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Innovation in Green Building Technology: The Impact of Bamboo Metal Roofing

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Abstract

Of late, the human population has increased tremendously, accelerated pace of development caused the depletion of resources and changes in the earth's environment. As a result, the approach to minimizing the earth's environment is that to fulfill human needs are required. One of the approaches is by use of the green building which low carbon footprint in construction as well as reduces the negative environmental damage. The current study is aligned with ongoing global efforts for sprouting robust green building technologies. Using bamboo as the main environmental-friendly material, this paper is to create enhancement in the materials of metal roofing while solving the complications (i.e., corroding, lack of proper installation, natural defects, and unsafety) that have been occurring using metal roofing in the construction industry. Therefore, this study aims to propose an innovative idea for Bamboo Metal Roofing which includes its components, manufacturing process, dimensional guide design, and potential impact. An overview of Bamboo Metal Roofing through an extensive literature review via three main databases (ie., Web of Science, Science Direct, and Scopus) was conducted. Then, the 3D model using Google SketchUp was used to visualize the concept and idea of the proposed Bamboo Metal Roofing. The findings indicated that the proposed Bamboo Metal Roofing has great potential to be marketed (i.e., local or international) due to its impact (i.e., simple, easy, and fast installation, environmental-friendly, cost-effective (i.e., material management), and high-quality construction. Hence, it is hoped that the proposed Bamboo Metal Roofing would reduce the issues associated with the existing metal roofing as well as minimize environmental impact.

Keywords: Bamboo Metal Roofing, Green Materials, Green Building, 3D Model

Introduction

The building sector is a key contributor to greenhouse gas (GHG) emissions, representing around one-third of global greenhouse gas emissions (Krishna, 2020). It is also responsible for 40% of global energy use which is partly from the direct use of fossil fuel energy and the production of the electricity and heat used in buildings. As a result, green materials are environmentally responsible due to their impacts that are considered over the life of the product as well as meet the human requirement. For instance, the use of natural materials

such as bamboo and timber have been used in building construction for many years due to enable minimizing energy consumption, a healthy environment, reduce pollution, and conserving non-renewable natural resources.

One of the well-known green building materials is Bamboo. It is widely used as the mainstream construction material in the conventional construction method. Among others, bamboo is used as a replacement for steel, wall and floor panels, and roofing materials (Manandhar et al., 2019). This is because Bamboo has low density, equivalent flexural strength to steel reinforced concrete, lightweight, economical, and seismic resisting properties (Kandya et al., 2017). In this study, the potential use of bamboo is recommended to improve metal roofing which normally faces numerous problems (i.e., i.e., corroding, lack of proper installation, natural defects, and unsafety) for their occupants. Consequently, this paper was carried out to innovate the existing metal roofing with creative concepts that may improve metal roofing. Accordingly, this study aims to propose an innovative idea for proposed Bamboo Metal Roofing which includes its components, manufacturing process, dimensional guide design, and potential impact.

Methodology

The study involved two phases of research design. Phase 1 is using literature reviews. Sources such as journal articles and conference proceedings gathered from three main databases (i.e., Scopus, Web of Science, and Science Direct) have been used as a literature review in this study. These journal articles and conference proceedings were drawn from international and local publications, particularly in Malaysia towards obtaining updated information regarding Bamboo Metal Roofing. After an intensive literature review (phase 1) is conducted, then the 3D model using Google SketchUp (Phase 2) was carried out to visualize the concepts and ideas of the proposed Bamboo Metal Roofing.

Literature Review

Type of metal roofing

Corrugated Metal Roofing

A Corrugated Metal Roofing is made out of metal sheets that have been rolled into panels (Kittisak & Prayoon, 2021). Screws are then used to secure the panels to the roof. Corrugated metal is an exposed fastener panel, which means that every fastener on the panel's surface is visible. Corrugated sheet metal is often circular and wavy in form. It's inexpensive, lightweight, sturdy, energy-efficient, long-lasting, and simple to set up. When utilized for metal roofing and siding projects, corrugated panels' longevity makes them suitable for both commercial and residential applications (Setyanto; et al., 2020).

Standing Seam Metal Roofing

A Standing Seam Metal Roof is one of the most durable forms of metal roofing available and may last up to 50 years. Unlike regular metal roof panels, which are often screwed down with exposed fasteners, Standing Seam Metal Roofing has hidden fasteners, which removes the risk of leaking. Standing Seam Metal Roofing may be put over an existing roof, in addition to its durability, sustainability, and energy efficiency. Aluminum galvanized or galvalume steel, copper and zinc are the most common materials used in standing seam metal roof panels (Mooneghi, et al., 2015).

