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Bamboo Deployable Structural Systems: An Exploration Study in Responding to Rapid Alteration Challenges

Anastasia Maurina
Architecture Department
Universitas Katolik Parahyangan
Bandung, Indonesia
maurin@unpar.ac.id

Budianastas Prastyatama
Architecture Department
Universitas Katolik Parahyangan
Bandung, Indonesia
mikail.budi@unpar.ac.id

Abstract— **the conventional notion of architecture and the built environment is that they are meant to be relatively static and final, once constructed according to the well prepared plans based on users' needs and wants. That notion, however, overlooks the reality that change is inevitable during a building's lifetime. That change arrives in the form of user-related factors such as new or growing functional requirements and aesthetic aspirations. The change has affected and will continue to affect the dwelling habits, which in turn will affect the way the built environment is perceived and delivered. The conventional construction method that relies on the assumption of a static and ascertain future will find it difficult to sustainably and ecologically accommodate the changes. The transformable capability of architecture and the built environment, supported with the use of natural and renewable material, can offer a plethora of solutions to that contemporary challenge. The deployable structural system, which has the ability to transform from compact to predetermined configuration, offers a prospective opportunity to create building structures that can adapt to the necessity of both rapid and gradual alternations. Coupled with the use of bamboo, a notable renewable material, the promotion of deployable bamboo structure(s) will have a positive impact on the effort to realize the sustainable architecture. This research explored and compared four designs of deployable bamboo structures with planar and spatial scissor-like elements (SLE) systems. Through these experimental projects, the research aims to discover the application of the deployable structures with appropriate bamboo technology to meet the challenge of transformations of sizes and dimension in building; and the generated variations in building form, space and dimension. The research concludes that deployable bamboo structures with the SLE planar system have the size and functional adaptability to create more variants of building form, space, and dimension to the user's flexibility. Meanwhile, the greatest potency of S-SLE is the compactness, because it has fewer additional elements and it even has self-locking mechanism.**

Keywords— sustainable architecture, deployable structure, bamboo, scissor-like element

I. BACKGROUND

The conventional notion of architecture and the built environment is that they are meant to be relatively static and final, once constructed according to the well prepared plans based on users' needs and wants. That notion, however, overlooks the reality that change is inevitable during a building's lifetime [1]. Change arrives in the form of user-related factors such as new or growing functional requirements and aesthetic aspirations [2]. The other forms of change are related to what Andjelkovic defined as "socially-demographic destabilization" to describe forced displacement of people by dramatic economic downturns, social clashes, wars, as well as disasters-both natural and man-made [3].

The above-mentioned changes have affected and will continue to affect the dwelling habits, which in turn will affect the way the built environment is perceived and delivered. The conventional construction method that relies on the assumption of a static and ascertained future will find it difficult to sustainably and ecologically accommodate the changes. The transformable capability of architecture and the built environment, supported with the use of natural and renewable material, can offer a plethora of solutions to that contemporary challenge.

II. METHODS

This research explores and compares four designs of deployable bamboo structures with planar and spatial scissor-like elements (SLE) systems. Through these experimental projects, the research aims to discover the application of the deployable structures with appropriate bamboo technology to meet the challenge of transformations in the sizes and dimension of buildings; and the generated variations in building form, space and dimension.

A. *Design Inclusive Research*

The four experimental designs were part of the research method that Horvath called "design inclusive research (DIR)" [4][5].The design process is considered as the essential activity in design-related research that Horvath proposed as a specific characteristic that discern academic research in this subjects from the other conventional scientific research conducted

Horvath's first phase of the DIR is the "Explorative Research Action" [5] in which researchers/designers conduct observation of phenomena and/or cases related to the particular research area(s) as stated in section I (Background). The researchers also complement the observation with exploration through theories and methods through literature studies on the research topic (Section III). A certain (design) problem(s) should be defined and hypotheses in the form of (design) criteria should be formulated as the outcomes of this phase.

The second phase is the "Creative Research Action" [5] where the experimental design processes were conducted based on the criteria from the first phase. Researchers experimented with concepts and models as the means to test the formulated hypotheses/criteria. The variants were studied through scaled analog models which were subsequently evaluated based on the criteria. Potential variants were then proceeded to be developed into 1:1 scaled models or prototypes as described in Section IV and V. Afterwards, they were evaluated once again based on the same criteria to see how the performance differed from the scaled ones in order to verify and validate the hypotheses to produce useable knowledge on the specific topic of this paper, which makes it the third phase of Horvath's DIR (Section VI). These two phases are also the focus of this paper.

