Sustainability through Modularity: Design Assessment of Prefabricated Hospitals in India

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***Abstract*— This study briefly assesses the effect of implementation of modular & prefabricated building construction technique in existing crippled infrastructure of urban and rural medical facilities. With India being a fastest growing developing country, there is a need for continuous up-gradation of existing healthcare facilities and setting up of new mobile or permanent structures. Prefabricated intelligent healthcare facilities enable care-givers and medical practitioners an improved operational efficiency. With 1024 sub-divisional hospitals, 755 district hospitals and 1458 mobile medical units in India, modular expansion of medical infrastructure will provide state-of-art healthcare facilities to remote areas and existing hospitals in need of upgraded remodeling and refurbishing. Several modular examples were studied under technical guidelines. Various modular constructions related professionals specifically into healthcare were contacted and interviewed. Design assessment for the process of modularization & prefabrication was made by the analysis of the live, virtual and literature studies.**

***Index Terms*— Innovative construction techniques, Modular Construction, Prefabrication, Sustainable Healthcare Facilities, Upgrading hospitals,**

I. INTRODUCTION

As per WHO statistics 2010, Hospital bed density in India is 9 beds/10,000 population that shall be 50 beds/ 10,000 population. This conspicuously indicates the poor state of healthcare facilities in growing rural and urban India in terms of bed strength, lack of updated infrastructure and need of advanced state of art medical technology. With increasing medical tourism, elevating affordability, promising healthcare sector ecosystem there is a need for integrated healthcare system that embraces technology and places patient care at its core. In current scenario, pre-fabricated modular construction could be a rescuing solution guaranteeing speedy augmentation of healthcare sector.

Healthcare is a sector that is well-suited for prefabrication/modularization techniques. The interior layout of hospital rooms allows for efficient use of modularization, and it is a sector highly responsive to strategies that shorten schedule. (McGraw Hill Construction, 2011). Prefabrication is the process of assembling building systems to a nearly-complete state offsite to later deliver to the project site for installation. Modularization involves constructing a finished project offsite and then delivering it to the construction site to assemble with other modules to create the final product. It is a design approach that involves breaking down the design or proposed structure of a building into pre-engineered discrete scalable room-size volumetric units called modules that can be fabricated in factory and can be assembled on site in a variety of permutations & combinations. The modular units may form complete rooms, parts of rooms, or separate highly serviced units such as toilets, lifts, consultation clinics, hospital administration rooms, radiological units (CT-Scan, MRI, X-Ray, etc.) or diagnostic & treatment areas (Operation Theatres, ICUs, Endoscopy rooms, etc.) The collection of separate modular units usually forms a self-supporting structure or may rely on an independent structural framework.

The paper aims to achieve a vision for modern and sustainable healthcare industry via escalated modularization techniques by analyzing the current scenario and proposing a hypothesis for future healthcare industry.

The research questions include how the modularization assists in the process of recovery of decaying healthcare infrastructure? What are the shifts in modern & sustainable construction

techniques from conventional to hybrid to complete modular spatial units.

The methodology to achieve the aim will include literature study of current scenario vs. scope of modularization of Indian healthcare facilities, to understand the importance, advantages and methods of action & installation in context to conventional construction techniques. The figures and calculations used in the paper have either been derived after interaction with several industry experts and professionals involved in prefabrication and modularization of specifically Healthcare infrastructure both externally and internally through virtual and live case examples.

II. MODULARIZATION: DRIVING FACTOR IN HEALTHCARE INDUSTRY

Prefabricated hospitals take about one quarter of the time to build than standard construction. The savings on construction financing are substantial. Modular medical facilities involve minimal waste and can not only save up-to 35-50% on the initial construction cost like labour & materials, but also provide with ease of on-site coordination, speedy installation, low maintenance, adaptability. Speedy construction in turn assures early start of hospital for increased revenue generation. Modularization proves to be an ideal solution for extension of existing healthcare facilities with minimum disturbance to existing structure and its occupants. Also, since the modules are manufactured in factory controlled environment it enables effective quality control, safer construction site, multiple construction activity simultaneously and year- round construction allowance for all-climate types. At the top of all, modularization and prefabrication can provide an access for advanced patient care services to remote & rural areas in the form of mobile hospitals, rural community healthcare centre, maternity homes etc.

