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3D Concrete Printing Technology: Implementation & Financial Assessment

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Abstract - In the construction industry, 3D concrete printing technology is one of the advance technique that can be used for the construction of building components or to print entire buildings. The 3D concrete printing techniques are being foreseen as a solution for solving the housing crisis across various parts of the world. There are various advantages associated with 3D concrete printing technology over conventional building methods as well as other advanced techniques such as its fast construction, cost-effective, minimal wastage, that would lead to the sustainable construction process as well as a cost-effective construction method.

The goal of the paper is the evaluating the financial feasibility for advance technologies such as Monolithic concrete construction, Precast system & 3D concrete printing for the Affordable mass housing in the construction industry which gives the benefit in financial aspect with respect to to time in the construction project. Financial factors are being derived by various case studies of 3D concrete printing & market rates for the cost of construction, and used in sample case for assessment. The current hypothesis of the dissertation is to use advance 3D concrete printing technology as a cost-effective technique for affordable housing. The research concludes with the study of technique, SWOT analysis, organizational implementation of the process of the project, advance Construction methods used for affordable housing, Time & cost factors attached to it. The end-stage of the research is about the assessment financial feasibility of the techniques amongst themselves which can be useful for the construction of affordable housing projects as well as other projects.

Keywords - 3D concrete printing, Advance construction Technique, Cost & Time, Affordable housing, Financial feasibility, Internal rate of return.

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INTRODUCTION

3D Concrete printing which is also known as "Additive manufacturing" is currently considered as one of the advance construction technique & key drivers of an ongoing "4th Industrial revolution". 3D concrete printing Construction with the concrete material changes the ample of logistics plan, organization of resources on-site, generate lesser wastage. The technique benefits the significant reduction in cost, time, waste generation, and significantly retains the construction quality, and becomes the safer construction technique with the reduction in labor requirements at heights, eliminating the factor of safety.

MATERIAL & METHOD

About 3D Concrete Printing Technique & implementation process: This technology works primarily with toolpaths provided by computerized systems, so when raw materials are added to the printer, toolpaths provide nozzle's position, orientation, velocity, and rate of application throughout the build time. This information is converted into a set of machine tasks before being sent for implementation. User can manually integrate the electrical conduit & plumbing the printing process. The concrete used for the printer is hardened at a specific ratio for the lowest time for settling. The printer is a gantry system with an extrusion nozzle that travels on two parallel rails installed in the field, as shown in Figure 1. The trowel smoothens the surface of the layer as the concrete is extruded. Each extruded layer can maintain its shape as subsequent layers are added successively. Automated reinforcement is possible by adding steel mash or reinforced plastics. The prediction from the case study is that

the printer can build 2000 square feet within 24 hours.

Figure 1 : Gantry system Printer with multi-storey construction

The aim of the paper is "To Assess the financial feasibility for the implementation of 3D concrete printing technology in the construction industry in India, for affordable housing projects." The goal of the paper is not only to showcase the significance of the 3D concrete printing technique & its implementation but also to quantify the working capital & its returns in percentages when the time factor is involved. The concept of the Time value of money is evaluated & quantified with the help of sample study consideration on paper, which can be useful for affordable housing in today's time, where the need for houses is the Government's Primary agenda by introducing various schemes such as PMAY, RAY, Light House Project (an initiative towards the advance technique for affordable & speed construction), etc.

Case Studies:

Tvasta Nirman Manufacturing: Company, India has built the 2BHK ground structure with 600sqft area, with the Gantry system printer. The entire printing process was completed in 5days & the house was ready in three weeks,i.e. 1/8th of the time of the conventional method, and 1/3rd of the waste was generated as the formwork for construction & wet construction process is eliminated. The construction cost was estimated at around 5.5lakhs. As a conclusion, this technology can enable deep personalization of construction for the ultimate target segments. With financial & material research, 3D concrete printing can ensure that affordable, good-quality housing availability.

US based API SCOR; manufacturing company transported robotic arm-based extrusion printer in Dubai, to create a two-storey Municipality structure with an area of 640 m² (6900 sqft.) & a height of 9.5 m (31 ft.). The estimated period was 2 months, but due to extreme weather condition in Dubai, machine was operated at only night and completed it in 4 months. According to the company, the total printing time was about 500 hours, 8 hours a day. After installing the ceiling on the 1st floor, the printer was carried onto the 2nd floor and started printing. Construction costs were reduced by 50-70% and labor costs were reduced by 50-80%. The average construction cost when using APISCOR's 3D printer was calculated to be approximately $ 223 / m².

SWOT Analysis of 3D Concrete Printing Technique

With the detailed case studies & interview SWOT analysis is developed & discussed in the table 1.