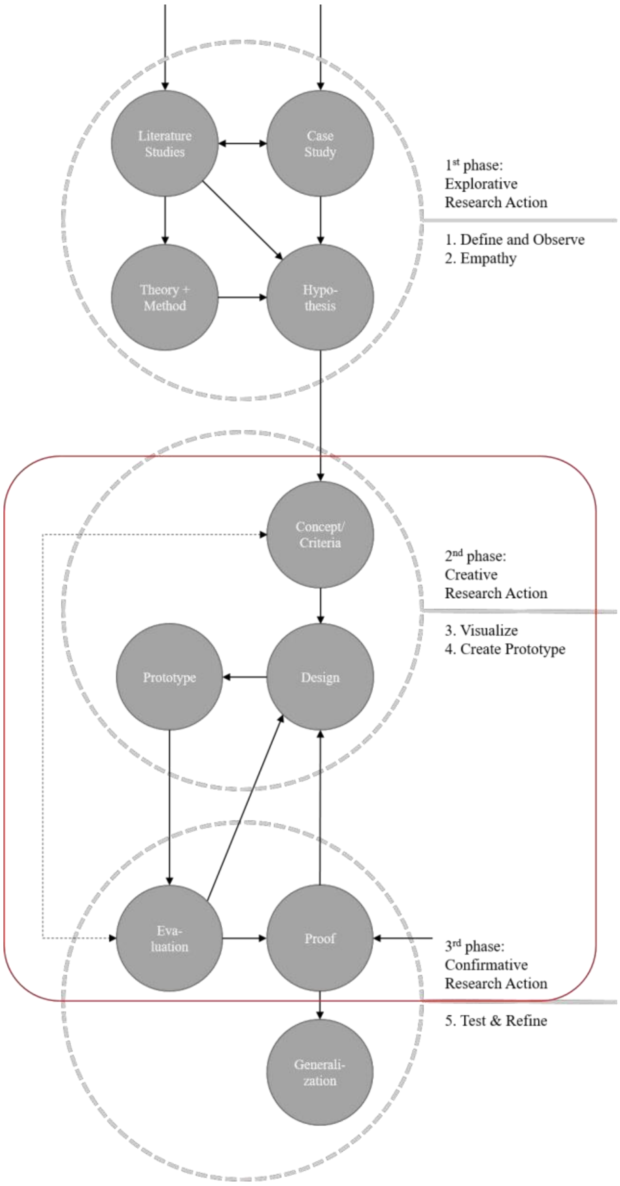


Fig. 1. Research Framework

B. Limitation

Based on the discussion at Point I.C about adaptability, the criteria used in this research are adjustability, extendibility, versatility, appropriateness, move-ability, refit-ability and recyclability (Fig.2). However, this paper limits itself within the context of three main aspects of the deployable structure system: first the adjustability, second the extendibility, and last the versatility, which are related to the aspect of spatial geometry. The conducted (design) studies on both aspects were discussed on the aspects of the structural system and structural module. The others, which related to construction technology, will be discussed later.

The adjustability factor requires and evaluates the design variants in terms of their capacity to fulfill multiple possibilities of adaptation in the user's needs and wants. This factor directed the (deployable) structural system aspect to have a compact stowed state that needs to be installed easily and work perfectly, with the smallest number of movements/actions possible by the user, while the structural module aspect was directed to offer the potential of providing various building shapes and/or forms through the arrangement of identical structural modules.

The extendibility factor requires that the deployable structure system(s) has the capability to transfer loads acting on the building in its deployed state and other loads while being stowed or transported, which directed the design to have adequate structural redundancy. This factor also evaluates the structural modules' capability of repetition along X, Y & Z axis, and the capability of the structural span's adjustability.

The versatility factor evaluates how both the deployable structural systems and their respective modules can offer degrees of adaptability in the spatial profile, spatial dimension, and grid system(s). The versatility factor posed the question how each variant can be easily adapted to the challenge of change in needs and functions that require alteration of spatial shape(s) and dimension(s) in future circumstances.

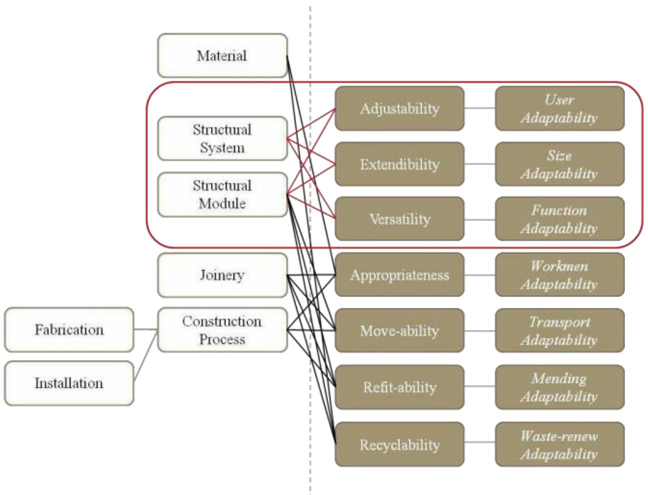


Fig. 2. Research Limitation

The other factors (appropriateness, move-ability, refit-ability and recyclability), which are related to technological aspects will not be discussed in this paper.

