Sustainable Building Design and Construction: Integrated Disassembly Principles with Pre-fabricated Structural Modules for Wide-Span Structures

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Abstract

This research develops prefabricated structural modules that enable the construction process to be faster, easier, and more accurate. This module is designed to provide innovative solutions for accelerating the construction of building structures by utilizing prefabrication technology.

It employs multiple research methods. First, a literature study is conducted to understand the basic concepts of prefabrication and the latest technology that can be applied in prefab construction. Next, we conduct a needs analysis of prefabricated construction is carried out, including factors that influence the speed, ease, and accuracy of the construction process. This is followed by surveys and interviews with construction professionals to gain valuable inputs and insights. Finally, a design of prefabricated structural modules is produced that includes step-by-step instructions, design guidelines, and optimal material recommendations. This module also covers efficient construction techniques and best practices in the use of prefabricated elements. It integrates digital technologies, such as 3D modeling and construction simulation, to facilitate the planning and execution of prefabrication projects.

The results of this research are prefabricated structural modules that have been designed and arranged systematically. This module provides clear and comprehensive guidance for construction professionals and project owners in adopting prefab technology to speed up the construction process. This module has been tested in several real construction projects and has succeeded in producing significant improvements in work time, labor efficiency, and structural accuracy.

Keywords: Modules, Structures, Prefabricated, Fast, Easy and Precise

Introduction

Wide-span building structures are very interesting to create compactly with precise precision. Therefore, the right prefabrication method is the choice. Moreover, in this modern era, everything relies on technology and computer applications to help people. Thus, tools that help and make things easier for people to solve these problems must be invented. Currently, new prefabrications for houses and concrete buildings which are generally made conventionally require large costs and is permanent. Thus, the difficulty when it is developed or there is a need to expand it, is felt by the lower middle class of the society. They feel it to be very difficult.

Permanent buildings also suffer from shortages when they are added if they want to increase the area and so on. Methods of building structures and constructions for military facilities with a new idea, namely prefabricated structural modules that are fast, easy, and precise need to be applied to industrial buildings later.

The urgency of this research is increasingly visible with the existence of several studies that are similar to the themes and sub-research that have been studied. These include applications to traditional buildings that use structural modules. The results of this research are traditional building structural modules in the Payango concept (Umar, 2023).

In order not to give rise to excessive multiple interpretations, the research also looked at one more research result that was appropriate or related to the research we conducted. Research was conducted through the concept of digital sustainable tectonic theory, to finally extract the mechanism of tectonic theory. Its application in sustainable architecture, has relevance to the research, because its application can be used in both objects. (Yusuf, 2023)

Another consideration is the flexibility of using materials that can be dismantled. It is also necessary to use local materials without reducing the economic values and the aesthetic values. From the background of the problem, it can be formulated that the "prefabrication system for wide span building modules" has a solution for the future with a practical building method with aspects of speed, convenience, and accuracy that can be obtained according to the purpose of disassembling and assembling later.

In this context, this research aims to provide an overview of prefabricated structural systems with a module system that can be assembled using a fast, precise, and easy building method (Lisa, 2021). Its objectives are:

- To produce a system that can be applied in all regions/regions.
- To ensure the reduction of costs due to high costs on wide stretches in general.

The expected contributions of this research are:

- Providing new insight into the knowledge of wide-span structures that can be dismantled.
- Providing extensive knowledge on mass and sustainable prefabricated production.
- Providing a reference for building concepts that have wide spans which are practical and inexpensive in future building methods.

Theoretical Framework

Smith (2010) discusses the basics regarding prefabricated architecture in the form of construction types. According to Putra (2019), these includes 3 things namely:

1. Prefabricated Material
   Analyze the materials used in buildings, such as the use of materials: concrete, steel, wood, containers, and others
2. Modular Components
   Analyze the types of existing components, in the form of structural and non-structural components in the building.
3. Prefabricated Structural Systems

There are several types of systems listed in Smith's theory. They are precast systems, structure steel, MET (Mess Engineered Timber), PPVC (Prefabricated Prefinished Volumetric Construction), and module systems Containers (containers). If a building has these three systems and the construction or manufacturing process has been completed 60% -90% outside

the site, namely in the factory, then it can be said that the building is modular and applies the theory of Ryan's prefabricated modular architecture (Smith, 2010).

