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Design and prototyping of a FRCC modular and climate responsive affordable housing system for underserved people in the pacific island nations

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ABSTRACT

This paper outlines the process of design and prototyping of a modular housing system aimed at serving the needs of people in the Pacific island nations. Many people in these islands are economically challenged and live in sub-standard housing at low elevations, making them vulnerable to increased tropical storms brought about by climate change.

A collaborative team comprised of architecture and engineering faculty and students is currently developing a system to address the need for improved housing in the Pacific islands based on the criteria of affordability, customizable design, thermal comfort, durability, sustainability, and local reproducibility.

To best address the design criteria, the team reviewed indigenous building and tropical architecture literature, studied climactic factors, formed alternative design strategies, and selected the most promising for further development. A method of using precast fiber-reinforced cementitious composite (FRCC) modular components was chosen, with a limited number of parts to lower unit cost. The assembly was designed to allow homeowners to participate in the construction process, and the house is adaptable by adding or reconfiguring modules. To provide thermal comfort, the design evolved to include shading overhangs, a narrow floor plate, porous walls, and a ridge vent for stack ventilation. Durability is addressed through structural design and material selection. The structure is designed to withstand anticipated hurricane and storm surge events. Local reproducibility is sought by using materials and methods of construction possible with moderate workforce training and minimal capitalization costs.

A successful housing system for the Pacific Islands must address cultural, environmental, constructional, and structural factors, and therefore benefits from a collaborative design approach involving both architects and engineers. The proposed system as developed to date appears to be a promising solution to provide affordable, sustainable, and resilient housing for underserved people in the Pacific islands. Pending availability of funding, a first prototype house is slated for construction on a Pacific island site and evaluated for cost, thermal comfort, climate effect resistance, and occupant satisfaction.

1. Introduction

The purpose of the project is to provide an affordable, sustainable, thermally comfortable, and resilient housing solution for tropical Pacific islands. There are a number of challenges to face in providing improved housing in this context. Over 40% of the population in the Pacific Islands lives in inadequate housing that does not meet the United Nation's minimum housing standards. The majority of current housing is too expensive for average or low-income people, does not provide safe and resilient construction or hygienic conditions, and is ill fitted to the social, cultural, and environmental context [6]. Many housing settlements are situated at elevations very near sea level and are therefore vulnerable to storm surge. The Pacific islands have a high percentage of shoreline in relation to land area, making them particularly vulnerable to the effects of climate change, rising sea levels, and storm events [7]. These climate effects have and will continue to

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impact wage-earning capacity as the major industries – such as tourism, fishing, and agriculture – depend on more stable sea level conditions. Due to the difficulty in maintaining traditional methods of living off the land and sea, in addition to other factors, large numbers of people are migrating to the urban areas in hopes of finding employment [15].

To respond to conditions in the Pacific islands and address the area of housing, a primary set of project goals was established:

1. *Quality housing*: Provide affordable, sustainable, resilient, and thermally comfortable housing.
2. *Cultural responsiveness*: Allow people to reconnect with their traditional culture and way of life.
3. *Job creation*: Facilitate startup of new industries to prefabricate and erect improved housing, and incorporate local cultural/climatic expression in housing design to bolster the tourist industry.

2. Methodology

The first phase of the project included research on the conditions in the Pacific Islands, including climate, economy, indigenous housing, and current housing stock. This research provided a basis for designing the housing system.

The project is currently in the second phase that includes design, simulation, prototyping, and component testing. The design has now evolved to address the project goals and design criteria. A penultimate design solution was defined, and one key modular component was prototyped using actual materials. This channel slab component was subjected to structural testing to determine resistance to anticipated dead, live and wind uplift loads. It is anticipated that all other key components will be similarly tested, along with the critical connections between them. In addition, simulations were conducted to evaluate building envelope thermal transfer and natural ventilation, and to compare the findings with a standard house being built in the Republic of the Marshall Islands.

The third phase will be carried out pending financial support. A first prototype house is proposed to be constructed using local labor under the supervision of the research team. It is anticipated that this prototype will serve as a demonstration house and will result in a demand for more houses built using the improved modular system.

3. Background research

3.1. Climate and topography

The islands of the Pacific are characterized as continental, volcanic, atolls, and raised limestone types [4]. In the low-lying atolls, elevations rarely exceed a height of two meters above sea level, making the threat from sea level rise and the effects of climate change serious and immediate[11]. They are especially vulnerable, because their fresh water reserves are shallow and susceptible to drought and contamination from salt water [3]. Islands formed by volcanic action may have much more dramatic topography. However, settlement has typically been at lower elevations and close to the shoreline.

The majority of the Pacific Islands are in the hot and humid tropical climate zone. Temperatures do not vary much over the year, staying between 26 and 32 °C. Most islands have a dry season and a wet season, with the length and timing of each varying based on regional factors [8]. The islands are also vulnerable to typhoons, hurricanes and storm surge. Storm events have been increasing in intensity and frequency in recent years [3].

3.2. Economy

Besides having to suffer the effects of inadequate housing, many Pacific Islanders struggle to provide for their own basic needs. The economy needs to grow and offer more and better paying jobs. In the Pacific island nations, formal work occupies only 20% of the population, mainly in service and administrative jobs, and unemployment rates are high [15]. The tourist industry is an important economic driver for many Pacific islands. Tourists are attracted to expressions of local culture, including the traditional houses and villages [10].

One solution to providing higher quality houses and augmenting tourism revenue would be to initiate the rebuilding of traditional housing. Unfortunately, the materials and methods to build such houses are mostly unavailable. In addition, the traditional houses are often unable to withstand hurricane force winds, and require frequent maintenance to maintain weather resistance. As a result, few traditional houses remain [12].

Contemporary low-cost houses predominantly rely on imported materials and are built using a concrete slab on grade, concrete masonry walls, and a corrugated metal roof. Small islands suffer from an economy of scale and encounter high costs for shipping [13]. Therefore, it would be advantageous to develop economical and robust building systems that limit the quantity of imported material and that are instead fabricated and constructed locally.

3.3. Materials and practices

Originally, Pacific island houses used natural local materials to make timber or bamboo frames, woven reed mat walls, and thatch roofs (Fig. 1). These houses were built by local people, in a group process with local knowledge and material, representing self-sufficiency, a connection to the natural environment, and strong social ties [12]. However, the housing has changed progressively since Western contact. The change in housing is strongly linked to social, economic, and environmental factors [12]. In many islands, non-natives have influenced islanders to build in a Western style. Each island has its particular history, but islanders have continuously both resisted and adapted to the colonizer's way of building. Traditional housing was characterized by open frame family and meeting houses set in a collective village formation that forged a strong sense of community. In many Pacific island areas, a

Fig. 1. Example of a traditional Pacific island house (*Source*: Wikipedia.org).