III. Literature Studies

A. Bamboo as Structural Material

Traditionally, bamboo as a construction material is well-known in South Asia, East Asia and the South Pacific, because of its abundance. Although bamboo has been popular as construction material for the poor, the use of bamboo has intensified recently since people recognize its sustainable values. Bamboo has a very strong fiber that is regarded as one of the building material with high tensile strength at approximately 28,000 N per square inch, which is higher than steel [6]. Moreover, the compressive strength of bamboo is two times higher than concrete.

The drawback of bamboo as a structural material, which has always been questioned, is the issue of durability against insect attacks and rot. Consequently, bamboo requires thorough material preservation before being used as a structural material. Durability can also be achieved through a good architectural design [7]: keeping bamboo from direct contact with the ground, providing good natural air flow, and protection from rain and sunlight through wide overhangs.

B. Deployable Structures

Deployable structure is one of the two classes of transformable structure [8][9], with the other class is known as kits-of-parts. The transformable structure as the general category itself can be defined as any structural system that is capable changing relative to its immediate contexts [8]. While this definition widens the transformation spectrum from shape to color, and one that relates closely to architecture is the ability of a transformable structure to change its form to accommodate the change of activities or special functions with the same physical parts from its earlier shape [9].

While the two classes are essentially different in their principles of transformation, this paper will focus on the deployable structure system. The specific characteristic of the deployable structure systems is their built-in mechanism(s) that enable them to be opened or deployed from a stowed or closed state to preconfigured shapes repeatedly and with adequate load bearing capacity [8]. Temmerman proposed several sub-classes within the deployable system [10]. They are the scissor-like mechanism (also known as the pantograph mechanism), the foldable panels, and the linear elements with membranes.

The scissor-like mechanism is the most common system that has been applied in foldable furniture, umbrellas, scissor-jacks, map-drawing tools, and other utensils. Temmerman defined this sub-class as the "scissor-like elements (SLE's)" which essentially is a mechanism composed of two poles or bars that are connected at a point along each of their lengths with a pin that acts as a hinge. This formation allows the two poles to swing freely on a plane that is perpendicular to the pin [10]. A pair of scissors illustrates this mechanism perfectly, hence the name "scissors-like element".

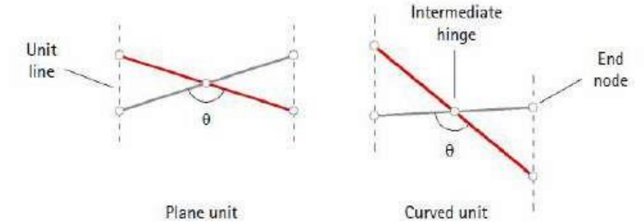
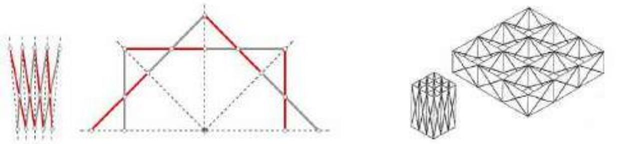


Fig. 3. Scissor-Like Element (SLE)

Based on this simple generic composition, various modifications can be made to allow different movement patterns, planar SLE or spatial SLE as well. The combination of this basic module with other similar or modified generic modules at a certain connecting angles and/or point opens up potentials of deployable forms with a predetermined deployed state. Theoretically, application of the same principles in longer poles and larger load-bearing capability will enable the deployed form to become a space-defining form, architecturally. This is where the potentials also open up towards technological innovations in architecture to accommodate the actual transformable architectonic spaces.



Planar Scissor-Like Elements (P-SLE) *Spatial Scissor-Like Elements (S-SLE)*

Fig. 4. Planar and Spatial Scissor-Like Elements

This paper focuses on only two types of SLE: the Planar SLE (P-SLE) and the Spatial SLE (S-SLE).

C. Adaptability

The rapid change in our social, environmental, and economic frameworks will transform construction significantly [11], including: reducing users' uncertainty and cost through accelerated design and construction processes; and increasing demand for physical elements that are reconfigurable for unpredictable future needs [12]. Discussing sustainable building, Graham [13] stated that it is not one that must last forever, but one that can easily adapt to change. Thus, accommodating rapid alteration can be responded through adaptable design strategies that produce a level of building transformability [14].