The Theoretical Framework

This research explains the theory related to the theme. The theoretical approach applied in this research is as follows.

1. Reflective Approach Theory (Santiago Calatrava): This means, being able to see very sensitively and intelligently in observing local conditions. It requires the introduction of technology applied to building structures which are deliberately exposed as open structure which has a strength characteristic for the building (high tech). This involves having knowledge of materials and combining them in a series of structures that support each other in the building.
2. Systematic Design Approach (Rafael Vinoly): This architect has produced many designs with excellent work and has received many awards for his designs. The philosophy used as a design idea involves experience. It requires paying attention to each design, always going through a complex process. It can be seen in the differences in the client's contributions and desires. This includes the existing physical conditions and cultural conditions. He employs a methodology as the basis for a systematic design concept. There are many different aspects that can be employed to obtain good design alternatives. Design can be measured in terms of:
    a. Function
    b. Operation
    c. Construction costs
    d. Significant areas/regions
    e. Community capacity
    f. Schedule.
3. Hi-Tech Theory (Renzo Piano and Richard Rogers): These architects worked together to design the Pompidou Center in Paris, France while still showing the existence of design strength. The design philosophy of which is to combine an understanding of materials by combining them with advanced technology ().

1. Prefabricated structural module system

Prefabricated structural module system is intended for wide-span buildings to support the industrial sector. Industrial buildings are mass-produced and sustainable so that the building method system will benefit from similar conventional buildings, both in terms of time and cost and the labor required. This employs the concepts of ease, speed, and accuracy in building space, prefabrication with the concept of structural modules with a knockdown system that can be reused in other places.

The system used as a solution in creating a form of mass-made component and with a building process that has the following advantages (Jenks, 1980):

a. Has installation difficulty compared to conventional systems.
b. Have precision in the modules used because they are connected well and strongly.
c. This is a short time because the time required is shorter than conventional building methods.

The principles used are by prefabrication theory using technology in a series of structural module systems (Hi-Tech Architecture), including:

a. Mass produced and sustainably.
b. Modules used as structures that are directly applied to the building.
c. Consists of several modules that are modeled as standard components and have precise sizes and shapes for each module.
d. Connections between modules have an easy locking system so they can be dismantled and reassembled quickly.

e. Prefabricated system with a duration material structure module that is light, sturdy, and rust-resistant so that it can be used repeatedly and has a lifetime guarantee.

2. Prefabricated structural modules with a dismantling system.

This prefabricated module system draws from the structural theory of HI-Tech Architecture with structural art, namely:

a. Efficiency
b. economy
c. Elegance

Looking at current industrial developments, the best solution is to create a module system that can be installed and dismantled for long-term use (long-life knock-down module systems). Considerations for prefabricated structural modules that will be used include:

a. Material
b. Dimensions
c. Lightweight

Looking at the considerations above, the material that is suitable for structural materials is duralium because it is aluminum and the content used is appropriate for the structure used in this material. Because the duralium material is consistent with Cu 3 - 4.5%; Mg 0.4 – 1 %; and manganese 0 – 0.7 %; Al can change the composition. IR 0.4 – 1%; Si 0.3 – 0.6 % (10).

Prefabricated Structures

Prefabrication is an industrialized construction method in which the components, both structural and non-structural, are standardized, mass-produced in separate locations and then transported and assembled on the building site with the help of cranes and other transportation and handling equipment.

1. Prefabricated Systems

Full unit fabrication is known as a way of constructing a building by taking all building materials using a fabrication system with the advantage of a complete and harmonious building structure system.

2. Prefabricated Materials

Materials in architectural science are classified based on their type, namely extrinsic and intrinsic (Fernandes, 2006). The type and material are an important part of the construction process, this is because the type and material will affect the strength of the building, both the structure and other parts.

The method used during the prefabrication process can be adjusted to the material used. The prefabrication process uses machine power, molds, or fabrication. The machining method in the prefabrication process aims to process material into other parts using mechanical technology.

Thus, the total displacement value in a certain static condition as a result of the external load and related to each force received is balanced.