III. MODULAR PRE-FABRICATION APPLICATIONS IN HEALTHCARE BUILDINGS

Since healthcare buildings have repetitive modules of same function typology, it is easier to breakdown it's structural components in smaller modules such as of 6.0 m x 6.0 m, 7.0m x 7.0 m, etc. in which all functions of different typology can also be fitted. For example, a module of 7.0mx 7.0 m can accommodate two Out Patient examination/ Consultation/ Treatment rooms, one CT-scan unit, one modular Operation Theatre, one Laparoscopy room, two Single/ Double bedded ward unit as well as one 6 bedded general ward unit. While two of these same modules can become an 8 bedded Intensive Care Unit. Modules can be easily planned and installed within the coordinated structural grid design.

Healthcare buildings can be constructed either as a combination of modular specialist rooms or complete modular buildings. The specialist rooms may include pre-moduled ward units, Out Patient Clinics, Operation Theatres, Diagnostics Imaging Suites, Pathology labs, Dialysis centers, Plant Rooms, Intensive Care unit etc. Additionally it provides benefits of multi-trade prefabrication such as fire and soundproof panels with reinforced cavities for pre-installed medical & engineering services such as plumbing, electrical, HVAC, medical gas supply, etc.

Modular units for the use in health sector are relatively large & have partially or fully open sides. In this way, the various types of functional spaces that are provided in modular form are combined to form complete healthcare building. The module size s used are typically 3.5 to 4 m wide and 7.5m to 18.5 m long. They are generally partially open--sided and often include corridor space. (Lawson, et. el., 2014). Figure V explains the idea of incremental modularization while Figure VI shows the module plans available with modular construction company called US Modular Group East in healthcare sector and Figure VII how these modules can be combined to form complete buildings. All components of a building, including stairs, lift shafts, façades, corridors and services can be incorporated in such modules. Although, the shape, size and designs of a module can vary depending upon the architectural requirement, however, size should be compatible with manufacturing and transportation requirements. There are two generic forms of modular construction, which affects directly their range of application:

- Load-bearing modules in which loads are transferred through the side walls of the modules
- Corner supported modules in which loads are transferred via edge beams to corner posts. (Lawson, 2010)

Table I Typical dimensions for Planning In Modular Construction

Application	Internal wall height mm	Internal module width mm	Internal module length m	Ceiling-floor zone (typical) mm
Study bedrooms	2400	2500–2700	5.4 to 6	300
Apartments	2400	3300-3600	6 to 9	450
Hotels	2400–2700	3300-3600	5.4 to 7.5	450
Schools	2700–3000	3000–3600 open-sided	9 to 12	600
Offices	2700–3000	3000-3600	6 to 12	600–750
Health sector	2700–3000	3000-3600 open-sided	9 to 12	600–750

In Colchester General Hospital in UK 148 steel-framed modules up to 14m long and 3.3m wide, and each weighing up to 12 tonnes, were delivered and installed in a total of 17 days. The units were partially fitted out off site, including internal partitioning and first fix M&E services.

Figure I: Modules being prefabricated in factory

Figure II: Modules being lifted with crane

The modular construction can support up to 6-8 storeys depending on the type of system used and configuration of steel members installed. The modules are tied at the corners and finished with sealants to form the seamless structures internally. The modules are tied at the corners to bear the wind and seismic loads. Moreover, these modules can be fitted in a variety of internal finishes and external cladding options.

