited variables, there are activities and weather changing/climate condition. These variables formulated into two conditions, open and closed building. Open building state in sports building have requirement that either natural or artificial lighting should not cause glare in field area. So, natural lighting was simulated by using Ecotect Analysis to find solar path movement and shadow angle. The result of the solar path simulation shows that daily solar movement must be responded directly because high rotation rate and regular changes, while the monthly sun path does not require significant movement due to low rotation rate and insignificant changes. This study will show design process of deployable structure into sports building.

1 Introduction

In every country, building must be designed to resilient in any weather condition either by using passive design, and also active design. Passive design is known as inherent compact design that can be used in every situation. However, active design usually equated as automation and machinery system that can be used as needed. This system has ability to adapt situation by changing form, shape or function as needed, such as smart secondary skin, retractable roof, etc. This development is based on technology and structure system which is attached to building.

Active design or active system also developed to provide multiple needs of building function. Amphitheatre, theatre, or circus needs building system that can be used in various activities and even places. This phenomenon had been already developed since Romans era. They used system called simple retractable system to provide buildings with roof that can be opened-closed and also protected users from many weather conditions. They used material such as wooden beams, ropes and canvas [1].

Nowadays, retractable structure system has been mostly used in sports building because they considered the needs of building, such as to provide diverse activities, to adapt environmental and weather changes, to provide natural conditions for grass growth in the pitch inside the building, to enable lighting and ventilation, or even to give different ambience and experience for users [1]. Margaret Court Arena in

Australia, National Stadium Warsaw in Polish, and The All England Club at Wimbledon are several examples of sports building that using deployable structures. These buildings using this structure because of extreme weather and technology development in their country. Similarity of these buildings is their roof structures that provides open and closed condition. However, it is very rare to find this structure directly responded to climate changing. Most of previous studies was focused on more efficient structure and form development.

Designing deployable structure is not simply just form finding or choosing technology for movement, but how to create this structure appropriate in the building, suitable for its needs and resilient from climate change. In this research, it will show design process of deployable structure in sports building and how form finding were made appropriate in sport building in Indonesia.

2 Methodology

To develop deployable structure system in Indonesia, Pajajaran Sports Building in Bandung was the study case to exercise this structure in architectural building. The methods of this research are exploration of form and movement based on limited variables. The variables were limited by various activities (indoor and outdoor activities) and weather changing/climate condition (rainy and dry season).

Form and movement of deployable structure will be formulated through the following steps:

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- Formulation of various activity in sports building. Some sports need an open space, while some does not. Although, it does not have specific requirement of movement or specific covered area [2]
- Formulation of weather condition of Bandung. Weather in Indonesia just have 2 seasons, rainy season and dry season. In rainy season, rain condition cannot be tolerated. Then, the building must be closed from any openings, so the rain water cannot leak into the building, especially field area. However, in dry season, it is possible to open the building. But it still needs to consider whether glare effect from sun can distract the players or not. So, its still needs to create formulation of openings that should not disturb activity in the building but can provide natural lighting and outdoor environment.
- To avoid glare into field area, it required sun path simulation. So, in the dry season, the building can be opened effectively against sun glare. Simulation of sun movement by using Ecotect Analysis. This step will show sun movement in Bandung and how the structure must react to them. Thereafter, building can be operated without glare to the playground.

From three steps above, it has been clear that sports building activities and weather condition need two kinds of situation. There are opened building and closed building. There are no specific requirements of movement neither form structure. However, sun movement requires to create open buildings that can be effectively giving outdoor environment but should not causing glare. So, sun path variable will be main variable to formulated movement and form of deployable structure.

Fig. 1. Scope of variables to create deployable structure movement and form.

- So, after that, then exploration of form was done by using origami. This is because it could experience large configuration changes without cut or being stretched [3]. This could be exercised before more precise design of structure. Thereafter, it needs to be evaluate whether it is stable and adaptive structure or not.
- The last step of this research is implementation the structure into the Pajajaran Sports Building. It is required possible structure and system to withstand movement load and dead load. Therefore, the deployable structure will be more rational and possible to develop.

3 Solar paths in Bandung

Result of Simulation in Ecotect Analysis provided stereographic diagram and tabular data of time, HSA (Horizontal Shadow Angle), and VSA (Vertical Shadow Angle) based on location of the building. Pajajaran Sports Building in Bandung, Indonesia, have coordinates of 6°54'28"S 107°36'4"E and tilts 5 degrees from north. It shown in Fig.2 that this building is near other sport facility, such as running track, training facility and many more. Although, the study case of the sports building as shown is the main sports hall.

Fig. 2. Location of pajajaran sports building, Bandung, Indonesia.

Fig. 3. Stereographic diagram of sun path movement in Bandung.

These data are the basic step to work on climatic consideration to reduce consumption of conventional energy [4]. Nature of sun movement and natural light was responded to create formulation of movement and form. To avoid glare, inside the building must be covered from direct light. So, it is important to create the deployable structure similar to shading devices.

From the stereographic diagram and tabular data, schematic movement diagrams were made to predict the possible variant of adaptation of deployable structure movement. These diagrams were made on the north-south and east-west side. These diagrams were also limited by time, there are in 07.00 to 17.00 which is the standard operational hours of this sports building in daytime. Referred sun movement was during 21 March,

21 June, 23 September, and 22 December. These diagrams shown in Fig.4 and Fig.5.

Fig. 4. Vertical Shadow Angle (VSA) from south elevation.