Problems associated with an existing metal roofing

A problem that can occur with existing metal roofing is corrosion (Yadla et al., 2012; Al-Sherrawi et al., 2018). Corrosion can occur on the edges of the metal panel and may develop if the metal is not properly covered. When water molecules become trapped between the panel and the insulation, without adequate coating the metal may begin to corrode. Also, if a granulated underlayment is utilized or laid directly over a shingle roof, the protective backside coating on the metal roof system may be scratched, causing the metal roof system to collapse from within. When two dissimilar metals are joined, a negative interaction may occur, resulting in early corrosion that would not have occurred otherwise. Adding to it, cut edges on a steel roof will experience edge creep, which is corrosion at the cut edge. The cut edge of the metal is often hidden by folds or hemmed edges on a standing seam metal roof (Habte et al., 2015).

The next problem is related to the installation error during the installation process on-site. This includes missing components or accessories, loose screws, or incorrectly connected flashing, which are delicate concerns because of their unpredictability (Yang et al., 2020). As a result, leak problems can occur due to a lack of proper installation on site. In many cases, roof leakage can jeopardize other valuable items in the home or property. Leaks in metal roofs can occur due to various causes, which are beyond our control and due to other causes that are the result of human error. An untreated roof can cause leaks which can damage the building's structure as well as the property assets, drastically and increasing the expense of restoration. Leaks can occur as a consequence of the age and installation of the roof's seam, which connects many panels, and was initially not constructed properly. Moreover, it may also occur due to a lack of proper installation of the roof's flashing, which functions to protect the roofing against leaks, protect against weather extremes, and outside disasters (i.e., water penetration)(Architect Centre Sdn Bhd, 2012).

The common phenomenon of a metal roof problem is oil canning. Oil canning is a natural feature of almost every metal roof (Graham, 2015). An over-stressed metal on a standing seam metal system is unable to maintain a flat form, leading the metal to give way and create visible waves (Kim et al., 2017). Oil canning is a metal roofing difficulty since it's tough to explain and measure. Consequently, these problems (i.e., corrosion, lack of proper installation, and oil canning) may lead to an unsafe environment for the occupant of the building.

Innovation of Bamboo Metal Roofing

Components of Bamboo Metal Roofing

The proposed Bamboo Metal Roofing is made up of Metal, Bamboo, Polyurethane foam, Polyurethane Adhesives, and Epoxy Coat which have gone through six manufacturing processes (i.e., adhesive, cooling, cutting, coating, stacking, and wrapping).

Metal

Metal refers to several metal-based roof coverings that are meant to protect buildings from the weather, allow for proper water drainage from the roof surface, and keep contents and inhabitants dry and comfortable. Steel, aluminum, copper, zinc, stainless steel, and titanium are among the metals available for metal roofing. In many cases, a Metallic-coated steel sheet is the most common metal roofing substrate (Yang et al., 2020).

Bamboo

Bamboo has become well-known as a sustainable building material due to these factors; (Nurdiah, 2016) bamboo rods have circular, segmented, jointed, and hollow characteristics. Segments or internodes, which are divided by a diaphragm, make up a part of bamboo culms or stems. Internode lengths and thicknesses vary depending on the species and environment. The form, size, and vascular bundles of the bamboo culm dictate the internode structural anatomy. The vascular bundles in the outer culm (peripheral zone) are smaller, while those in the inner culm (central zone) are larger and more numerous. From top to bottom, the number of vascular bundles in a bamboo culm decreases but the density remains essentially constant. The bamboo culm is composed of 50% parenchyma, 40% fibre, and 10% conducting tissue (Sugesty et al., 2015; Nurdiah, 2016).

Bamboo has a highly strong fibre to be utilized as a building material. It has compressive strength that is two times that of concrete and tensile strength that is comparable to steel. Bamboo fibre has higher shear stress than wood and has a greater range of motion than wood. Bamboo is one of the strongest building materials, with a tensile strength of more than or equal to 28,000 N per square inch, as opposed to steel, which has a tensile strength of 23,000 N per square inch (Dauletbek et al., 2022). It may also be bent without breaking and has a high amount of silicate acid, making it an extremely fire-resistant plant. When filled with water, it can endure temperatures of up to 400 degrees Celsius while the water within is boiling. This is especially appropriate for roofing materials. Apart from that, it is an anisotropic material. The qualities in the longitudinal direction differ significantly from those in the transverse direction. In the longitudinal direction, they are strong with rigid cellulose fibres, while in the transverse direction, there is fragile and brittle lignin (Hong et al., 2020). Bamboo is commonly conserved in construction using a solution of boric acid borax by a variety of methods, including immersion, gravity or vertical diffusion, and injection with a compressor machine. Boric acid borax has been demonstrated to be useful in extending bamboo's lifetime (van Dam et al., 2018).

