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Efficient Building Modifications: The Case for Flexible and Modular Structural Composition of Buildings

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ABSTRACT

Modular construction has long been utilized in the construction of residential and many other commercial product types as a means for potentially quicker construction delivery times. A modular building is a pre-engineered structure that is flexible enough to satisfy virtually any requirement tougher than standard drywall construction, expandable, can be relocated and completely re-usable. One obvious advantage that modular construction has over conventional construction is cost. It can not only save up to 35% on the initial construction costs like labor and materials, but there are other benefits as well. It has been found that Modular coordination is an outstanding choice having a minimum on-site modification and material wastage. This paper addresses the numerous advantages of modular systems present in both design and construction works viz a viz buildings' flexibility that could be applied to enhance modification.

INTRODUCTION

Building a project is expensive and most times, hard to change later. The need to expand or contract the use and size of buildings may arise due to changes in buildings functions. These modifications sometimes come at very great inconveniences. A not properly planned and coordinated modification most times would present varying challenges ranging from health, safety, hazards issues to high costs and time waste. The challenges that are present in "conventional" design and construction systems have made it imperative for designers' world over to look critically at the possibility of using flexible" Modular" structural compositions and construction systems to make modification works less cumbersome. Design and construction choices and patterns in forms of material types, construction methods, size and volumes of spaces, etc affect the overall project outlook and design sustainability. Slaughter (2001) argues that three general types of changes can be expected to occur in course of a building's life changes in the function of the space, changes in the load carried by the systems of the building and changes in the flux of people and forces from the environment. These changes come at a very high inconvenience sometimes. It is not made any easier with the thought or realism that this could have been handled or provided for from the onset by more flexible design options. Flexible options that could be modular in composition. This paper addresses the challenges faced by industry professionals and project ones in modification works.

DEFINITIONS

Modular Design or "Modularity in design" is a design approach that subdivides a system into smaller separate component parts called modules or skids. (Wikipedia encyclopedia)
The Cambridge dictionary defines a "**Module**" as one of a set of separate parts that, when combined, form a complete whole.
The Oxford Living dictionaries also defines a "**Module**" as each of a set of standardized parts or independent units that can be used to construct a more complex structure, such as an item of furniture, building etc.

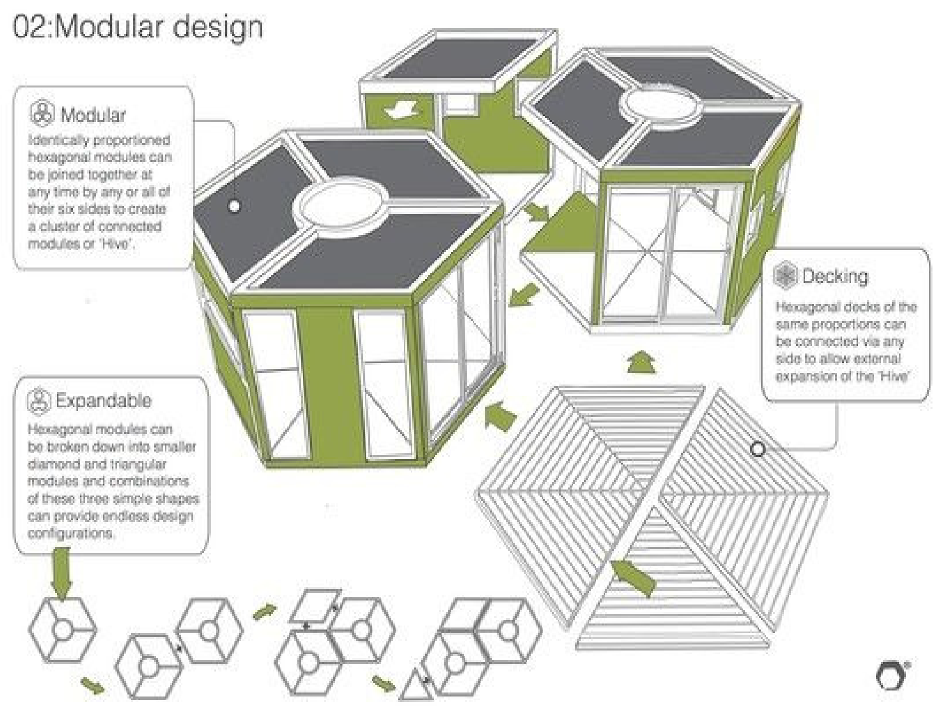

Figure 1: Showing Modular Design Possibilities

A modular system can be characterized by functional partitioning into discrete scalable, reusable modules; rigorous use of well-defined modular interfaces; and making use of industry standards for interfaces. It is a self-contained unit or item which can be independently created, connected or combined together with others like it to create different shapes of designs for a system. The beauty of modular architecture is that you can replace or add any one component (module) without affecting the rest of the system.

