Manufacturing and Assembling Buildings as 3D Monolithic Shearwall Modules

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Abstract – **Built spaces are transitioning from being static and dumb to becoming dynamic, responsive, intelligent functional systems for live, work, production, storage and retail. This transformation driven by the demands of the urbanizing world and enabled by a bouquet of technologies are increasing the extent of manufacturing in making the building.**

Infusion of intelligence into the design and engineering activities of construction as AutoCAD, CAE has spread and now straddles the full activity-chain of construction. Singapore is the most successful country to avail segmental manufacturing of buildings for over 40 years.

Monolithic Shearwall Module technology eliminates numerous joints, connections – the root cause of leakages and seepages and all other problems in buildings made by assembling multiple elements to create one volumetric space. Bangalore-based hoMMission India applied this technique to Indian market requirements and cost expectations. A 5-storey building with 20-apartments was manufactured and installed in 33 days in Mumbai. The 3D Monolithic Shear Wall Modular manufacturing and assembly of all types of buildings, promises to be a potential game changer.

Keywords: Shearwall monolithic modules, Precast construction technology, Building manufacturing, Transformational technology for construction industry

I. INTRODUCTION

BUILDING a building is not a craft anymore. Manufacturing them as Building Materials and Building Products to form and finish them into buildings with manual labour also appears to be ending. The "labour" and "skill" appear to be rushing into the list of endangered species. The pace, quantum and quality of construction demanded by the surging urbanization across the world is pushing construction to a long overdue, now inevitable tipping point."Stop building – start Manufacturing and Assembly of Buildings as the first choice" is the new Mantra / Moto.

Hence, the staid and steady incrementally evolving construction is transforming. Imperceptible to the unseeing but obvious to the ardent practitioners of design, engineering, construction, finishing, and building management are developments impacting each stage of making a building.

Functionality is finally dictating the form. Aesthetics now must ensue from the Form serving Functionality.

Also, efficiency is chosen over expanse of space. A room soon may have many roles. Bedroom in the night, office during the day that serves as the living room or party room during non-working hours. The expensive micro-apartments of New York are now multi-tasking its miniscule space thanks to the movable internal walls and foldable, motorized, modular, multi-task able furniture.

Multi-tasking the space to meet the need of the time of the day/ night with the design and technology invention of MIT, Boston and made in China are already in action in New York, Tokyo in Japan, Mumbai in India. These and many tier 1 cities with the most expensive real-estate are breeding this phenomenon of demanding efficiency over expanse.

Functionality as heightened functionality is dictating form and is replacing expensive expanse with efficient, multi-taskable space. Infusion of intelligence into the design and engineering activities of construction as AutoCAD, CAE has spread and now straddles the full activity-chain of construction. With BIM, it has now gone beyond construction and onto operation and management of the building too.

This infusion of Intelligence is turning the static shells of the building into a functional, responsive "live-in systems". Smart Homes, Smart Cities are here now – a mission of the Government of India indeed.

The functionality, performance, convenience, responsiveness, strength and stability of the manufactured products like the automobile, aircraft, cruise ships are now coming home or coming to homes that hitherto were dumb core and shell. All built spaces are transitioning from being static and dumb to becoming dynamic, responsive, intelligent functional systems for live, work, production, storage and retail. This transformation driven by the demands of the urbanizing world and enabled by a bouquet of technologies are increasing the extent of manufacturing in making the building.

Based upon Invited lecture at National Seminar on 'Automation, Robotics and 3D Printing' held on 15-16 October 2018 under the aegis of Department of Civil Engineering, Ajay Kumar Garg Engineering College, Ghaziabad.

The pre-fabrication and pre-casting of buildings is increasing as substitutes for labour intensive sequential steps in building a building. Batching of materials into RMC followed bunching of activities via Cast-in-Situ into manually arranged form works is now moving into mechanized casting equipment placed in a factory setting. The Precast plants have sprung up in Northern, Central, Western and Southern India.

These plants in India manufacture the buildings as various structural elements of building such as wall panels, solid or hollow core slabs which are later assembled at site to form a monolithic structure [1].

The National Building Code of India and the Bureau of Indian Standards have developed and published the first set of codes and standards for this segmental manufacturing and assembly of buildings.