Adaptability is the built-in ability to adapt and be adjusted to change by meeting different purposes, allowing various spatial and functional configurations, and updating technologies without requiring significant disruption of the building, the ongoing activities and the environment [15]. Beadle, et al. [16] defined six criteria for adaptable building, which are availability, extendibility, flexibility, refit-ability, move-ability, and recyclability. The adaptability of buildings is investigated by developing two design strategies. First is the pre-configuration that has to do with initial design choices related to speed and quality through the standardization of building components. Second is the re-configuration that deals with subsequent changes in use, which represented the spatial geometry.

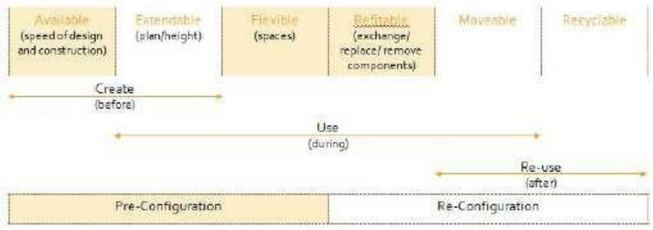


Fig. 5. Design Strategies for Adaptable Building

The criteria above have been developed by Schmidt III [17] as a cyclical framework to explain the nature of preferred adaptability into six design (motivational) strategies: adjustable, versatile, refit-able, convertible, scalable, and movable.

Fig. 6. Framecycle for Adaptable Building

Based on both criteria, developed by Beadle and Schmidt, the criteria for assessing the deployable structure, used for evaluating the adaptability, are adjustability, extendability, versatility, appropriateness, move-ability, refit-ability, and recyclability with respect to the user's needs and wants, building size, building function, workman's skill, transportation's tools, mending technique, and after use, in consecutive order.

IV. Planar Scissor-Like Elements (P-SLE) Experimental Projects

A. *P-SLE Project 1: Bumi Awi Kabula-Kabale (2016) [18]*

Bumi Awi Kabula Kabale[1] (hereinafter referred to as BAKK) is a prototype of folded-frame structure using a P-SLE system. This structure was built for the first time in 2016 and was upgraded with added mezzanine in 2017. It functions as the community shelter for aqua-ponic activities at Sindang Pakuon Village, West Java, Indonesia.

Compact State *Deployed State*

Fig. 7. Structural Form of P-SLE Project 1

Having only one adjustable structural module is highly beneficial; this module can be easily duplicated during the production and erection, thus speeding up the construction process. The structural system is a folded-portal truss, derived from the bending moment diagram as its optimum structural modular form. This structural form can withstand the bending moment of a simple cantilever beam and column with fixed joints and will transfer the axial loads of all members. This structural module requires only one adjustable bar to be deployable properly, which is noteworthy.

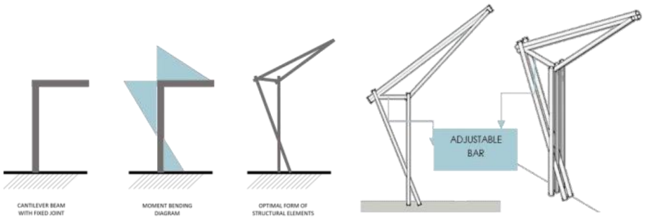


Fig. 8. Structural Module of P-SLE Project 1

By arranging only a number of structural modules, BAKK can create various building spans, varying between 3,00 and 7,30 meter. Some variations also can accommodate a mezzanine or full upper storey.

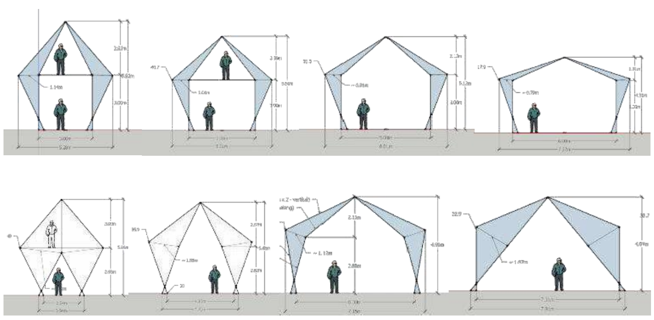
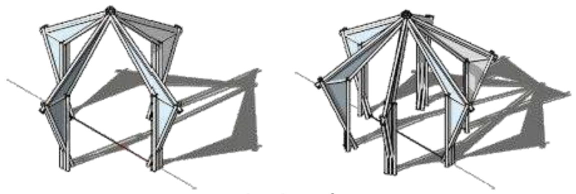


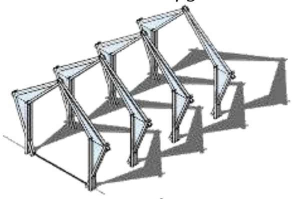
Fig. 9. Module's Adjustability of P-SLE Project 1

In addition, this module can be arrayed horizontally, thus creating the various building and spatial forms that are either centralized or linear.

