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Environmental Design of Emergency Prefabricated Structures with the Approach of Reducing Energy Consumption and Pollution

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Abstract
Providing temporary housing has always been one of the challenges facing crisis management organizations in the aftermath of natural disasters. Therefore, prefabricated structures are usually used for this purpose. Prefabricated structures are predominantly box-shaped. Among the problems of this form is the need for more heavy vehicles for transportation, which leads to increased consumption of fossil fuels and air pollution. This study proposes a structure that is broken down into smaller parts to reduce transportation. Moreover, a set of rails and a large pin component were designed to facilitate movement and folding/unfolding, which reduces the need for specialized manpower. Rhinoceros 3D software and Grasshopper plug-in were respectively used to model the structure and make rotations. In addition, the optimal packing angle of the structure was calculated through a comparison between the Genetic algorithm and Surrogate model. The quasi-hemisphere model designed in this research can optimize more than 50% of fuel consumption due to reduced transportation and provide faster relief.

Keywords: Air pollution; Energy; New materials; Prefabrication; Transportation

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Introduction

Population growth and, consequently, the increase in demand for housing in recent years have led many countries to adopt prefabrication as a “clean” construction strategy. Many governments incorporate the use of prefabricated buildings into their development plans to fulfill their demand. Researches show that proper adoption of prefabricated construction requires a political, economic, social, and technological analytical framework. Providing decent and affordable housing is a major challenge in emerging industrial countries, where conventional construction methods put a lot of pressure on resource costs and productivity, especially in dense metropolitan, rural or remote areas. Prefabrication can provide a good opportunity for environmental and economic activity, which makes it a fitting alternative for on-site construction.

Contrary to popular belief, prefabrication is not a new construction method; it has been widely used for years. Moreover, the method is not necessarily based on high-tech approaches, but rather is suitable for low-income societies. Research on the use of prefabrication in China, Colombia, India, Mexico, and Nicaragua has shown that under the right circumstances, the method reduces cost and creates employment opportunities for both men and women. The history of prefabrication goes back to Scotland. In 1829, the use of corrugated metal sheets in construction became highly popular. Since then, the sheets went on to significantly contribute to the development of the prefabrication industry.

Prefabricated construction is advantageous in many ways such as reducing debris and environmental degradation during the life-cycle of buildings. It is clear that with the passage of time and with the advancement of technology in the field of analysis, design and manufacture of prefabricated components, today elements and materials are used that have the least risk to the environment and bring maximum energy conservation for users. Prefabrication also saves time and money, facilitates energy optimization, and is regarded as a major solution for the dangerous and energy-consuming practices associated with conventional construction methods. To maximize the profitability of prefabrication, our future focus must be directed to financially supporting the technological development of prefabrication, structurally optimizing prefabricated buildings, and improving the prefabrication market.

The aim of this study was to explore ways to protect the environment by reducing transportation, air pollution, and the energy consumption of prefabricated houses, as well as ways to allow the assemblage without skilled workers.

Materials and methods

Rhinoceros 3D was used to model the design. Having modular components in the structure, the Grasshopper plug-in was used to make rotations. To ensure minimum space occupation by the structure, the optimal packing angle was calculated through a comparison between the Genetic algorithm and Surrogate model. The walls were made of fiberglass cladding, two-sided polyurethane insulation over an alloy steel interwoven wire mesh, and another fiberglass cladding layer from outside to inside.

Discussion of Results

Studies suggest that providing temporary housing is one of the challenges of crisis management organizations always confront with after the natural disasters such as earthquakes. To solve this issue, these organizations tend to use prefabricated structures like shipping container housing units. However, one problem with these structures is their transportation; due to their inflexibility, only a few can be packed into a truck for shipment. This immensely increases heavy-vehicle traffic which is a major contributor to air pollution. The emission of carbon monoxide, nitrogen oxides, hydrocarbons, and particles by fossil fuel-based vehicles cause air pollution. Besides, service delivery to large populations slows down which is something crisis management tries to avoid.

In general, temporary structures are two types: fragmented and integrated. All the problems mentioned above are inherent to the first type. By allowing more assemblable parts to be packed into each truck, integrated structures reduce transportation difficulties. However, they pose another problem: the need for many skilled workers to assemble the parts.

Most prefabricated structures are box-shaped which means that most of their surface becomes shaded in winter and exposed to strong sunlight in summer. It necessitates the need for cooling, heating, and ventilation systems in different seasons. However, these systems pose many issues in a temporary housing setting including heavy use of fossil fuels, the burning of which releases many pollutants into the air. The local environment of a crisis region may not be able to quickly clean the polluted air, causing breathing difficulty in small, densely-populated areas. Some heating systems, e.g. electric heaters, can also cause fires and other incidents.

On the other hand, ordinary buildings are extremely difficult, time-consuming, and costly to build in a crisis situation. Such buildings release large amounts of pollutants into the environment annually using masonry materials like cement and bricks.