The Building material and Technology Promotion Council of India under MOHUA of Government of India, is promoting the manufactured RCC Buildings and also assisting the alternate building materials ranging from Bamboo, Reinforced Thermocol, Light gauge steel framed structures etc.

Towards mainstreaming the manufacturing of buildings, CPWD has released the Schedule of Rates enabling the Government to avail this newer, stronger, better manufactured building to meet their needs.

Impressive as it may seem, this movement of Manufacturing the different types of buildings for India, lags possibly, by a generation.

Post-world war, Europe adopted the Manufacturing of Buildings as elements, panels, segments of slabs etc. Singapore is the most successful country to avail segmental manufacturing of buildings for over 40 years to abode all its citizens. Other continents such as USA, Australia etc. have all moved to the next level of manufacturing of buildings.

They now manufacture the buildings as shear wall modules cast in one single pour replacing the multiple structural elements, multiple wall panels, and slab pieces too. This Monolithic Module also eliminates numerous joints, connections – the root cause of leakages and seepages and all other problems in buildings made by assembling multiple elements to create one volumetric space.

The 3D Monolithic shear wall modules manufactured by just one pour besides eliminating the problems arising out of multiple joints amongst many elements also bunches the multiple manufacturing activities into one step. The consequent savings in effort, time, equipment, space and manpower enables the increase in productivity by orders of magnitude.

There are many other benefits inherent to this advanced building manufacturing system. The handling stress of segmental or 2D elements is more and demands more steel and other material in addition to the normal quantities needed for the building. The modules have a much lesser handling stress and do not consume additional steel. Also, all the service conduits for electrical, plumbing, extra low voltage cables including the wall boxes can be cast-in -- needing no tedious interconnections that are time and effort intensive in segmental / 2D construction.

The remote-control operated 3D Moulds manufacturing the monolithic shear wall modules are made of high tensile seamless steel plates and also have built-in vibrators and curing facility. Hence, the modules attain strength of 12-14 MPA in 12 hours and come out with a Class A, Fair face finish on both sides needing no grinding or plastering and are ready to paint. Such manufacturing of buildings as 3D Shear Wall modules is known by varying names across continents and their countries. Singapore calls it Precast / (Prefabricated), Prefinished Volumetric Construction (PPVC). It has made this manufacturing technology mandatory for all buildings built on the land of Government of Singapore. The manufacturing of these modules is done in Malaysia and assembled into fully finished unit before they are transported on trailer for installation in Singapore.

The Building and Construction Authority (BCA) of Government of Singapore engaged many multinational Design, Engineering and Building Manufacturing firms over the past years to operationalize this most advanced manufacturing of buildings as shear wall modules.

BCA now runs a course in “Design for Manufacturing and Assembly of Buildings (DfMA). It targets to train 16,000 professionals annually for the next 5 years.

Global construction industry, thus, is embracing manufacturing as the new norm to deliver better, stronger, functional and intelligent buildings as live-in systems are increasingly demanded by both people and the activities.

The Government of UK is engaging its famed universities and firms specialized in designing for manufacture and assembly. It is promoting modular manufacture of buildings to solve the falling productivity of its construction industry.

The engineering code for modular manufactured buildings has been arrived at by a large Australian consortium of universities, practicing engineers and construction industry. This effort of codifying the engineering standards is led by the University of Monash in Australia.

A small team in India, started in 2011, searched the global markets for the most advanced system for manufacturing of

buildings in India. After obtaining a comparative study of then available nine building manufacturing systems offered by about 58 global companies, the Indian team chose and adopted the 3D Monolithic shear wall Modular Manufacturing technology from Australia. Over the years this small Indian team, now called hoMMission India has applied this to Indian market requirements and cost expectations. A 5-storey building with 20-apartments was manufactured and installed in 33 days by this small Indian team.