Polyurethane foam

Polyurethane is a versatile polymer which has unique chemistry with excellent mechanical and optical properties and provides good solvent resistance. Polyurethane foam covers almost 29% of the total market polyurethane (Shoaib et al., 2014). The application of polyurethane material is determined by two important parameters: density, and rigidity of the polyurethane material. They also added that polyurethane materials are widely used in the construction industry, particularly in the making of plastics, cushions, foams, rubber goods, synthetic leathers, and fibres. In this study, polyurethane foam was used as the polyurethane sandwich panels which comply with heat insulation, insulation properties, and good bearing capacity.

Polyurethane Adhesives

Polyurethane Adhesives are polymer or thermoplastic glue that contains replicas or organic chain units linked to urethane links (Sung et al., 2016). The chemical reaction between the polymers create an adhesive and becomea multi-purpose product that is used to bind a variety of building materials; metals, glass, wood, and concrete. In this study, it is used as a primer in the production of sandwich panels (i.e., Polyurethane foam).

Expoxy Coat

An epoxy coating is a coating compound that consists of two main components; a polymer hardener (i.e., catalyst) and epoxy resin. When these components are mixed, the resin and hardener engage in a chemical reaction which creates cross-linking of the elements when it cures (Pradhan et al., 2016).

The manufacturing process of Bamboo Metal Roofing

The manufacturing of Bamboo Metal Roofing involves six processes. These are the adhesive, cooling, cutting, coating, stacking, and wrapping processes (Kindus, 2022).

Adhesive Process

In this study, polyurethane adhesives are used to bind between materials (i.e., metal, bamboo, and polyurethane foam). This adhesive system uses the spreader machine (Figure 1) to spread the polyurethane adhesive on all surfaces of material by layering the material one by one (i.e., bamboo, metal, and polyurethane foam). Figure 2 shows the texture of the polyurethane adhesive after being applied to the surface material before layering on a new material. The layers are installed without the epoxy coat.

Figure 1: Spreader machine

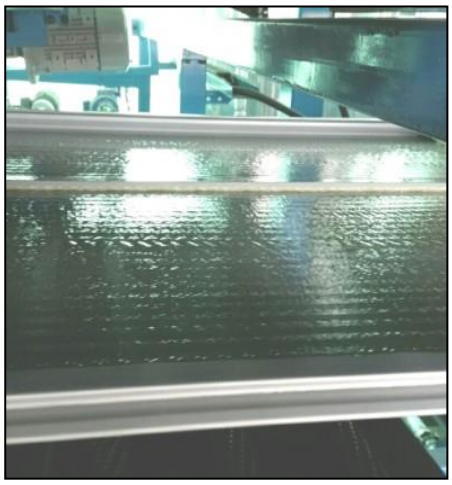


Figure 2: polyurethane adhesive texture

Sources: (Kindus, 2022)

Cooling Process

A cooling process is required to cool the latent heat of the produced layer. Each Bamboo Metal Roof Panels stand horizontally and move because the latent heat varies with the thickness of the panel. If the bamboo metal roof panels are stacked without this process, the surface temperature will increase and lead to post-deformation through contraction and expansion. To prevent damage to the bamboo metal roof panel, it uses a PVC belt drive system as protection. Figure 3 shows the cooling machine that was used for this cooling system, which consists of a roller to move the panel.

Figure 3: Cooling machine
Sources: (Kindus, 2022)

Cutting process

The cutting process is done after the cooling process and functions to cut the Bamboo Metal Roof Panels. The process uses two saws, band saws, and circular saws. This type of circular saw in Figure 4 has two rotating circular tip saws and is used to cut the outside of the panel. Next, the cutting process continues with the cutting of the inside using a rotating band saw as in Figure 5. Cutting can be done smoothly due to both saws having good anti-rust performance.

Figure 4: Circular saw

Figure 5: Band saw

Sources: (Kindus, 2022)

Coating Process

The coating process is done after the cutting process to prevent the roof from corrosion. It uses the coating machine as shown in Figure 6 which sprays all parts of the Bamboo Metal Roofing. Epoxy Coat is used as the material for coating Bamboo Metal Roof Panels.