Taking these factors into account, a type of prefabricated structure should be designed to be more optimal than the existing models in terms of pollution, transportation, and reliance on cooling and heating devices. One should keep in mind that because disaster survivors sometimes have to live in temporary housing for a long time before things go back to normal, architectural design values must be maintained in such settings as much as possible to improve their satisfaction.

Accordingly, after an extensive study of energy-optimal architectural forms, the quasi-hemispherical form was chosen for our proposed design. The reason behind this decision is that this shape reduces the need for cooling and heating systems becoming half-shadowed in summer and half-sunlit in winter, respectively—more shadow and sunlight than what a box receives in the same seasons. It is worth noting that the sphere has the smallest surface-to-volume ratio among basic three-dimensional shapes. It means that spherical objects have the least contact with cold or warm air and, thus, reduce heat transfer more than any other form. Furthermore, there is lesser need for additional structural preparations in spherical buildings due to their compressive behavior (load transfer is compressive in curved structures) which in turn reduces the used material. As a result, the activity of material producing factories is decreased helping to reduce air pollution.

Fragmentation of the structure into the smaller parts is a good solution for the transportation problem because it allows many more parts to be transported in each shipment. However, it also requires skilled workers for assemblage and installation. To solve this issue with our proposed model, a set of rails and a large pin component were designed for the convenient movement and folding/unfolding of the structure, respectively. Each panel of the hemisphere is designed smaller than the preceding panel to allow the structure to both fold perfectly and occupy less space. When the structure is completely unfolded and the rails are locked, a series of gaps appear where the sections meet. They will be covered by plastic sealing tape to prevent rain penetration and energy waste.

Adapting to Iran's overall hot desert climate and water scarcity, Persian architecture has historically sought to compensate for the harshness of nature., The Abbasi Great Mosque (also known as the Shah Mosque and Imam Mosque) in the Isfahan's Naqsh-e Jahan Square is a remarkable masterpiece that has been survived after many years from natural disasters in the harsh climate of the city. It attests to the efficiency of the quasi-hemispherical form in terms of energy conservation, material use reduction, and structural strength. The current design draws on and modernizes the architecture of Persian domes.

Choosing the right materials for the walls was a challenging part of this project because the optimal materials are needed to work well as thermal insulators and be structurally strong. They should also be flexible enough to be curved efficiently. Accordingly, the walls were made of fiberglass cladding, two-sided polyurethane insulation over an alloy steel interwoven wire mesh, and another fiberglass cladding layer from outside to inside.

To reduce the transportation, structure was divided the into smaller parts. In addition, a collapsible design of the structure was considered to obviate the need for skilled workers for assemblage. Transportation regulations do not allow trucks to carry loads longer than 12 m, wider than 2.60 m, and higher than 3 m. Therefore, the Genetic and Surrogate optimization algorithms were used to calculate the best packing angle. The Genetic algorithm produced a more optimal answer.

Standard shipping container housing units are 6.1 or 12.2 m (20/40 ft.) long and 2.44 m (8 ft.) wide. In each shipment, only one large-sized standard container (12.2 m × 2.44 m) can be transported which provides a living space of 29.76 m^2. Meanwhile, at least two units of our design accompanied with a "connector part," are transportable in each shipment providing a total of 65.33 m^2 living space. In

addition to energy conservation properties, the design is given architectural features that make it more comfortable to live in. Units can be joined using a connector part as a link to create larger spaces for big families. If each family is given one quasi-hemispherical unit, two displaced families will be sheltered by each shipment.
Thanks to its well-designed architectural features, the units can conveniently house families of 4 to 6 and could also be used as single-occupancy units to speed up emergency care if necessitated by the size of the affected population. The prefabricated building design discussed in this research, with a significant reduction in greenhouse gas emissions, energy consumption, transportation and pollution in order to preserve the ideals of the environment.

Conclusions

Awareness of the negative impacts construction on environment has generated public concern. Prefabrication is a method used to improve construction quality; however, there is a lack of scientific research on the instances where prefabricated structures were built for environmental protection. Many researchers have proposed ways to reduce not only the impacts of the construction industry on humans and the environment, but also all the activities that contribute to the climate change. Providing temporary housing has always been one of the challenges that crisis management organizations face in the aftermath of natural disasters, like earthquakes. To solve this issue, these organizations tend to use prefabricated structures like shipping container housing units. However, one of the difficulties these structures pose is their transportation which heavily increases the traffic of heavy vehicles. In general, an impact of inter- and intra-city transportation is the release of carbon monoxide, nitrogen oxides, hydrocarbons, and particulate matter by fossil fuel-based vehicles. The density and diffusion of these pollutants are depending on the speed, velocity, and on-site operation of vehicles. This study proposed a structure that is panelized to reduce transportation with a collapsible design to allow assemblage without skilled workers.