TABLE 1 – COMPARISON OF BUILDING MANUFACTURING TECHNOLOGIES

Factors	Cost Criteria with finishing	Time of Construction	Energy Efficiency	Material & local materials	Durability and life span	Fire rating & proofing	Renewableenergy/sustainability	Flexibility (Architectural style & Future expansion)	Ease of construction	Less labour number and skill labour level	System acceptance and authority approval	Projects profile world wide	Maintenance	Acoustics (Noise)	Total
Weightage	15	12	10	8	8	7	6	6	5	5	5	5	4	4	100
3D Monolithic Shear Wall Modules	13	12	8	8	8	7	5	6	5	5	5	5	4	4	95
Rexwall System	13	11	9	7	7	6	5	5	5	5	3	4	3	3	86
The Construction System MED	13	10	9	7	7	3	4	5	4	4	5	4	4	4	82
Econ Construction System	11	11	8	6	7	6	3	4	4	3	3	5	3	4	79
PlastBau System	10	10	8	7	6	6	4	4	4	3	4	4	4	4	78
ThermAlloy Pre-cast Concrete	11	8	9	7	7	6	4	4	4	3	4	4	3	4	78
Mercado System	12	9	8	7	6	3	5	5	4	4	4	4	3	4	77
Speed wall System	9	11	8	7	6	5	4	4	4	3	4	4	3	4	76
Moladi System	7	9	8	6	7	5	4	5	3	3	3	4	4	4	73
Low Cost Housing Int'l Ltd	12	7	8	7	7	5	4	5	4	3	4	2	3	2	72
DF Chinese framing	8	10	7	5	7	5	5	4	3	3	4	4	2	3	69
Quick Wall	7	8	7	6	7	4	4	4	3	4	3	4	4	3	68
Frame Max System	8	8	7	5	7	5	4	4	3	4	3	4	2	3	67
Ampac International	9	8	8	5	7	4	4	3	3	3	3	5	2	3	67
Mascon System	6	6	7	7	6	6	5	3	3	3	5	4	4	2	67
Hadrian Tridi-System	7	9	8	7	6	3	4	5	4	3	2	3	3	3	67
WTF Shuttering System	7	8	8	6	6	4	3	4	4	3	3	4	3	3	66
AZBUD System (LECA) Polish	7	7	6	5	7	6	5	4	3	2	4	3	2	4	65
Structural Light Steel frame	6	9	7	7	5	3	4	3	3	3	4	4	3	2	63

Post two-month long testing by Singaporean and Indian entities, the Client Tata Housing awarded the Virtual Completion and Acceptance Certificate. This building manufactured onsite as 3D Monolithic Shear Wall modules has stood exposed to the forces of nature including 3 Intense Mumbai monsoon rains even without plaster.

Use new 3 D technology to speed up housing construction: PM Modi..

The New Indian Express - 12-Jul-2017

Prime Minister's direction came when he was informed that about 1.25 ... Officials said that 3D technology in construction was introduced only ...

Standardization and consequent componentization are the key imperatives for any activity to be entering the domain of manufacturing. Finding standardisable components for construction of buildings may drown us in the myriad codal provisions of National Building code, the differing and evolving standards of Bureau of Indian Standards (BIS). The near anarchic prescriptions of Development Control Regulations of the Metropolitan Planning Authorities, Directorate of Town and Country Planning Authority etc are another quagmire. hoMMission over the years discovered the inputs for standardization to Manufacture Buildings are actually in the uncodified standards and dimensions arrived at and applied by the construction industry in response to the geographical, demographical demands as well as the type of real estate as residential or commercial etc.

The first key input for standardization and componentization for modularized manufacturing of buildings was glaringly obvious in the column grid dimensions spans and floor heights across the typologies of residential, commercial, industrial, logistical and retail buildings. This was the bedrock for the standardization that can lead to modularization and consequent modular manufacturing of buildings.

The four corners of the 3D shear wall modules, once aligned to this grid and its dimension, the module as a whole with all the walls or as a stool without the walls can be designed and manufactured. When this module has built in provisions it turns into one of the interconnectible structural elements. As is obvious, the multiple structural elements like columns plus beams and the slab with walls are bunched into one and is also manufactured in one pour. Thus, this consolidated structural system of a shear wall module is the new level of structural system that can be manufactured at one go. Hence, this becomes the most advanced system of manufacturing a building, given its ease and pace of completion.