Figure 6: Coating machine
Sources: (Kindus, 2022)

Stacking Process

The stacking process is to stack Bamboo Metal Roof Panels after the coating process for the panels to be cooled automatically from the input quantity by the operator. It can be manufactured as a vacuum pad type or a mechanical lifter type. The vacuum pad shown in Figure 7 is used to stack the panels one by one through the vacuum pad-equipped stacker. While a mechanical lifter (Figure 8) is used to arrange the panel in more than one part by using the acquisition device as a separator to prevent the coating layer from being damaged. After the stacking process, the Bamboo Metal Roof Panels will be transferred for the packing process by the longitudinal feed conveyor as in Figure 9.

Figure 7: Vacuum Pad

Figure 8: Mechanical lifter

Figure 9: Longitudinal feed conveyor

Sources: (Kindus, 2022)

Wrapping Process

The packaging process (Figure 10) is the last process in the Bamboo Metal Roof Panels production line. This process is necessary to avoid pollution on the surface of the panel, and damage to the coating layer that can cause abrasion to each other during transportation. Each bundle will be individually wrapped with PE film that often serves as the packaging medium. Four-sided or full-sided packaging is required depending on the type of insulation, and a PP

binding machine will also be installed during the wrapping process. After that, a forklift will be used to move the packaged products to an open storage location.

Figure 10: Packing process

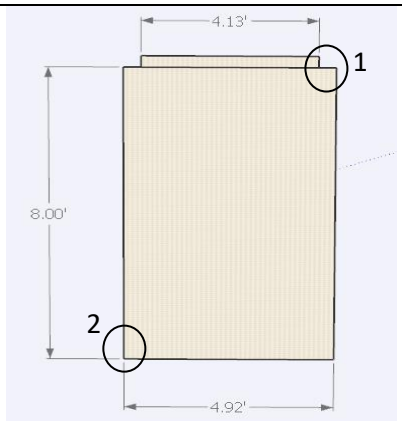
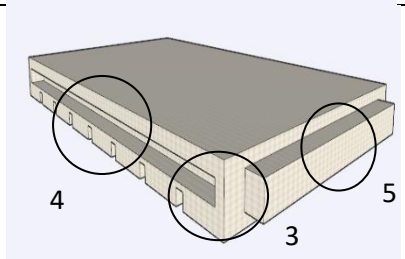
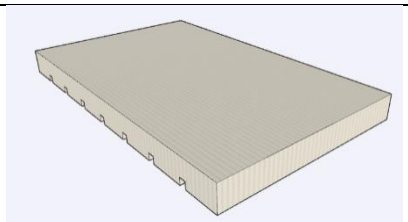
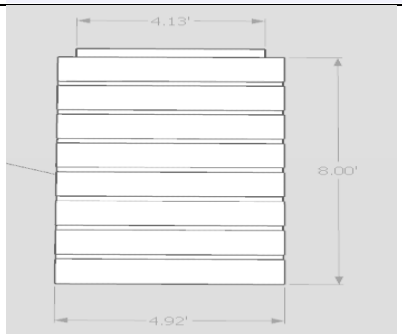
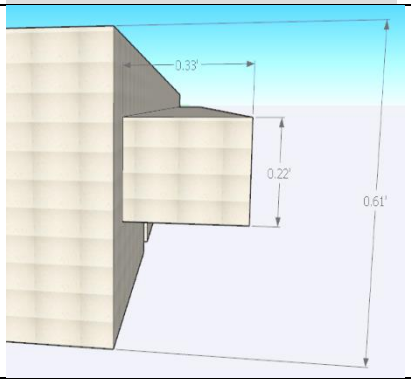
Sources: (Kindus, 2022)