[1] *Bumi Awi* is Sundanese word, meaning a house or shelter (*bumi*) made from bamboo (*awi*). The *kabula kabale* is derived from Sundanese proverbs "*Kudu Bisa Kabula Kabale"*, meaning that people ought to adapt or adjust themselves to wherever they are. Thus, *Bumi Awi Kabula Kabale* transforms that cultural value into a technical value through a bamboo structure that can be adapted and adjusted to limited lot size, various functions, and also various people's needs and wants.



Centralized Configuration



Linear Configuration

Fig. 10. Module's *Configuration* of P-SLE Project 1

B. P-SLE Project 2: Removable Cantina (2017) [19]

This structure was developed after P-SLE Project 1 in order to install more easily. P-SLE Project 2 simplified the joinery and deployment process of former project through a modification of top joinery from the portal with pins on top to the cantilever system. This structure prototype was made to function as temporary and removable food stalls on Universitas Katolik Parahyangan campus, Bandung, Indonesia.

Compact State

Deployed State

Fig. 11. Structural Form of P-SLE Project 2

The structural module is comprised of three primary members (each member may consist of more than one bamboo pole). At both ends of the beam, members made of two bamboo bars are pinned by a revolute joint. In its deployed state, the column members support the beam in a diagonal position, crossing at their midsections, fixed to position by a locking mechanism made of two perpendicular bamboo bars.

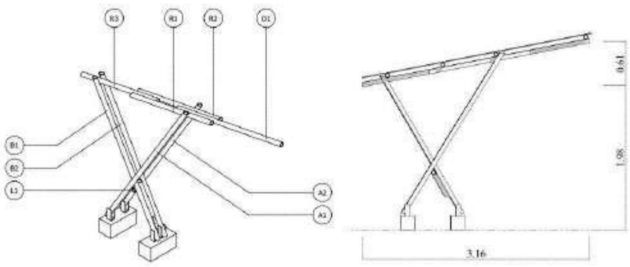


Fig. 12. Structural Module of P-SLE Project 2

This structure module can produce various building spans in three ways through alterations of the foundation point, the meeting point of the column and upper bar, and the combination of both.

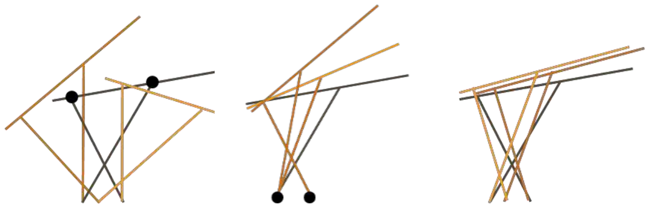


Fig. 13. Module's Adjustability of P-SLE Project 2

This module can be solitary, paired and mirror-paired. Other than that, similar to the BAKK, this module can be arrayed horizontally, thus creating the various building's arrangements that are either centralized or linear on one direction/axis.

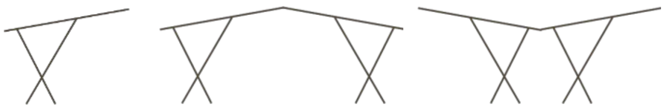


Fig. 14. Module's Arrangement of P-SLE Project 2

Centralized Configuration

Linear Configuration

Fig. 15. Module's *Configuration* of P-SLE Project 2

V. Spatial Scissor-Like Elements (S-SLE) Experimental Projects

A. S-SLE Project 1: Hexagonal Shelter (2016) [20]

The Hexagonal Shelter, built in 2016, is a structural system that combines reciprocal and deployable systems, thus allowing the module to be a spatial SLE system. The reciprocal system is used in the upper/roof bar to generate a self-locking mechanism on the deployable structure. This system is the result of exploratory research by a Parahyangan Catholic University student, named Bernadette Sudira, who fell under the author's supervision.

Compact State *Deployed State*

Fig. 16. Structural Form of P-SLE Project 2

Deployable with SLE system *Reciprocal System*

Fig. 17. Deployable and Reciprocal Systems In The Module

The use of a reciprocal system with six-pole members generates a centralized hexagonal form. Subsequently, this module immediately forms an architectonic space once deployed without being necessarily dependent on another module(s). However, the somewhat final spatial form itself does not offer various building forms such as the ones offered by the P-SLE. The module itself allows the potential to accommodate an intermediate floor due to its height.