As these shear wall modules are Monolithic and made with time tested and proven building materials like concrete and steel, the compliance to the myriad codes and standards is automatic. Except for the codes and standards for the connections which are least in number in this advanced systemof manufacturing of buildings. However, International codes are available for the connections between the modules as well as with other elements of a manufactured and assembled building. The codes for Manufacturing and assembly of high rises in different seismic zones are also coming into place. (AIT, Monash University, PCI).

The standardization of just the narrower side of the column grid is sufficient to design and fabricate the 3D Moulds, the magical core of Modular Manufacturing of Buildings. The same mould can deliver modules with different lengths, different wall thicknesses, different heights and openings of different sizes wherever required, the only fixed dimension is the narrow side of the column grid for fixing the width of the mould which is taken from the standardization. Any project of sufficiently large size demands manufacturing from a set of 3D Moulds to ensure delivery in a given time frame. Hence, a set of moulds with a range of widths can break this constraint and make 3D Shearwall construction a completely flexible one.

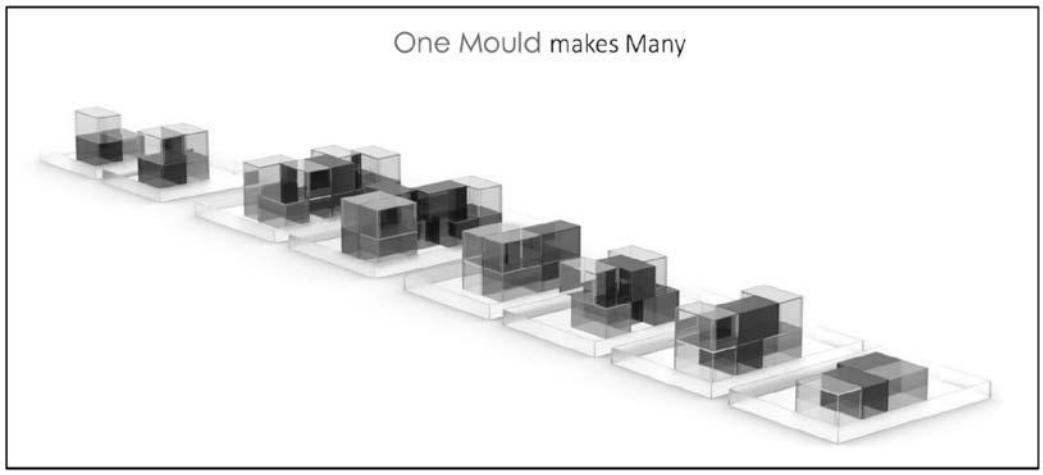

Figure 1. Mould standardisation

A true joy for the designers / architects / engineers of the building. An array of differing arrangements of these modules permit a kaleidoscopic range of building forms, shapes and sizes enabling the shading of the building envelope exposed to direct sunlight and heat. These 3D Monolithic Shear Wall modules as Monolithic structural system can distribute the load acting as spandrel and hence permit non-linear, asymmetrical stacking and structural connections. This can create exciting new forms and shapes of building that are not possible in framed beamed column structured buildings.

The openings too are not made by labour but formed as part of casting in the 3D Moulds, hence creating any shape and size of opening is possible as long as it does not interfere with the structural core of the module residing in its 8 corners.

Contrary to the notion, the building forms assembled from standardized components will be boxy, boring, monotonous, the cellular nature of this modularized structural system does permit a newer range of arrangements mimicking the nature arranging the cells into an awesome variety of forms, shapes and sizes.