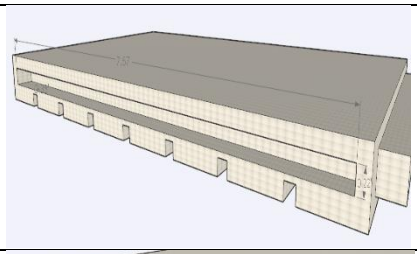
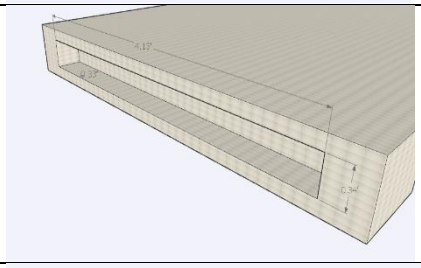
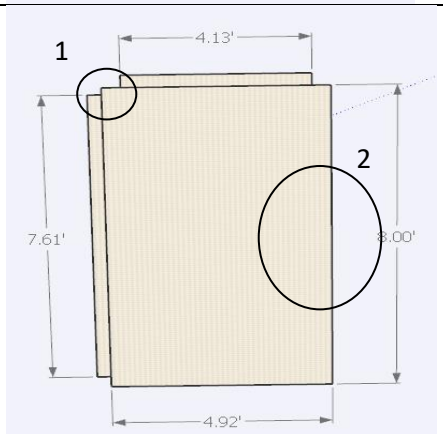
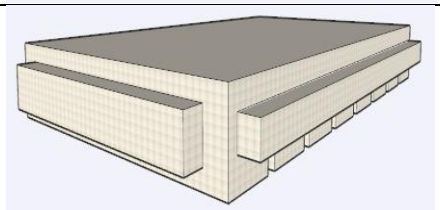
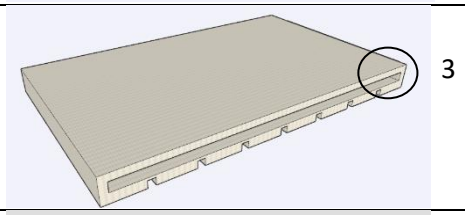
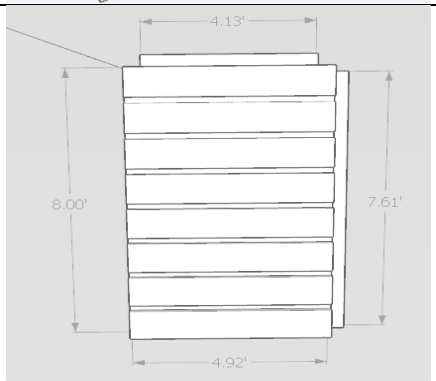
Dimensional guide design of Bamboo Metal Roofing

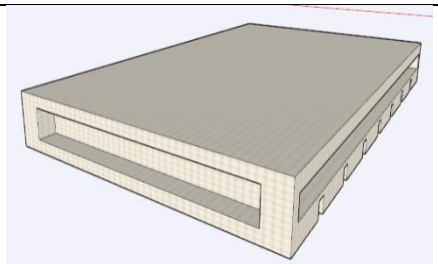
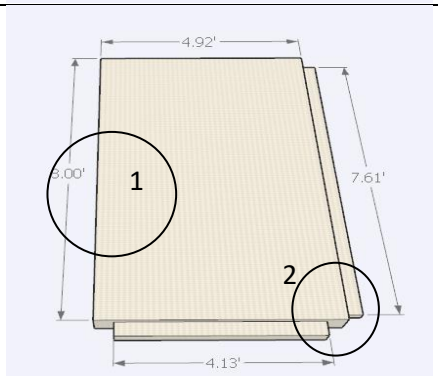
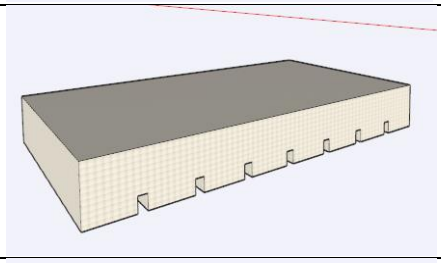
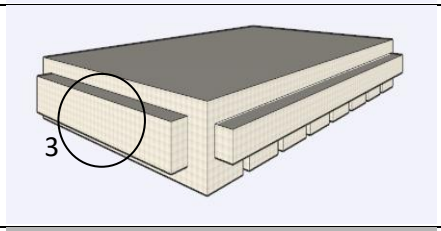
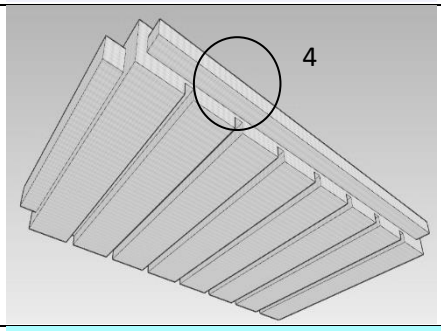
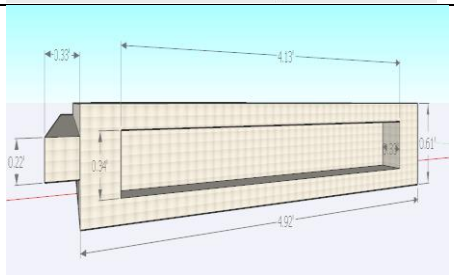
The following section presents the illustration of the dimensional guide design of the proposed Bamboo Metal Roofing Panels. The proposed Bamboo Metal Roofing concept was inspired by Lego which is easy to install because it does not use any screws or nails as its binder (Bao & Li, 2020). Moreover, it was also designed to minimize the installation problems, corrosion, and oil canning of metal roofing. The proposed dimensional guide design for this study is applied for three main components (i.e., the left side of the roof, the middle side of the roof, and the right side of the roof) as presented in Table 1. With the aid of Google SketchUp, the proposed dimensional guide design of bamboo metal roofing is able to be visualized clearly.