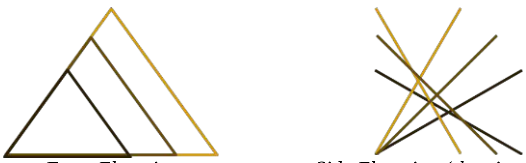
B. S-SLE Project 2: Triangular Prism Shelter (2017)

S-SLE Project 2 is a development of the SLE-spatial system in order to increase the ability to repeat horizontally. The prototype was built in 2017 and disseminated in 2018 to the community at Cibodas Village and students of Kuntum Cemerlang High School, Bandung, Indonesia.

Compact State *Deployed State*

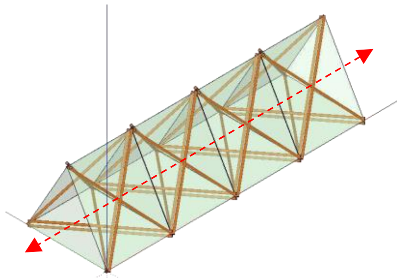
Fig. 18. Structural Form of P-SLE Project 2

A single module of the structure consists of three SLEs that are configured into a triangular prism. The module's dimension will be affected by the opening degree of SLE and allow for various grid dimension between 1.5m and 2.6m. The structural modules can also be duplicated horizontally on one axis.



Front Elevation *Side Elevation (showing various opening degree of a single module of SLE)*

Fig. 19. Module's Adjustability of S-SLE Project 2



Linear Array Configuration

Fig. 20. Module's *Configuration* of S-SLE Project 2

VI. Results and Discussion

As stated previously, this paper discusses the criteria of adaptability in terms of user-adaptability (adjustability), size-adaptability (extendibility), and function-adaptability (versatility). Table I will expand the criteria into several sub-criteria that are related to design of structural systems and structural modules.

TABLE I. Variable and Sub-Criteria of Adaptive bamboo Structure Deployable

	Criteria		
	Adjustability	**Extendibility**	**Versatility**
Structural System	Compactness	Structural Redundancy	Shaped Spatial Profile
Structural Module	User Control Level	Adjustable Modular Unit	Variety of Spatial Dimension
		Joinable Modular Unit	Grid System

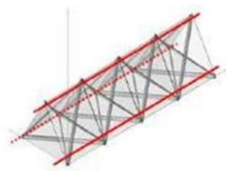
A. Adjustability: User Adaptability

In the criteria of adjustability, i.e. the structures can adapt to the user's needs and wants, there are two sub variables that will be used to evaluate the research projects, namely: (1) compactness, which is related to the structural system; and (2) user control level, which is related to structural modules. In the sub-criteria of compactness, the structure will be analyzed from the number of its primary module and the secondary element which functions as stabilizer to define whether or not it can be installed and work perfectly without any complex or numerous movement by the user. On the other hand, the arrangement of structural module is expected to create various building forms and dimensions, so that users can have control over the size and shape of space and form to fit their requirement. The concept is similar to the concept of mass-customization, which is stated by Mathur [21]:

> "Mass customization, wherefore, not merely about tailoring a technology to the needs of the idiosyncratic user (which is the case with customization); rather, it is about pre- tailoring the technology to the idiosyncrasies of every user."

TABLE II. Comparison of Adjustability

Project	Adjustability	
	Compactness	*User Control Level*
P-SLE 1	●▯▯▯	●●●●

Project	**Adjustability**	
	Compactness	***User Control Level***
Score: 5/8 (0.62) limited	 4 Primary Structural Modules Stabilizer : – 4 horizontal beams – 4 x-cable bracing	Various Building Forms (centralized, linear) Various Building Spaces (flexibility in building span; expandable in one axis; allowing the possibility of adding an intermediate floor)
P-SLE 2	●●□□	●●●□
Score: 5/8 (0.62) limited	 2 Primary Structural Modules Stabilizer : – 2 horizontal beams – 2 x-cable bracing	Various Building Forms (centralized, linear) Various Building Spaces (flexibility in building span; expandable in one axis)
S-SLE 1	●●●●	●□□□
Score: 5/8 (0.62) limited	Primary Structural Module Self locking mechanism through reciprocal roof	Fixed Building Form and Space
S-SLE 2	●●●□	●●□□
Score: 5/8 (0.62) limited	 Primary Structural Modules Stabilizer : – 4 horizontal beams	Fixed Building Form Various Building Space (flexibility in building span; expandable in one axis)

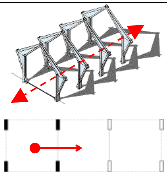
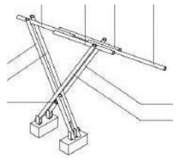
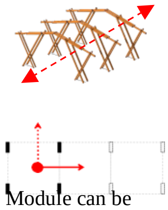
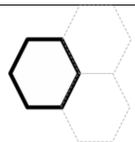
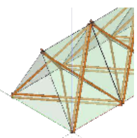
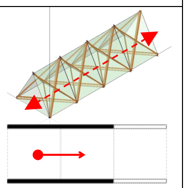
Scoring Average Level: 0.25-0.49 (unsatisfactory); 0.5-0.74 (limited); 0.75-1.00 (satisfactory)

It can be inferred from the table above that the most satisfactory design in terms of compactness is S-SLE Project 1, while the most satisfactory one in terms of user control level is P-SLE Project 1. However, none of the structure performs well judging by the criteria of adjustability.