Modularization & multi-trade prefabrication can also offer the opportunity to choose the components that have the right threshold of repeatability i.e. the choice lies with the designer that what is to be prefabricated off-site and what could be in-situ, thereby giving the advantages of hybrid construction. Therefore, it is possible to module mini- components like MEP infrastructure, headwalls, bathrooms, patient rooms, and exterior elements offsite in a controlled environment and assembling them on site.(Barista,2014) At the St. Joseph Hospital project at Denver, 25 feet long prefab overhead mechanical racks have been used that house the hospital's mechanical piping, ductwork, cable trays, electrical conduit, lighting conduit and pneumatic tubing as shown in Figure 7.

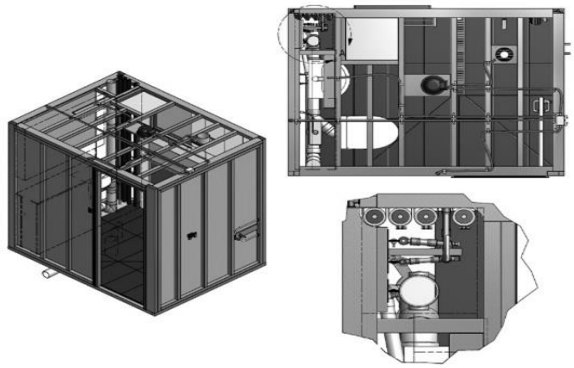

Figure III: Bathroom pod for hospital inpatient rooms

Figure IV: MEP Multi-trade racks site installation, Source: Modular services company

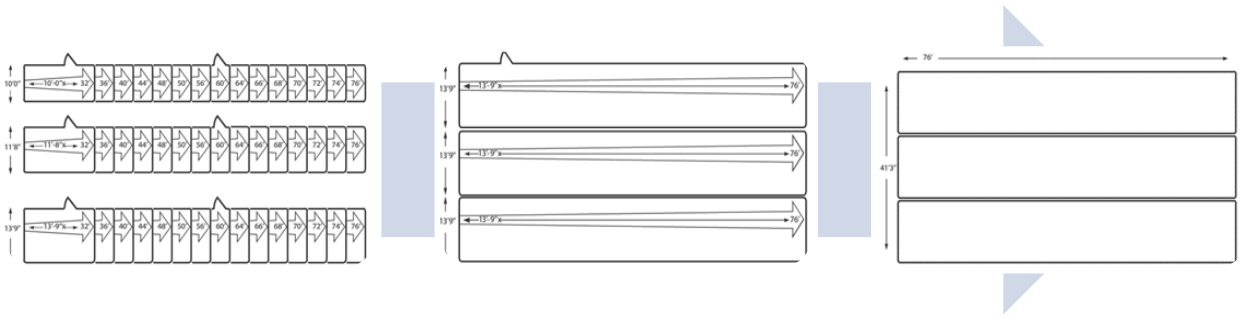

Figure V: Process of incremental modularization

Figure VI: Specimen Module Plans for Healthcare sector, Source:http://www.usmge.com/floorplans.html

Figure VII: Combining of modules to generate a complete plan, Source:http://www.usmge.com/floorplans.html

Bathroom pods have also become a popular prefabrication approach for healthcare building teams because of the potentially sizable schedule savings. At St. Joseph Hospital 440 bathroom pods have been fitted complete with lighting elements, wall and floor tile, and faucets and fixtures.