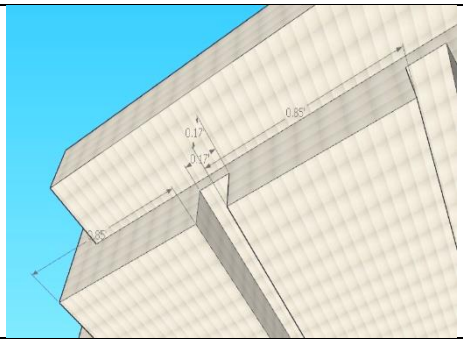
The purpose of the dimensional guide design is for faster retrieval of data (Jindal et al., 2016). The aid of the table (as shown in Table 1) enables users (i.e., owners, contractors, developers, and suppliers) to retrieve data faster from different data sources and easily generate queries (i.e., request for quotation). Other than that, the dimensional guide design presents a better understanding of the business processes. As such, the categorization of data into dimensions, and the entity-relationship structure of the dimensional model present a complex business process in a simple and easy-to-understand manner. In addition, the dimensional guide design allows the designer to easily modify the design to incorporate any new business requirements or produce any adjustments to the central repository. The new data can be added and changed to the table and modified in the business processes.

Table 1
Proposed the dimensional guide design for Bamboo Metal Roofing

Proposed dimensional guide design area	**Illustration**	**Dimension**
The left side of the roof a) top		8.00'(l) x 4.92' (w)
b) 3D dimension at 1		
c) 3D dimension at 2		
d) Bottom		
e) Panel connection at 3		0.33'(w) x 0.22'(d)

f) 3D dimension at 4		7.67’(l) x 0.22’ (d)
g) 3D dimension at 5		4.13’(l) x 0.34’(w) x 0.33’(d)
Middle design of the roof a) Top		8.00’(l) x 4.92’ (w)
b) 3D dimension at 1		
c) 3D dimension at 2		
d) Bottom		8.00’(l) x 4.92’ (w)

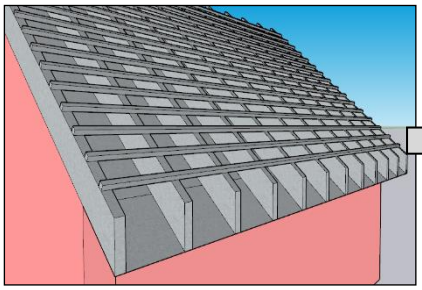
e) 3D dimension at 3		
Right design of the roof a) Top		8.00'(l) x 4.92' (w)
b) 3D dimension at 1		
c) 3D dimension at 2		
d) Bottom		
e) 3D dimension at 3		4.92' (l) x 0.61' (d)

f) 3D dimension at 4		0.85'(w)

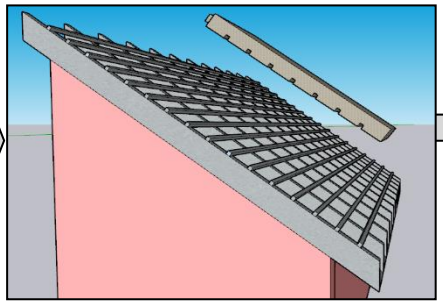
The potential impact of Bamboo Metal Roofing

The combination of bamboo and metal becomes a primary component in this study to enable the prevention of existing problems (i.e., corroding, lack of proper installation, natural defects, and unsafety) of metal roofing. Bamboo is one of the materials that have a longer lifespan, and higher strength which can provide support towards the strength of metal as a roof. It is also a green material that is easy to find in this country (Dauletbek et al., 2022). The advantages of Bamboo Metal Roofing are compared to the existing common metal such as the corrugated metal roofing and the standing seam metal roofing in terms of its installation, environment, and cost criteria. As such, the corrugated metal roofing has a problem with loose fasteners due to natural expansion and contraction of metal. Moreover, the corrugated metal roofing is heavy which is difficult for installation and leads to more workers during the ***installation*** process on site (Setyanto et al., 2020). Whereas the standing seam metal roofing is easier to install compared to the corrugated metal roofing but the roofing panel may leak if the trim is not well installed (Habte et al., 2015; Choi et al., 2021).