Review of Literature

This issue has been regularly studied, which makes this research even more interesting and shows its existence as a scientific work that is useful. For example, Primasetra (2020) uses qualitative research and examines prefabricated houses that already exist in Indonesia. By taking four samples RISHA (Simple Instant Healthy House), RUMANGGA (Local Prefabricated House), Domus House, and Dubldom House (Russian Prefabricated House), the research shows that houses built using prefabricated modules create a level of comfort and measurable spaces, through four modules whichwill help good and sustainable development.

Sanjaya (2019) examines the case of Siswalankerto flats, Surabaya. He focuses on the flat model and show that by using CLT prefabricated panels, the flats have acquired efficient and appropriate sizes. Modular CLT has simplified the structure, scope and finishing of the

building into a module. He concludes that this speeds up the development process and reduces construction labor. More importantly, Hallim (2023) focuses on modular technology as a time-efficient and cost-effective creative innovation. He uses a qualitative descriptive approach and shows that with modular technology, houses built using woven bamboo materials and resinous fabrics save energy, minimize costs and are environmentally friendly.

These studies examine prefabricated modular systems of their own types. And provide the context for the examination of sustainable building design and construction with the intention to integrate the demolition principles with pre-fabricated structural modules for wide span structures.

Research Methodology

This research employs a quantitative methodology to test whether the experimental variables engaged in pre-fabricated structural modules for wide span structures are effective or not. Experimental research is usually used more in the fields with exact data.

1. There are two types of experimental research, quasi-experimental and search, namely:
   - The experimental method is used in evaluation to obtain information which is an estimate that can obtain actual data. Various types of quantitative research methods such as experiments are usually used in conditions where it is not possible to control and/or manipulate relevant variables.
   - Experimental methods are used in evaluation to examine possible causes and effects. This is done by imposing one or more treatment conditions on one or more experimental groups and comparing the results with one or more control groups that were not subjected to the treatment.

The experiments carried out intends to prove the speed, that is, prefabricated construction will require a short time because structural modules are prepared that are strong and easy to install. It is also because the method used is by each module and the accuracy is due to each module being accurate. These are made prefabricated symmetrically by specified standards.

2. The research approach used is as follows.
   a. Data collection. (Palmer, 2007)
      - Study literature
      - Experiment
      - Source other information
   b. Stage Analysis. (S Verbruggen, 2014)
      - Human factor
      - Building factor
      - Fakor environment
   c. Design. (Khachatryan, 2020)
   d. Discrete Simulation and Continues Simulation and Monte Carlo simulation. We will also study queuing system algorithms, cluster, and prediction techniques in artificial intelligence using regression equation models as applied examples of simulation and modeling (Kroese, 2008).

Findings

1. **Hangar Design Model** - Structure module

   From the results of the modeling simulation design, a structural module is obtained as in the Figure 2 below.

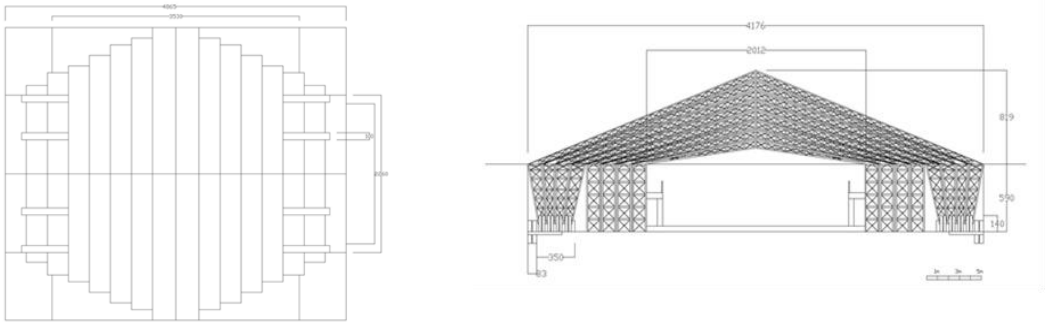


Fig. 1: Plan and section of the hangar building
Source: author

2. Calculation Structure

Structural calculations according to the flexibility method analysis system (Dipohusodo, 2001) regarding the formulation of movement in portal frames with movement at the same point being the sum of 2 movements and rotation at each end are taken into account when applying sign agreements. The load transfer at one point at each end is a result of the external load received with subsequent displacement so that by formulation, the thickness is 12 cm.