B. *Extendability: Size Adaptability*

In the criteria of extendibility, in which the structures are expected to be able to provide the redundancy and the flexibility of arrangement to expand in all axes (X, Y, and Z), there are three sub variables that will be used to evaluate the research projects, namely: (1) structural redundancy, which is related to the structural system; (2) an adjustable modular unit; and (3) a joinable modular unit, which are related to structural modules. In the sub-criteria of structural redundancy, the structure will be analyzed by the number of the redundant element. The (theoretical) benefit is that, should an element of the structure be damaged or removed, the structure will not necessarily fail or collapse, as another part can bear the load of the damaged or missing piece. Additionally, it offers more strength for further development. On the other hand, the structural module itself and its arrangement are expected to create flexibility in the size of the building.

TABLE III. COMPARISON OF EXTENDIBILITY

Project	**Extendibility**		
	Structural Redundancy	***Adjustable Modular Unit***	***Joinable Modular Unit***
P-SLE 1	●●●●	●●●●	●●□□
Score: 10/12 (0.83) Satis-factory	 5 layers	Span Range : 3.00 – 6.00 meter (approx. 2x) Height Range: 4.30 – 6.90 meter (approx. 1,5x)	 Module can be joined in one axis
P-SLE 2	●●●□	●●●□	●●●□
Score: 9/12 (0.75) Satis-factory	 4 layers	Span Range : Singular Module 1.40 – 2.40 meter Paired Module: 2.80 – 2.80 meter (approx. <2 x) Height Range: 2.40 – 4.00 meter (approx. 1,5 x)	 Module can be joined in one axis and paired.
S-SLE 1	●□□□	●□□□	●□□□
Score: 3/12 (0.25) Unsatis-factory	 2 layers + 1 layers (roof)	Span: 4.00 meter Height: 3.60 meter	 Module cannot be joined .
S-SLE 2	●□□□	●●□□	●●□□
Score: 5/12 (0.42) Unsatis-factory	 2 layers	Span Range : 1.50 – 2.60 meter (approx. < 2 x) Height Range: 2.30 – 3.20 meter	 Module can be joined in one axis

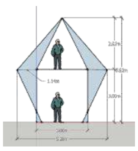
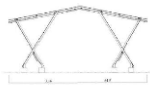
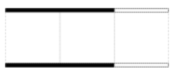
Scoring Average Level: 0.25-0.49 (unsatisfactory); 0.5-0.74 (limited); 0.75-1.00 (satisfactory)

It can be inferred from the table above that the most satisfactory design in terms of the structural redundancy and the adjustability of modular unit is P-SLE Project 1, while the most satisfactory one in terms of the join-ability of modular unit is P-SLE Project 2. Furthermore, P-SLE Project 1 and P-SLE Project 2 perform well judging by the criteria of extendibility.

C. *Versatility: Function Adaptability*

In the criteria of versatility, in which means the structures are expected to be able to provide the spatial flexibility (spatial shape, dimension, and pattern/grid) to serve a variety of activities, there are three sub variables that will be used to evaluate the research projects, namely: (1) the shaped spatial-profile, which is related to structural system; (2) a variety of spatial dimensions; and (3) the grid system, which are related to structural modules. In the sub-criteria of the shaped spatial profile, the space (formed by the structural elements) will be analyzed based on the effectiveness of space utilization. On the other hand, the structural module itself and its arrangement are expected to create flexibility for multifunctional spaces, allowing for a large variety of functions, as well as trans-functional spaces leading to the creation of new undetermined and unpredictable activities according to the users' personal experiences and their consumption of space [22].