Flexibility and Modularity

The Merriam Webster dictionary defines "**Flexibility**" as the capability to adapt to new, different, or changing requirements Also, Upton (1994) more specifically describes "**Flexibility**" as a reflection of the ability of a system to change or react with little penalty in time, effort, cost or performance. Flexibility has for a long time been a subject of interest for architects. This has resulted in many buildings with open, changeable planning around fixed service core. However flexibility doesn't simply imply the necessity of endless change and breakdown of accepted formula. The incorporation of "flexibility" into the design allowed architects the illusion of projecting their control over the building into the future, beyond the period of their actual responsibility for it. The main feature of a flexible design is that it is adaptable. Flexible design distinguishes between the load-bearing structure (structural framework and floors), the facades and installations. Flexibility must be seen as a proactive attribute designed into a system, rather than a reactive behavior. Edmonds and Gorgolewski (2000) for example, view buildings flexibility as incorporating, at the design and construction stage, the ability to make future changes easily and within minimum expense to meet the evolving needs of the occupants. General design approaches

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to increasing flexibility and more specific design strategies are also distinguished. The approaches proposed include physically separating the major building systems into smaller (modular units) and prefabrication. The design strategies include reduce inter-system interactions, reduce intra-system interactions, use interchangeable system components, increase layout predictability, improve physical access, dedicated system zones, enhance system access proximity, improve flow, phase system installation and simplify partial/phased demolition. Because modular systems are designed with flexibility in mind as component units rather than a solid or monolithic whole, it thus goes to give that they aid building flexibility.

Forms of Modular Systems

Modular Units

Modular units are totally prefabricated offsite and brought to site as a complete unit and joined to another complete unit. No extra internal detailing and fittings are needed to complete the functions that the unit is expected to perform.

Figure 2: Showing Modular Units

Modular Sections

Here, the whole unit is manufactured in possible standardized sections and these sections are individually assembled onsite to form the units. They can also be assembled into a complete system and not necessarily in units that form the system.

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Figure3: Showing Modular Sections

Attributes and Benefits of Modular Designs

The use of modular and other lightweight forms of building construction is increasing. The benefits of modular construction, relative to more traditional methods, include:

- Adaptable for future modifications, and ability to be dismantled easily and moved if deconstruction is required (flexibility of use)
- Economy of scale through repetitive manufacture
- Rapid installation on site (6-8 units per day)
- High level of quality control in factory production
- Low self-weight leading to foundation savings
- Suitable for projects with site constraints and where methods of working require more off-site manufacture
- Limited disruption in the vicinity of the construction site
- Useful in building renovation and remodeling projects
- Excellent acoustic insulation due to double layer construction
- Robustness can be achieved by attaching the units together at their corners
- Stability of tall buildings can be provided by a braced steel core

Interesting Examples of Modular Designs

The Kasita, Austin, Texas: An Austin-based start-up has created a prototype of a prefabricated micro dwelling that can be slotted into a framework like a bottle into a wine rack. The micro-housing called Kasita – adapted from the Spanish word for a small house – was launched by a professor-turned-entrepreneur who once lived in a dumpster.

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Figure 4: Showing the Kasita Building

The mobile structure is a rectilinear pod clad in metal and glass, with one side featuring a cantilevered glazed box. It is intended to slot horizontally into an engineered steel frame, or "rack", which can include many units stacked high and wide. Designed to be assembled in under a week, each Kasita would be able to swap between different racks.

Figures5: Showing the Kasita's Individual Units

Nagakin Capsule Tower, Tokyo, Japan; Designed by KishaKurokawa, the Nagakin Capsule tower consists of 140 self-contained prefabricated capsules, complete with bathrooms. The tiny capsules, are designed to be removable and replaceable.