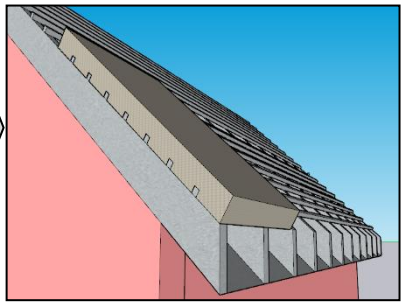
In terms of ***environmental*** criteria, the corrugated metal roofing may produce a noisy environment, especially during windy weather or severe storm (Yadav et al., 2017). Whereas the standing seam metal roofing has problems with oil canning (Graham, 2015). In many cases, when oil canning happens, the standing seam metal roofing will become wavier and more wrinkled.



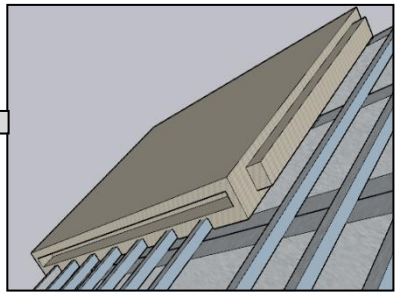
1) Installation of roof rafters and battens



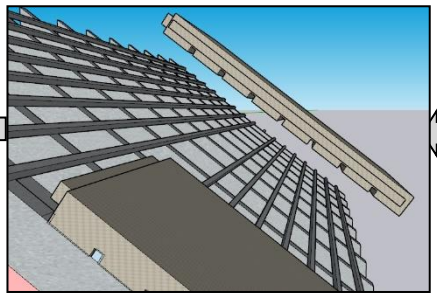
2) The left panel of the bamboo metal roof has been hoisted using a mobile crane to be placed on the roof structure



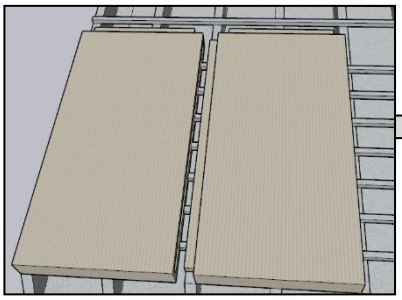
3) The left panel of the bamboo metal roof is being attached to the roof structure.



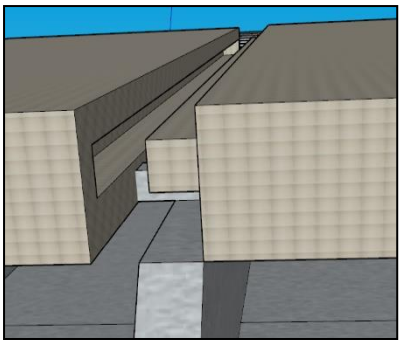
4) The view of the middle bamboo metal roof panel attached with the left bamboo metal roof.



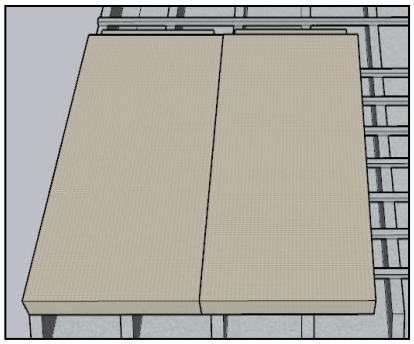
5) The top view of the left bamboo metal roof.



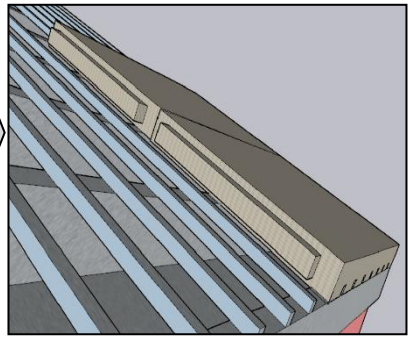
6) Two panels of the bamboo metal roof is attached with each other.



7) Detail connection between both panels.



8) The front view of both attached panels.



9) The side view of both attached panels.

Apart from that, in terms of ***cost*** criteria, the corrugated metal roofing is cheaper compared to the standing seam metal roofing (Cranston et al., 2016). However, due to the overlapping panels, corrugated panels will lose square footage during installation. Thus, this will raise the entire cost of work when employing metal panels. Compared to the standing seam metal roofing, it is more costly and the process to obtain this roofing is complex. This includes making an order with a standing seam metal roofing manufacturer which may be difficult to produce small amounts of standing seam roofings at one time (Choi et al., 2021). Consequently, the proposed Bamboo Metal Roofing is targeted to improve these three (3)

criterias'. The following section discusses the viability of the proposed Bamboo Metal Roofing in terms of installation, environment, cost, and quality of construction.