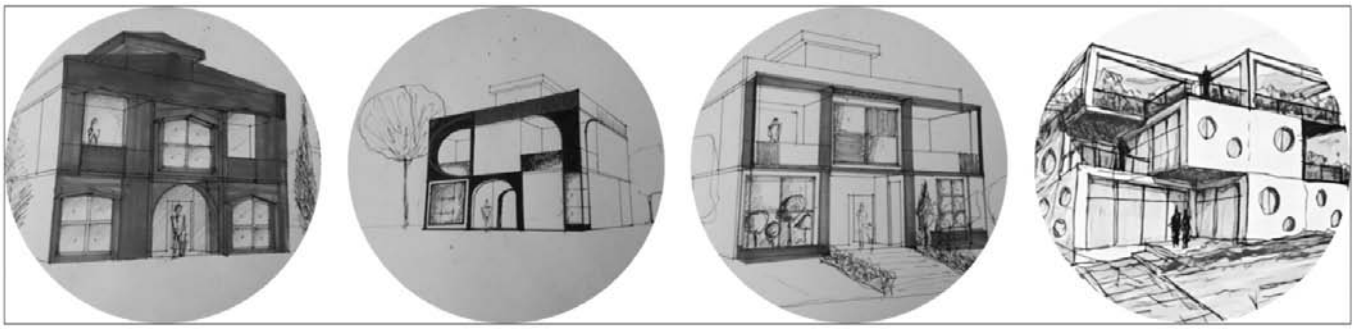

Figure 2. Possible openings.

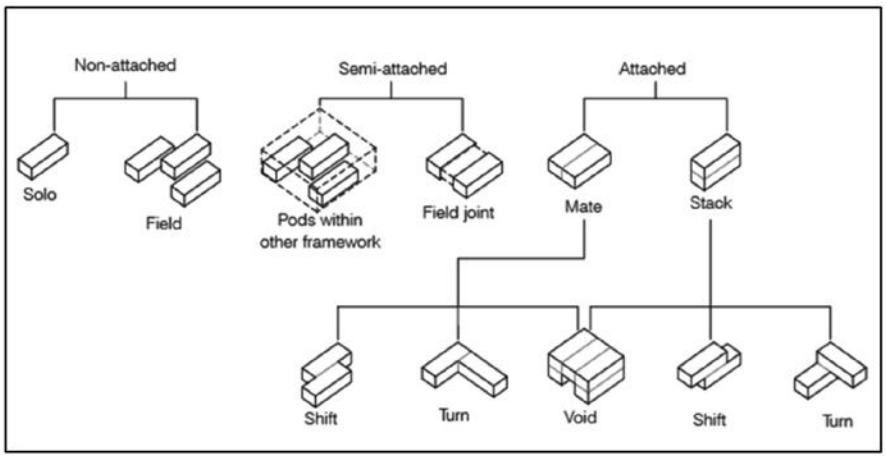

Figure 3. Modular systems.

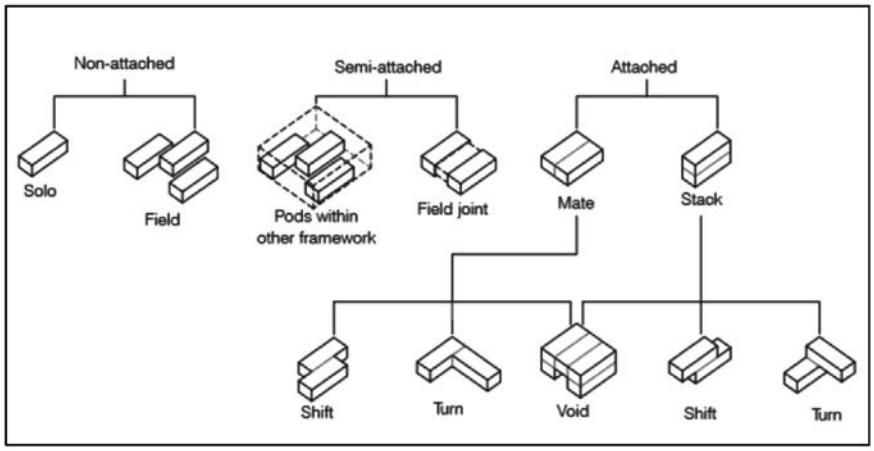

Figure 4. Elemental modular relationship.

The manufacturing of buildings as 3D Monolithic Shear Wall modules though appears to be manufacturing at a component level, it truly is manufacturing not as component but as true sub-assemblies. Further magic is in the fact that at one stroke this sub-assembly can also be made with all conduits required for delivering the services associated with the MEP. Thus, this sub-assembly is a structural and functional level sub-assembly. The installation of the doors, windows, tiles, painting, electrical and other fittings can also be done at the factory as the module stays there for 78 hours after demoulding.