Figure6: Showing the Nagakin Capsule Tower

Figure 7: Showing an Individual Pod

METHODOLOGY

Although modular technology has been around for decades, the technology does not exist in many countries especially Nigeria and very limited examples exist that have been completed or are under construction. As such, large data set analysis is not currently

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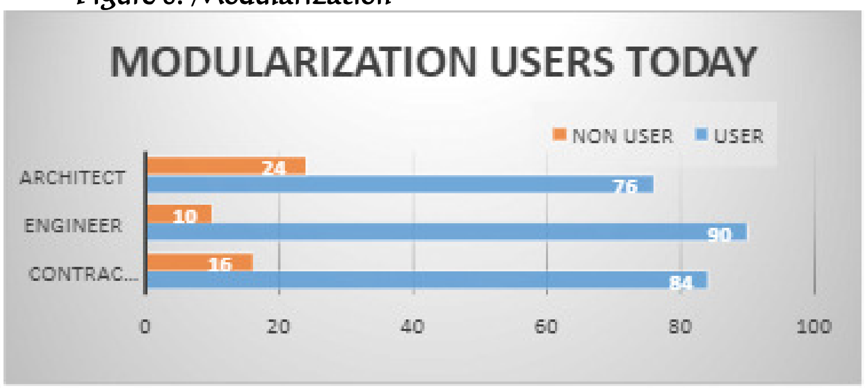
possible and analysis must be limited to the few dozen projects available for review around the world. In light of this data set, the methodology of research primarily relies upon literature review, interviews, case studies and financial analysis based upon scenarios of available construction data.

DISCUSSION

Modular building processes are now not new, from about 5 years the usage of modularization in construction is raised to 63%. It is expected that about 85% of the industry players today are using these processes on some projects-including 90% of engineers, 84% of contractors and 76% of architects shown in the figure.

Figure 8: Modularization



Source: Smart Market Report

Traditional contracts and on-site construction practices rigidly delineate responsibilities with much elaboration on the consequences of failure. This context reinforces risk-abating behavior, causing project teams to not engage in collaborative processes and present an adversarial construction culture, much to the disadvantage of all stakeholders. Owners are losing money on projects, architects and engineers are not seeing the quality of design increase, and contractors are bearing a great deal of financial burden and risk in the process. This fragmentation has been quantified in terms of waste and productivity.

Construction is essentially the design and assembly of objects fixed-in-place. Therefore, traditional buildings are site-produced goods, unique every time, and employ temporary teams – this triad might be called the peculiarities of construction, distinguishing it from other production industries. To make this process more productive we can remove the site, not make the building unique, and keep labor intact from project to project. Removing the site altogether is clearly not possible, but removing the site peculiarities to a degree vis-a-vis factory production certainly helps. Keeping teams in tact is an idea that has brought success to design-build entities and designers or builders who continually engage with the same engineers, contractors, and subcontractors. Modular production has the capacity to keep teams more intact by controlling the workflow. Finally, the uniqueness of the building design and production process is a variable that may in fact be controlled (or segments within the work flow at least), removing waste and adding value in the building process.

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Further comparing construction to manufacturing, according to the U.S. Bureau of Labor Statistics, 57%, of activities in construction are wasteful and non-value adding. These are activities that are not compensated. Manufacturing is directly opposite with 62% of all activities being value adding. Replacing the wasteful elements of construction with manufacturing benefits through modular processes can remove waste and increase value for projects.

Increasing construction efficiency through modular requires examination of construction performance. Every project must consider a number of performance factors including:

Cost: Capital and operational investment
Labor: Skilled and unskilled human workforce
Scope: Extent or breadth of project program
Quality: Meeting or exceeding design and construction goals
Risk: Exposure to potential financial loss

Although not all of the factors will be equally valued in any given project, they generally have a contingent relationship to one another. For a given program, the design team usually establishes relationships, maybe even unknowingly, between quality, schedule, and budget where one change affects all the others. For example, an owner team may opt to select a lower quality material in favor of saving cost or allow the project to be completed on time. In this balance of factors, risk plays a critical component.

Off-site and permanent modular in particular, is not a blanket solution to every building project. As such, the principles of cost, schedule, labor, scope, quality, and risk represent a sliding scale of opportunity and tradeoffs rather than definitive answers. When enacted intentionally and with pre-planning, modular construction can be a solution to help find balance between these sometime competing performance goals of construction. Off-site delivery and early planning are co-lateral concepts. Engaging the off-site fabrication industry early in the design process to help solve this equation is fundamental to successful utilization of the off-site design and construction process.