Fig. 5. Vertical Shadow Angle (VSA) from east elevation.

From Fig 4, it could be simplified that daily movement on the East-West was highly rotated movement and insignificantly changing during monthly movement. This was shown in the Vertical Shadow Angle on the simulation result which were remain constant in each month. Meanwhile, the sun movement on the North-South shows that during peak hour (10.00 – 13.00), the sun mostly on the northern hemisphere then southern hemisphere.

Because daily sun movement is more dynamic than monthly sun movement, daily sun movement need to be directly responded. Monthly sun path does not require significant movement due to low rotation rate and insignificant changing. To respond this condition, optimal movement to against shadow angle is using rotation movement perpendicular to shadow angle.

4 Structural form and movement

F. Otto in N. Friedman [5] classified movement of retractable roof classified by a movement matrix based on type of movement and direction of movement. These movement divided into sliding, folding, and rotating movement. The direction of movement divided into parallel, central, circular and peripheral.

So many systems of retractable roof are developed from the basic of deployable structure system. Hanaor in

Doroftei [6] identified deployable structures system into four main groups; (1) spatial bar structures, consisting of hinged bars (transformable lattice structures); (2) foldable plate structures, consisting of hinged plates; (3) strut-cable (tensegrity) structures, and; (4) membrane structures. Hanaor classified these structural systems by their morphological and kinematic characteristics.

Origami exploration started by using paper. Basic form was created following classification of folded plate system by Engel [7], that was one-way folded plates. This type is the only type that can be developed into rotation movement. From origami exploration, it shows that diamond pattern has ability to provide rotation movement closer to rounded form. So, the movement of the folded plate more effective than other shape. This is because of the positive curvature of diamond pattern (Fig. 6, no 6).

Fig. 6. Exploration of origami pattern to create space.

Notes:

1. Linier pattern
 2. Two-hinged frame pattern
 3. Counter profile in center pattern
 4. Ridge to valley folding pattern
 5. Diamond pattern with non-symmetric modular pattern
 6. Diamond pattern with symmetric modular pattern
- The selected geometry was the most optimal because it obeys the geometrical rules for stable adaptive structures folding patterns from Knippenberg [8], which are:
- Diamond folding pattern fully consists of triangles
 - The supports are connected to each other with a maximum of two boundary edges
 - In the unfolded state, there is two support points present which could be lie on the same line
 - The pattern is foldable because it basically from origami
 - Adaptable by moving the supports
 - Stabilized by pinning the supports
 - Constructed of rigid panels (or triangular frame) and hinges

From the selected geometry, the movement was then calculated based on the Vertical Shadow Angle. Movement of the deployable structure for blocking the sun could be seen in the Fig 7 and Fig. 8. It shows that

from east-west angle need to be more dynamic and stable than north-south side. So, movement of deployable structure need to provide sun movement in east-west side first than north-south side.

Fig. 7. Movement of the structure from east-west side.

Fig. 8. Movement of the structure from north-south side.

5 Implementation in sports Building

After the form and movement were found, structure was then applied to the building. Pajajaran Sport Building could not be oriented East to West because lack of space. So, the movement of the structure must cover to building that oriented North to South. Then, the span of the roof used was approximately 100 meters. The proposed structure was arc member with steel material.

Fig. 9. (a) Open State and (b) closed state of deployable structure with stabilizer and cable.

The structure was developed into possible details, such as using stabilizer, cable, joints, and hinge. Those details must be able to provide rotation on deployable structure in the building. Illustration of open and closed scenario of structure can be seen in Fig.10.

Fig. 10. Example of structure reacts to weather:(a) rain weather, extreme heat from sun, or night (b) daylight at 3.00 pm.

After the structure has been implemented in the building, then it developed using hard material and support structure. It was to simulate the possibilities of building the origami shape with hard material in the real construction. However, difficulty was found on the rotation capabilities of hard material. It was due to the technical problem of material and connection. However, it still possible to build this structure in other way such as frame structure then cover the hole between the triangle, but it still to be developed.

Fig. 11. Implementation of deployable structure in Pajajaran Sports Building. Closed state (above) and opened state (below).

6 Conclusions

Deployable structure system developed by formulation of movements and form based on their building requirement itself. In sports building, many considerations could be formulated to create requirements for developing deployable structures. From climate changing and various activities, Pajajaran Sports Building requires to have open and closed space in their building. Based on sun movement, it shows that rotate movement that perpendicular to the sun path is possible as optimal movement.

By using origami, optimal folded form to provide rotation movement can be done by using symmetrical diamond pattern. This pattern has ability to create geometrical stable and adaptive. Although, problem still arose on how to maintain the movement and the structural integrity of the deployable structure. However, it still possible build deployable structure in Pajajaran sports building to create architectural active structure. So, the users of sports building in Indonesia will have different experience and ambience of sports building itself. Not only for users, but also give ability to the building to adapt from its environment.

Lack of similar topic was the most difficulty in this research. Further literature research should be done to evaluate the result and quantification of the structure in the future, especially the structure to support the movement according to the environment and gravitational load.

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