3. The Structural Module

a. Hangar Structure Module

Structure module, from the results of the modeling simulation design, a structural module is obtained as in the Figure 2 below.

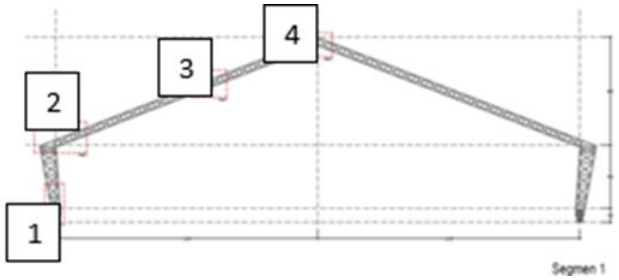
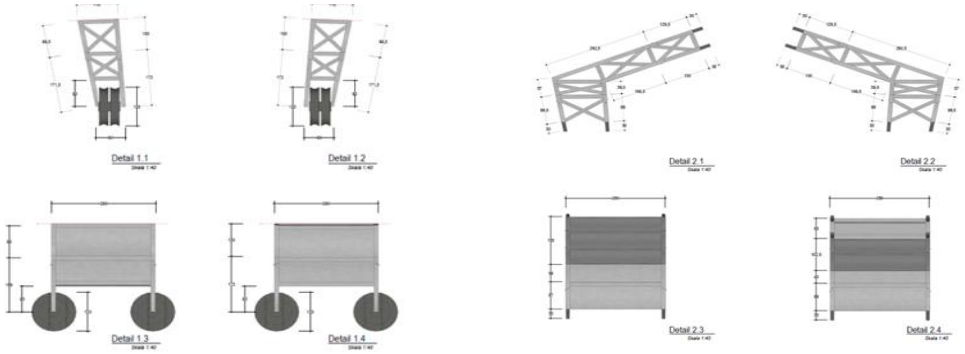
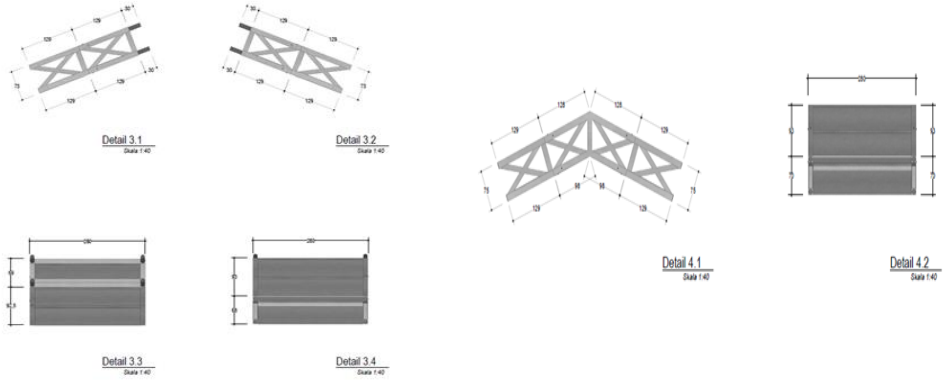


Fig. 2: Hangar structure module model
Source: Author

From the hangar building structure simulation model above, 4 structural module division models are produced. They can be seen in the Figure 3.



Division Module 1 Division Module 2

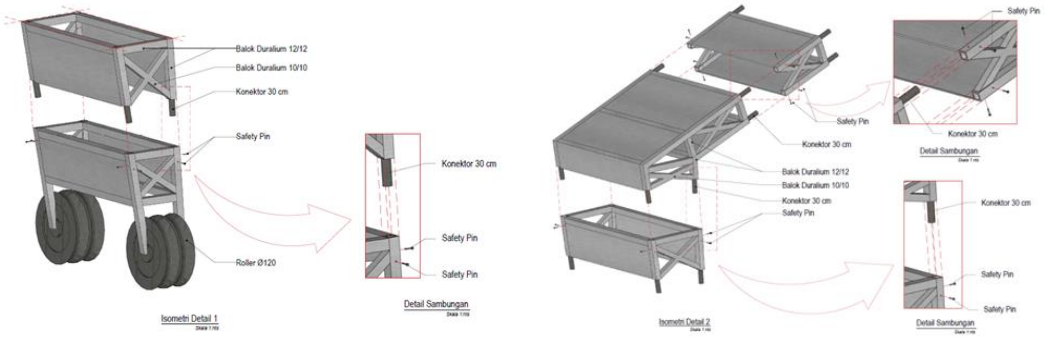


Division Module 3 Division Module 4

Fig. 3: Structure division module model
source: author

b. Installation Method

After obtaining a simulation model of structural division in the hangar building, based on 4 simulation division models of structural division models, the installation model uses 4 installation models based on the structure division module. This can be seen in the Figure 4 below.