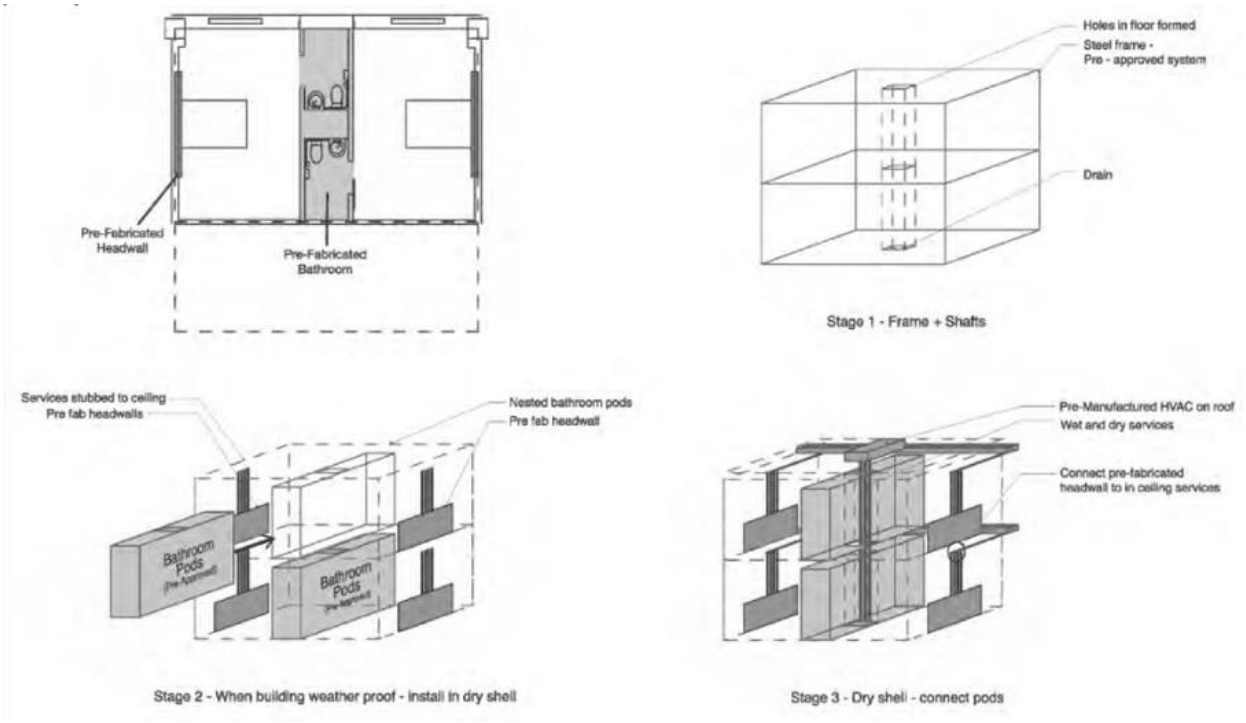

Figure VIII: Installation of bathroom pods, Source: Smith Group

IV. ROLE OF PREFABRICATION & MODULARIZATION IN SUSTAINABLE CONSTRUCTION

Prefabrication can and has been playing a major role in making construction industry more sustainable. Prefabrication and modularization provides:

- Optimal flexibility and functionality
- Reduced materials and costs
- Increased quality

The following sections cover the environmental and economic aspect of prefabricated sustainable construction of a healthcare facility:

Environmental Aspect

The types of environmental impacts anticipated from prefabrication will depend on the type of prefabrication system chosen such as Volumetric, partial modularized components or prefabricated construction elements. Following are the indicators and their impacts:

Operational energy: Positive-

Upto 35 % energy consumption can be saved. Since prefabrication can be done off-situ in factories, where same moulds and casts are used for same type of modules, operational energy cut down and accuracy can be achieved. Improvements in build quality ensure consistent standardization of service installation.

Embodied energy: Positive

50% reduction in use of quarried materials. Reduced waste and increased recycling in off-site manufacture reduces the embodied energy.

Transportation energy: Negative

Transportation of modules from factory to site requires heavy duty vehicles particularly in case of volumetric prefabrication. This is one of the major reason behind India's lack of role in Macro-level prefabricated Healthcare facilities, since modules of healthcare infrastructure are complex and require

column-beam less spans specially in spaces like OTs, ICUs, X-Rays, etc.

Waste: Positive

Since, manufacturing of modules occurs in factorial setups, the waste generated can be recycled there itself.

Water consumption: Positive

50% reduction in the amount of water used.

Ecological Impact: Positive

Reduction of pollution on site by prefabricating in a controlled environment, limits the impact on existing species on and nearby site.