Much research has been performed and is ongoing regarding the benefits of off-site construction. Documented benefits of off-site construction versus traditional on-site construction include:

- Shorter construction schedules
- Greater degree of predictability in cost
- Reduced material waste
- Reduced carbon emissions due to transportation to and from site associated with on-site construction
- Reduced site disturbance, and finally
- An increase of safety and security of laborers and trade equipment.

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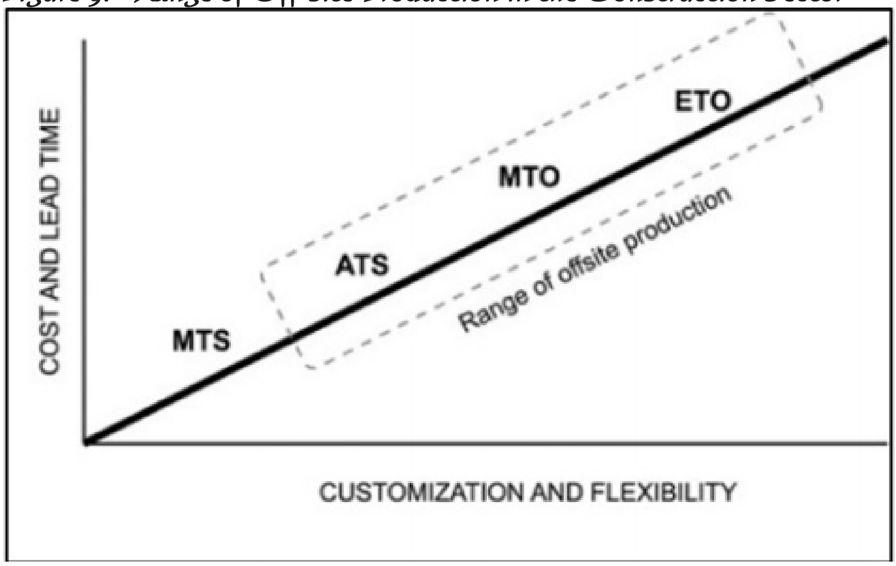
Labor productivity has shown an increase of 30% on off-site projects when compared with on-site projects. Ultimately, risk is reduced with off-site construction. (McGraw Hill 2009; FMI 2013; Mortenson Construction 2014; Quale et al 2012)

Figure 9: Range of Off-site Production in the Construction Sector



Source: Graph courtesy of R.E. Smith

Numerous projects have demonstrated that schedule savings are the most easily documented and noticeable savings that occurs as a result of modular construction. Savings from 15% - 50% by virtue of modular construction is not uncommonly reported. This is due to concurrent site and factory work, as well as factory production being faster than on-site framing, removing weather delays and subcontractor sequence delays associated with on-site construction.

Clearly, material waste is reduced because fall off is recaptured in the manufacturing stream. However, the greatest environmental benefit demonstrated by off-site construction documented in a recent publication in the Journal of Industrial Ecology *is* attributed to the reduction in transportation energy and carbon as a result of workers commuting to a factory instead of the job site and supply yards throughout the day. (Quale et al 2012) Modular and panelized construction projects are regularly meeting LEED standards today.

There are also notable disadvantages to off-site construction that should be pointed out:

- Structural bulkiness: floor to floor heights and wall thicknesses affected
- Transportation restrictions limit module and panel size
- Spans and configurations of design are somewhat restricted
- Lack of transparency in overhead, profit margin, transport, setting (cranes), and associated increase in designer fees if new to the process.
- Flexibility and changeability of structure through future renovations becomes more difficult

CONCLUSION

Building technologies and designs that enable flexibility and adaptability have been identified as bringing a number of benefits. These are primarily associated with the requirements for upgrading and maintaining buildings throughout their life and enabling internal fit-out changes in high turnover internal environments. The cost and time of refurbishments is reduced if buildings are designed for modular flexibility. This is echoed in respect of building services. Facilities managers may be able to increase the adaptability of both new and existing buildings and reduce the financial impact of change. Increasing designers worldwide are going modular so a shift in this direction is encouraged and can be seen as keeping in touch with an emerging reality.

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