Module Installation Method 1 Module Installation Method 2

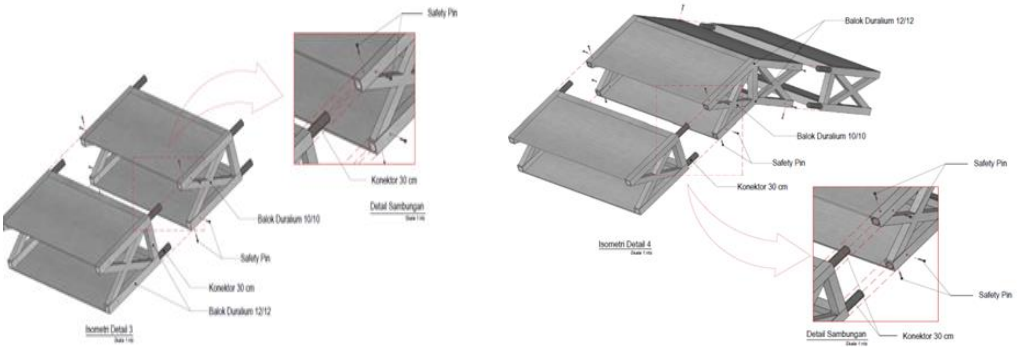


Fig 4. Structural Model Installation Method
Source: Author

The use of prefabricated structural modules that are disguised using the disassembly method has the following criteria:

a. Building speed:
    1) Prefabrication technology through a module system is one way to achieve building speed.
    2) Short planned time
    3) Save on the workforce that carries it out.
b. Ease of building, namely:
    1) The number of modules used does not vary much
    2) The module model has a fixed structure and is interconnected with each other
    3) Can be built and assembled anywhere according to local natural conditions
c. Building accuracy, namely:
    1) The model used by the structural module is more precise and accurate in dimensions and shape. Have different sizes for each module so that they are not confused with each other or reduce the error rate in assembling them.
    2) Has a module form where one is integrated with the others.

The main structural material used is duralium as the basic material for this building. Duralium is consistent with Cu 3 - 4.5 %; Mg 0.4 – 1 %; manganese 0 – 0.7 %; Al can change the composition. IR 0.4 – 1%; Si 0.3 – 0.6%. This alloy is used in a wide field not only for the household appliances but also for industrial purposes, namely for the aircraft industry, car components, regulator components, and other construction.

Since the metal content is dominant with Aluminum (Al), this metal must be very lightweight. Only 15% of the weight of steel, and the presence of copper (Cu) magnesium (Mg), and manganese (Mn), making this a mixed metal. has very strong strength and can match the strength of steel, the strength of this metal has been proven in various studies.

This duraluminium metal is light weight but is as strong as steel because it has been used in airplanes, ships, train carriages, motor vehicles, as well as in bridges and buildings. This metal can be easily mixed and formed with concrete according to the size and needs to form wide spans with guaranteed strength and functionality. It is also used for household tools and decoration (because aluminum is resistant to rust, it is easy to plate with nickel/Ni), and for making pipes and bolts. It is light and rust-resistant, also because it is non-toxic.

Duralium has shown improvements in its mechanical properties (tensile strength, ductility, toughness, and hardness) under the multistage aging process. Duralium morphology has shown that there is a change in the presence of precipitates and also in their size due to the multistage aging process. The precipitate has the smallest size in the second stage of aging (200-300 nm while in the third stage of aging, the CuAl2 precipitate becomes larger (400-500 nm).

Duraluminium (chosen as an industrial structural material) contains 94% Aluminum metal, 3.5 – 5.5% Copper metal, 0.05% Magnesium metal, and 0.5 – 0.8% Manganese metal. The most perfect mixture because apart from being rust resistant, it is also strong against stretching and tensile stress under movement and loads.