Extreme productivity assured sustained quality, greater strength with lesser materials, guaranteed and faster delivery, greater variety of forms, embedding functionality, provision for adding intelligence are not the only advantages of this Modular manufacturing of buildings.

Any type of building required - a Villa, Apartments, Hospitals, Hotels, Schools, Shops can be manufactured mostly from the same set of 3D moulds.

The warehouses, factories and even badminton courts with wide spans well-supported by the truss-less roofing now available in India is a true testimony of the versatility of 3D Monolithic Modular Precast. The cellular or modular nature of this advanced manufacturing permits many types of construction activities.

Just as a 3D Monolithic Shear Wall module is "self-contained structural and functional unit" of a building, a 3D Mould by itself is a core production unit.

Hence the factory setup to manufacture the building can be modular and is mould by mould. Effectively it can start as a "one-mould" factory of buildings.

Hence the attendant demand for factory space, financial capital, engineers, technical contingent are also modular. The modularity in production enables a start with the least and also provides for scaling to address surging demands, if any.

Other dimensions of this approach to manufacturing of buildings with 3D Moulds lies in its ability to do the production onsite and obviates the challenges and cost of transporting manufactured building elements.

Whenever necessary, the production can be at a hub supplying to a cluster of projects in a radius of a hundred kilometres.

Mounting these moulds on trailers and making it a mobile "Building factory" can cater to highly distributed demand in rural areas. This mobile building factory, like the circus of yesteryears can be the "Touring Casters".

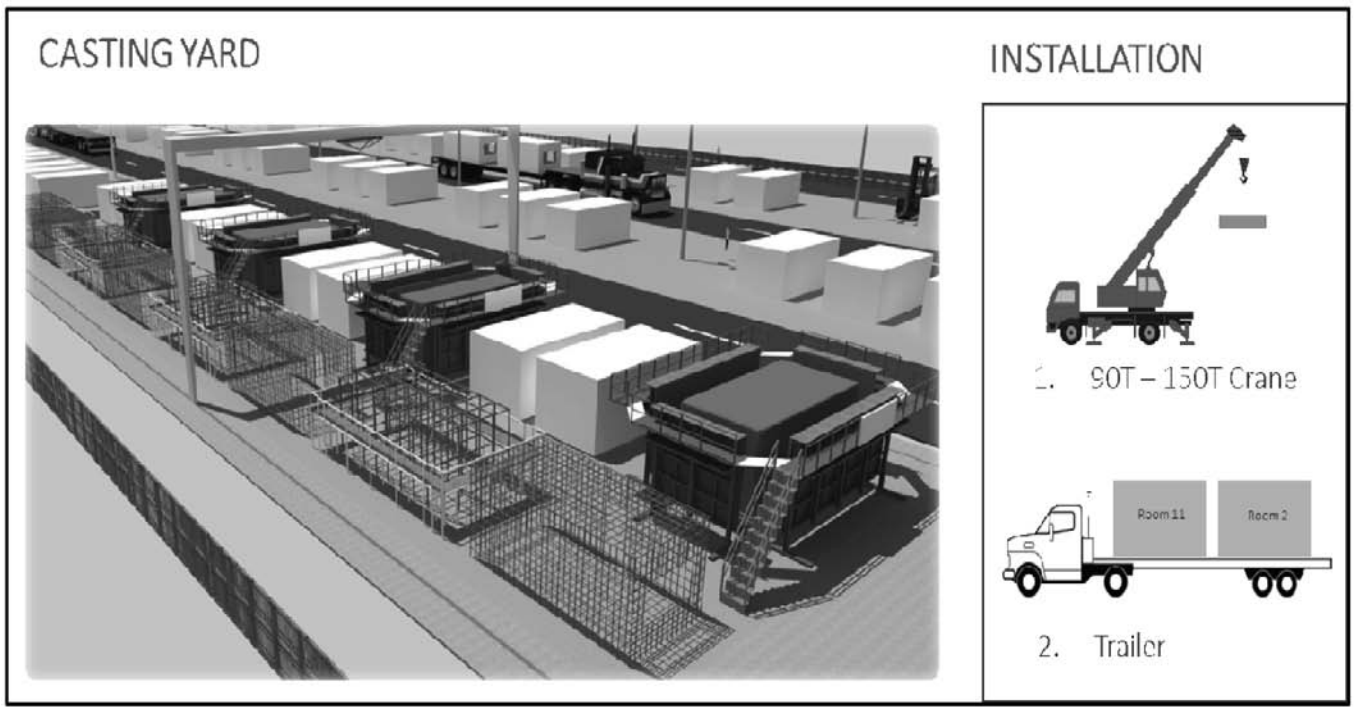

Figure 5. Typical casting facility.