Economical Aspect

Prefabrication and modularization of healthcare care infrastructure can lead to:

- 25% overall costs reduction
- 60% reduction in defects, hence, a high degree of accuracy.
- 35-55% reduction in construction and installation time. In India, where we are in urgent need of speeded construction of upcoming healthcare facilities in both urban and rural areas, prefabricated and modularized construction will lead to improved health treatment and well-being.

The following figure clearly earmarks the difference achieved between Conventional method of construction vs. combination of conventional and modular construction techniques. Installation of Modular OTs and ICUs within an existing or upcoming hospital, e.g., Peerless Hospital in Kolkata, India had 7 OTs that have been upgraded to so-called in-situ Modular OTs with prefabricated panels and service installations summing up to an up gradation cost of Rs. 3.6 crores.

V. INDIAN SCENARIO

In spite of technological progress, globalization, boom in healthcare industry and increasing affordability Indian modular construction industry, especially in healthcare sector, is at a very primitive state. India doesn't have a single healthcare facility that could be called completely modular. A variety of reasons could be attributed to this appalling scenario, which includes:

- Lack of awareness about this advanced construction technology and its implied benefits over construction schedules, labour costs, multi-site and multi-climate suitability etc.
- Lack of skilled labour & technicians with hands on experience in the technology. Although, with demand comes the supply. There has not been much demand of modular construction and hence the technicians opting for the field remain limited.
- Use of advanced Building Integrated Modelling (BIM) systems, 3D printing and manufacturing control systems are important for modular construction to be successful. The supply & knowledge of these especially in the extended dimensions of BIM is very limited in India.
- Modularization is typically carried in controlled environments of massive factories over state of art assembly lines. In India, there are quite few players that deal in modularization and prefabrication of healthcare buildings. L&T constructions, TATA Housing, Hindustan Prefab. Ltd. (HPL), Jindal Steel Ltd. are the major giants in Indian markets, who unfortunately deal mainly in prefabricated housing. Total Alliance Health Partners India (TAHPI), Speed4 Prefabricated Systems Pvt. Ltd., KEF Holdings are some of the local modular prefabricated manufacturers with their manufacturing plants located mainly in southern-India.
- Transportation & logistics form a governing factor in modular construction. Availability of suitable trailers, height restrictions on roads that need to be travelled on during transport of the modules, road taxes, interstate tolls, distance & cost of transportation etc. need to be accounted beforehand. This turns out to be the major impeding factor in India.
- Modularization and prefabrication requires substantial initial design planning. Collaboration of the entire Building Team at the earliest stages of design is vitally important which means the contractor, consultants, and even the prefab manufacturers should be involved in the design process. In India, however, planning & scheduling of the project still remains the weak spot for project management & delivery team.

Currently, Indian modular construction industry is limited to micro-moulding in healthcare sector i.e. modular construction of micro-components like

patient headwall systems, modular medical services in pre-fabricated enclosures that could be installed on conventional brick & concrete construction etc. Modularization of highly specialized & mission critical facilities has also started in India like Modular Operation Theatres (MOTs) & Intensive care units (MICUs). Though, these are called Modular but in literal sense of the construction techniques these are just prefabricated panels assembled on site.

VI. EXPERTS' VIEWS

In 2001 Ian Davis, the Director General of the Federation of Master Builders made the following response (Federation of Master Builders. Response to Egan Report from Ian Davis, May, 2001): "Increased prefabrication is seen as one answer to problems that beset the industry, including the skills shortage, inconsistent quality and low margins. Whilst prefabrication has a role in improving the industry it must not be pursued at the expense of the skills shortage training needed for traditional forms of construction."

Prefabrication is much more than a fashionable concept, it offers the possibility of innovative sustainable construction. It represents one of the positive ways forward for supporting the foremost changes that have been acknowledged as necessary for improvising construction.