4. Mechanical Structure Modelling

The aim is to determine the strength of the material, so we try to examine the quantities that can be used as a guide to determine the strength of construction because in general, it experiences tensile pressure and tension, but what can be ascertained by strength experiments is tensile strength, so that other forces such as compression and compression with something on the tensile strength, the unit used.

a. Research on Tensile experiments

This tensile investigation aims to obtain the tensile strength provided by the tensile fracture stress. The tensile-fracture connection is obtained from the maximum strength force, in the fracture experiment over a wide cross-section of the sample. Next is elasticity, the amount of which can be determined by the stiffness stretch = l up to a certain limit, namely the proportional limit point (P), then the increase in ϵ is proportional to the increase = constant. The examples used for several countries for Hooke's research are so that the cross-sections provide different areas but the lengths can

exceed the limits. The examples used in Indonesia are taken from the Netherlands or also from Germany.

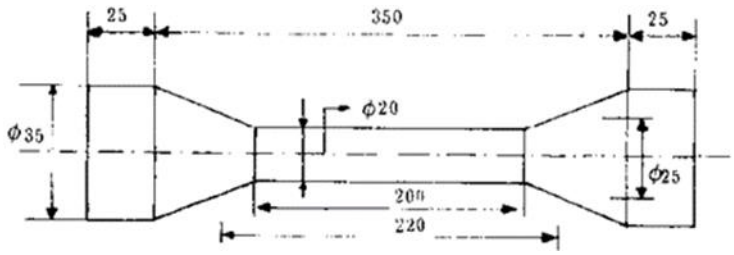


Fig. 5: Cross section of the Hooke model
Source: Blanc, Elvoy & Plank, 2017

b. Research on pressing experiments

This experiment determines whether the strength of the load is still the same as the material under normal temperature conditions and the results obtained depend on the speed of experimenting. The factors that must be considered are the voltage received (pushed) and the temperature that influences it.

c. Research on this experiment

This experiment determines the change in plastic shape in the cold state, if the strength is estimated sufficiently by experiment, but for machine work purposes it can be carried out in hot plastic shape changes in the incandescent plastic state. For example, it is rotated with an electric motor at 3000 RPM (revolutions per minute) with a certain load (σ B) and rotated 5,000,000 to 10,000,000 times, if no cracks occur, then it meets the good requirements.

d. **Research on shear experiments.**

The shear experiment determines the strength of the material against the force divided by its cross-section (knikan strength). usually applied to bolt strength and others. In this experiment, a frame that has column legs is given by measuring it in a swing which, in general, is 6 x R (cosβ- cosα) and is determined in kg/m.

e. Research on punter experiments

This experiment determines the strength of the material due to the twisting force due to the resulting movement. This is done by controlling the crushed material and automatically connecting it to a marking device to determine any changes that occur in the material. The proof method is carried out by using a roller controller that is installed and this rod moves 40m/to detect any disturbance which shows that it is smaller, between 0.75 – 0.75 – 0.75 mm. The result is that this metal can be easily mixed and formed with molds that suit the size and need to form wide spans with guaranteed strength and functionality.

Conclusion

This research has provided an overview of the research results obtained in engaging integrated disassembly principles with pre-fabricated structural modules for wide-span structures. In order not to cause excessive multi-interpretations, the research has elaborated on them in a complex manner as follows.

1. Production of a hangar building design model.
2. Identification of the calculation structure in the hangar building planning.
3. Implementation of the structural model used in the hangar building using:
   a. Standard model
   b. Installation method.
4. Proving mechanical and comprehensive structural modeling in the hangar building design process.

Furthermore, the results of this research are prefabricated structural modules that have been designed and arranged systematically and thoroughly. This module provides clear and comprehensive guidance for construction professionals and project owners in adopting prefab technology to speed up the construction process. This module has been tested in several real construction projects and has significantly improved work time, labor efficiency, and structural accuracy.

This research provides new insights into the knowledge of wide-span structures that can be dismantled. It adds extensive knowledge to mass and sustainable prefabricated production. Indeed, it can be used as a reference for building concepts with wide spans, which are practical and inexpensive in future constructions.

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