At the industry and professional levels this industrialization of construction through modular manufacturing and installation of buildings augments production significantly and hence can increase the employment opportunities for the current unemployed or underemployed civil engineers and also may increase the compensation they receive.

This expertise-intensive construction will also attract other engineering specialization like mechanical, electrical etc. unto itself and may create a new breed of "building manufacturing and assembly" engineers.

days from the first day of 2019 to the last day of 2022, the target day of the Mission is about 1200 days assuming 300 days of manufacturing each year. Assume all the required moulds are ready by the beginning of 2019. The 10 + 20 Million housing units for Urban and Rural with an average size of just 400 sq. ft. means a manufacturing and installation of 1,200 Cr. sq. ft. in 1200 days.

Yes, a staggering 1 Crore sq. ft. per casting and manufacturing day. Eight thousand "building-factories" each on a half-acre space with four moulds in operation or 4,000 building

Figure 6. A 20-apartments five-storey building under construction using 3D Monoithic Shearwall Technology. The project was cast and installed in 33 days at Tata New Haven, Boisar-II, Mumbai. A two-month long testing of the building structure, connections, joints including leakage and seepage tests was successful.

The best scenario would be at least a few thousands of them becoming intrapreneurs or entrepreneurs availing the opportunity sketched below.

The final test for any promising change is putting it to test and checking whether it can deliver at least one of the large immediate opportunities.

So, let us put all this astounding potential of manufacturing the buildings as 3D Monolithic Shear Wall modules and Assembling into buildings to test.

A test if and how this Shear Wall module can deliver at least one well known Mission of the Government of India and the States. The Mission "Housing for All'.

Factually, a 20,000 sq. ft. factory deploying four 3D Moulds and a team of about 50 can manufacture, transport, erect and finish about 1,250 sq. ft. of built-up space in a day. The casting factories each on one-acre plots with 8 moulds in operation hypothetically can make Housing for All achievable.

Interestingly, India has 4,000 statutory towns. In reality, beginning in the 100 smart cities promoted by Government of India's Smart Cities Mission and following it up by establishing in the 400 AMRUT cities promoted again by Government of India's Mission Amrut is the immediately visible goal of hoMMission India [2].

This may create a few 1,000 engineer enterprises each managing one of the Nationally networked building factories drawing the collective advantages of economies of scale, aggregated buying power, shared learning and global expertise in Designing for Manufacturing and Assembly etc.
India and its Construction industry along with the various missions of Government of India is truly at the threshold of transforming not just the Indian construction but the global construction industry.

CONCLUSION

The 3D Monolithic Shear Wall Modular manufacturing and assembly of all types of buildings, promises to be a potential game changer. Unlike the conventional and traditional 1D and 2D Precast methods, this technology is the new unique truly 3D, monolithic, Modular solution that can be poured complete with window and door frames, electrical and plumbing conduits already inlaid.

Major advantages of this technology over competitors are: Rapid construction on-site, Quality and accuracy (±2mm-5 mm), Long term strength and durability, Fire, water, cyclone, earthquake, termite, marine and corrosion proof, Fire rating / sprinkler concessions, All weather production facility, Reduces scaffold and formwork, No propping, caulking, brackets, Clean and neat construction site, Windows, doors and other modular furniture can be ordered straight from the drawings due the accuracy, The external and internal walls painting can be done without the need to plaster or render, The doors, windows along with their frames can be fitting at the time of casting the modules. This results in upto 80% faster than traditional construction methods, 50% stronger (each unit 1 piece), upto 90% Waste Free (relocatable recyclable) and upto 50% cheaper material and labour cost. On-site manufacturing eliminates transportation & multiple handling, Improved thermal & acoustic performance besides reduced operating maintenance costs.

REFERENCES

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