- **Users**: Every healthcare facility is designed to provide treatment, care and generating a sense of well-being among the society. With lesser pollution during construction and a fast-track construction will lead to better, accurate and high-tech medical-care. Specially, in India, we lack tremendous bed strength, treatment and diagnostic facilities, both in rural and urban areas.
- **Architects & Healthcare Planners**: A healthcare planner/ architect plays a major role in designing, planning and setting up a healthcare infrastructure and determining the implementation of prefabrication & modular (P&M) construction techniques during initial stages of a project. As per our Indian healthcare architects, P&M will lead to improved project productivity, producing more sustainable built-unbuilt space. P&M can measurably:
  - Reduce project schedules and time.
  - Decrease procurement and installation costs of materials—ultimately decreasing the project budget.
  - Increase construction site safety—resulting in fewer accidents and lower insurance costs.
  - Eliminate considerable amounts of construction site waste, making the project greener.
  - Allow the specification and installation of better quality and more sustainable building materials.
  - The timely choice to implement P&M into the project allows for superior stability of design maximizing positive productivity payoffs. One of the reasons that Engineers & contractors give for not integrating P&M is that the architect did not embrace it in the project design.
- **Engineers**: As the experts primarily responsible for the structural integrity and systems efficiency of buildings during their design and construction, engineers should evaluate the quality and availability of prefabricated/ modular products and be the catalyst for their use. Many engineering firms are already using P&M elements for the building super-structure; exterior walls, roof and floor, interiors, services and they view their use as a way to distinguish themselves from their competition.
- **Contractors**: Need to upgrade and acquire experience in P&M in order to remain competitive.
- **Manufacturers**: Although there are many manufacturers who deal on volumetric/ module based P&M in developed countries, but India lacks the macro level implementation in construction industry due to transportation issues especially in healthcare architecture industry. Only micro level healthcare modules such as modular OTs, modular ICUs, automated bed head panels, laminar flows, steel anti-bacterial panelling, etc can be seen in India. E.g.: Surgdent Medicare, Medikart, etc.

VII. HYPOTHESIS: FUTURE POTENTIAL: AN ANALYTICAL DISCUSSION

While modular construction bestows an impressive list of benefits, there's still a certain stigma the method is struggling to overcome. Though, initially our construction industry might face challenges due to lack of advance P&M industry, but by standardizing the healthcare standards of spaces and components, healthcare planners can exert more controlled process ensuring consistency to the design vision and creating a better sustainable environment in-turn generating public well-being.

Despite some design constraints (for example, required column work often doesn't allow for bigger modules like patients & relatives waiting areas, seminar halls, etc), the ability to finish these structures with just about any exterior—be it brick, stone, stucco, or glass—means today's modular buildings can look just like conventional architecture.

And as more modular healthcare projects will be deployed, experts believe lingering doubts about the method will dissipate. Through P&M, healthcare industry can foresee a day when designing a freestanding clinic, hospital wing, or a critical access hospital will be similar to picking out a car, with all the features and amenities chosen by the end user.

VII CONCLUSION

P&M is at a primitive stage in Indian healthcare industry though it can be seen in various housings, flyovers, bridges, resorts, for example Delhi Metro Railway Corporation (DMRC), etc. There are, however, a range of barriers to its full potential use which stem from previous incidents of prefabrication that have left it labeled as a low quality process with linked social disgrace. Prefabrication within the construction industry is most affected by this perception, yet offers substantial opportunity for those willing to use it properly. The advantages of using prefabrication include:

- Higher quality products for users;
- Enhanced productivity and profitability for both users and investors
- Environmental gain associated with its use.

There are abundant statistics quoted by industry sources of the prospective savings that could be made with P&M, however, diminutive independent assessment of dependable performance has been made. Such independent confirmation of real performance characteristics is desirable in order to conquer the perception of parts of the industry that prefabrication is an inferior quality substitute for conventional construction techniques. P&M has the competence to make a difference within the healthcare construction industry in economic, social and environmental terms. It is important that how much of a probable difference it can make, is established, so that significant development can be executed.

Hence, from the above analysis, it can be concluded that P&M can lead to considerable escalation in Healthcare delivery sector in future.

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