The proposed Bamboo Metal Roofing involves a simple, easy, and fast ***installation***. As such, the proposed Bamboo Metal Roof Panels are brought from the manufacturer to the site using a lorry or trailer and placed in the proper storage. The installation of the Bamboo Metal Roof Panels uses a mobile crane for hoisting it to the roof structure. There are approximately 6 workers required during the installation. The installation of the Bamboo Metal Roof Panels may start after the rafters and battens of the roof have been installed as shown in (1) Figure 11. Next, the left panel of the bamboo metal roof is brought using the mobile crane (2) and attached to the roof structure (3). After the installation of the left bamboo metal roof, the middle bamboo metal roof will be attached (4). The connection between both panels employs the concept of lego which does not use any nails or screws (Bao & Li, 2020). As such, the middle panel will be inserted into the left panel and soon locked together securely (6-8). The lego concept employed to attach the Bamboo metal roof panels has similar patterns of panels (i.e., consisting of three basic designs) that allow faster construction on site (Musa et al., 2016). Furthermore, it allows the installation of the Bamboo Metal Roof Panels to occur simultaneously on site and reduces the timeline of the project. Other than that, this lego concept will lower the cost of failure due to a lack of problems during the installation process.

Bamboo Metal Roofing which consists of bamboo provides attractive features and is ***environmentally*** friendly due to its ability to absorb carbon dioxide and produce oxygen. As a result, it is useful for air protection, reducing negative effects, and playing a key role in improving human ecosystems and comfortability in their buildings. Other than that, the indoor construction environment also reduces the risk of accidents due to the lack of use of nails or screws on site. As a result, it may also lower the ***cost*** of construction for the building (Jangde & Waghmare, 2015). Likewise, the design of Bamboo Metal Roof Panels can be reused and is long-lasting as it is correctly placed. This situation will eliminate the waste of recycling materials, enable the control of the site inventory, protect the building materials as well as the ability to minimize cost (i,e., material management) (Lawson & Ogden, 2010). The Bamboo Metal Roof Panels are less exposed to humidity, rain, and snow and are resilient to adverse weather conditions which may cause the potential for a high level of moisture (i.e., can cause mold growth) and damage to the panels. Apart from that, the ***quality control*** for the manufacturing process at the factory is better due to the streamlined assembly process. As a result, it benefits the tradesman to install the electrical wiring and heating to the panels and is able to work comfortably in completing the roof installation.

Hence, to ensure that Bamboo Metal Roofing is accessible to customers, various strategies should be taken by construction players in the Construction Industry. The attractive features and durability of Bamboo Metal Roofing is the potential to market either locally or internationally market. As such, the awareness campaign about using Bamboo Metal Roofing can be spread using social media platforms (i.e., Instagram, and Facebook). These platforms are fun, easy ways to connect with customers and bringing are more people and prospects to the business product of Bamboo Metal Roofing. In addition, promoting strategy by e-commerce marketing via official websites, and blogs will manage the buying process, product development, and payment modes and enables easy exports. Therefore, these mentioned strategies will enhance the development of Bamboo Metal Roofing in the construction industry as well as protect, save the earth and global environment.

Conclusion

This paper proposed Bamboo Metal Roofing in improving the existing metal roofing. The proposed Bamboo Metal Roofing is made up of Bamboo, Metal, Polyurethane foam, Polyurethane Adhesives, and Epoxy Coat that goes through six manufacturing processes (i.e., adhesive, cooling, cutting, coating, stacking, and wrapping). The proposed Bamboo Metal Roofing is viable to be used on construction sites due to its great potential impact. This is due to its simple, easy, and fast installation, being environmentally friendly, cost-effective (i.e., material management), and producing high-quality construction. Hence, further research should be emphasized on the experimental, application, and effectiveness of Bamboo Metal Roofing on construction sites. The evaluation aspects in terms of physical properties (i.e., ductile, malleable, heat and electricity conductors, melting and boiling points, density, and strength), usability, durability, and maintenance also require further research.

The study contributes to the proposed innovative idea for Bamboo Metal Roofing (i.e., components, manufacturing process, dimensional guide design, and potential; impact). Those parties (i.e, contractors, suppliers, and manufacturers) who are interested in promoting their green building material business may find these ideas helpful in guiding their efforts.

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