TABLE IV. COMPARISON OF VERSATILITY

Project	Versatility: *Shaped Spatial Profile*	Versatility: *Variety of Spatial Dimension*	Versatility: *Grid System*
P-SLE 1	●●●●	●●●●	●●●○
Score: 11/12 (0.92) Satis- factory	 Main Zone: Rectangular Prism Secondary Zone: Triangular Prims	X Axis: Flexible (3.0 m – 6.0 m) Y Axis: Flexible (max. 6.0 m) Z Axis: Up to 2 floors	 Point elements
P-SLE 2	●●●○	●●●○	●●●●
Score: 10/12 (0.83) Satis- factory	 Main Zone: Rectangular Prism Secondary Zone: Triangular Prims	X Axis: Flexible (1.4 m – 4.8 m) Y Axis: Flexible (max. 6.0 m) Z Axis: -	 Point elements (can be solitary or paired)
S-SLE 1	●●●○	●○○○	●○○○
Score: 5/12 (0.42) Unsatis- factory	 Main Zone: Hexagonal Prism Secondary Zone: Hexagonal Pyramids	X and Y Axis: Fixed (6 m) Z Axis: Up to 2 floors	 Closed-plane elements
S-SLE 2	●○○○	●●○○	●●○○
Score: 5/12 (0.42) Unsatis- factory	 Main Zone: Triangular Prims	X Axis: Flexible (1.50 m – 2.60 m) Y Axis: Flexible (1.50 m – 2.60 m) Z Axis: -	 plane elements (closed in one side)

Scoring Average Level: 0.25-0.49 (unsatisfactory); 0.5-0.74 (limited); 0.75-1.00 (satisfactory)

It can be inferred from the table above that the most satisfactory design in terms of the shaped spatial profile and variety of spatial dimensions is P-SLE Project 1, while the most satisfactory design in terms of the grid system is P-SLE Project 2. Furthermore, P-SLE Project 1 and P-SLE Project 2 perform well judging by the criteria of versatility.

VII. CONCLUSION

The satisfactory level of all experimental projects, both P-SLE and S-SLE, to each criteria and sub-criteria of adaptability in terms of use, size and function adaptability are high-lighted in the table below. It concludes that P-SLE projects fulfill most criteria, except the compactness. Conversely, the S-SLE projects fulfill only the sub-criteria for compactness.

TABLE V. SATISFACTORINESS OF ADAPTABILITY

		P-SLE		S-SLE	
		1	**2**	**1**	**2**
Adjustability	Compactness			☑	☑
	User Level Control	☑	☑		
Extendibility	Structural Redundancy	☑	☑		
	Adjustable Modular Unit	☑	☑		
	Joinable Modular Unit		☑		
Versatility	Shaped Spatial Profile	☑	☑	☑	
	Variety of Spatial Dim.	☑	☑		
	Grid System	☑	☑		

The un-satisfactoriness of each experimental project, both P-SLE and S-SLE as well, regarding all criteria and sub-criteria of adaptability in terms of use, size and function adaptability are illustrated in the table below, which concludes that S-SLE project 1 does not meet most of the criteria.

TABLE VI. UNSATISFACTORY OF ADAPTABILITY

		P-SLE		S-SLE	
		1	**2**	**1**	**2**
Adjustability	Compactness	☒			
	User Level Control			☒	
Extendibility	Structural Redundancy			☒	☒
	Adjustable Modular Unit			☒	
	Joinable Modular Unit			☒	
Versatility	Shaped Spatial Profile				☒
	Variety of Spatial Dim.			☒	
	Grid System			☒	

The score of each criterion is compared in the table below that concludes that the most satisfactory in adaptability is P-SLE 1, while S-SLE projects are unsatisfactory.

TABLE VII. COMPARISON OF ADAPTABILITY

Project	Adaptability *In terms of User, Size and Function Adaptability* *Adjustability*	*Extendibility*	*Versatility*	*Total*
P-SLE				
1	5/8 = 0.62 limited	10/12 = 0.83 satisfactory	11/12 = 0.92 satisfactory	0.79 satisfactory

Project	**Adaptability** *In terms of User, Size and Function Adaptability*			
	Adjustability	***Extendibility***	***Versatility***	***Total***
2	5/8 = 0.62 limited	9/12 = 0.75 satisfactory	10/12 = 0.83 satisfactory	0.73 limited
S-SLE				
1	5/8 = 0.62 limited	3/12 = 0.25 unsatisfactory	5/12 = 0.42 unsatisfactory	0,43 unsatisfactory
2	5/8 = 0.62 limited	5/12 = 0.42 unsatisfactory	5/12 = 0.42 unsatisfactory	0,48 unsatisfactory

Scoring Average Level: 0.25-0.49 (unsatisfactory); 0.5-0.74 (limited); 0.75-1.00 (satisfactory)

The research concludes that deployable bamboo structures with the Planar SLE system have the size, spatial and functional adaptability to create more variants of building form, space and dimension toward user's flexibility. The greatest strength of S-SLE on the other hand is the compactness, because it has fewer additional elements and even shows the potential for a self-locking mechanism.

Further studies will compare those experimental projects through the other criteria of adaptability, specifically regarding appropriateness, move-ability, refit-ability and recyclability, which are related to technological aspects. Afterwards, the bamboo deployable structure will be designed thoroughly to meet the terms of all the criteria.

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