Table 1: SWOT Analysis of 3D concrete printing technique

STRENGTH	WEAKNESS
• Machine can anytime of the day • Limited amount of heavy equipment for construction • Limited human factor is involved increases the safety factor due to indirect increase in co-ordination • No formwork is required, lowers the cost of usage &wastage • Simplified Site job layout & Logistics • Material & resource management can be simplified with scheduling of machine & productivity	• Higher cost of construction equipment • Continuous monitoring- carefu planning of supply material in order to obtair continuity of production • High performance production of rav material • Energy consumption for making of rav material is higher
OPPORTUNITIES	**THREATS**
• Low Cost of building with massive scale • Use of recycled materials for printing • Lower the cost on logistics & implementation work • Increasing the safety on construction site • Carbon emission due to construction activity is lowered & leads to wards the less harmful & sustainable	• Printing Material needs specific materials, difficulty in supply construction market • Reduction of worker lead the job reduction on site • Lack of data on weather condition; it may damage the machine

Advance construction techniques in Affordable housing

With the study of cases in India, as well as across the globe, the time factor is reduced due to ease in the supply chain for material, logistic plan on-site as the reduction in the human factor, and also the building of formwork. This creates the opportunity for building Modular houses with economic cost & fast construction ultimately will create affordable houses for people.

With this target, the Government has proposed the Light house project across the 6 cities in India, where houses are going to be built with various advanced construction techniques. This is an initiative of an experiment towards affordable housing schemes with advanced techniques which include Monolithic concrete construction, Pre-cast components system, 3D volumetric components, Prefabricated panel system, Light Gauge Steel Structural System & Pre-engineered Steel Structural System, PVC Stay in Place

Formwork System. For the assessment of financial feasibility on paper of these techniques, two techniques viz. Monolithic concrete construction & Precast Structural component system are chosen to have the comparative analysis with the 3D concrete printing technique. The study of quality & technique comparison with respect to conventional construction is shown in the table 2.

Table 2 Comparison of Advance Construction Techniques

	Factors	Monolithic concrete construction	Pre-Cast components	3D concrete printing Technique	Conventional
1	Quality	Superior (in housing)	Better	Superior(in Every kind)	Normal
2	Speed of Construction	Fast, as wall & floorcast together	Faster, as the pre-castcomponents has to assemble	Faster, as construction is h help of printer	Slow due to step bystep completion
3	Aesthetics	Smooth finish clean lines	Smooth, & Joineries ofcomponents with formwork is visible	Smooth finishlayered with lines	Column show – Beam slight Projection
4	Raw Material	More than Conventional	Factory based component & exactamount of material	Higher-strength & exact quantity in printer as no wastage	Normal
5	Repair & Maintenance	Not frequentl y required.	Not frequently required.	Not frequently required.	Required in every 3-5 years.

Calculation for COST & TIME of Advance construction Techniques

To assess the financial feasibility of all these advance construction techniques, considering the implementation case as the sample case of floor area 150sqm with G+10 Structure with 10 number of modular units, where these techniques will be implemented on paper with respect to Cost & Time associated with each technique.

Calculating the costing data, the current market rate's BOQ & Rate card is considered & calculated in Table 3.

Table 3 Cost Calculation for Advance construction technique

	Construction Activities	Monolithic Concrete		Pre-cast technology		3D concrete printing technology	
		(Rs/Sqm)	Total Cost	(Rs/Sqm)	Total Cost	(Rs/Sqm)	TOTAL Cost
Sub Structure	Foundation		4,50,000		₹4,50,000		4,50,000
Super structure	Shuttering	85	11,22,000	--	--	--	
	Concreting	1505	58,09,300	1400	22,12,000	1700	48,62,000
	Reinforcement	2115	81,63,900	1480	23,38,400	1900	54,34,000
	Brickwork(in Rs/cu.m)	--	--	6030	79,75,000	--	--
	Lifts (8 Lakhs/lift)		25,00,000		25,00,000		25,00,000
	Plastering	250	35,50,000	350	49,70,000	250	35,50,000
	Painting	300	42,60,000	300	42,60,000	300	42,60,000
	External Finish	300	45,00,000	300	45,00,000	300	45,00,000
	Services		12,00,000		12,00,000		12,00,000
Finishes	Interior	8500	2,99,20,000	850	2,99,20,000	8500	2,99,20,000
	Others(Equipment, Transportation in %)	10%	61,47,520	10%	61,47,520	18%	1,10,65,536
	Waste disposal	5%	30,73,760	8%	48,26,032	3%	17,00,280
	Contingency	5%	30,73,760	5%	30,16,270	5%	28,33,800
	TOTAL	7,33,20,240		7,38,65,222		7,18,25,616	

Similarly, timeline of project with all these techniques has to be calculated. For 3D concrete printing technique, the productivity of the printer is targeted as 2000sqft in 24Hrs, breaking down to that working hours are considered as 8hrs a day. Considering this productivity, printing of 150sqm floor area of G+ 10 stroey will take 8 weeks of time to finish (excluding sub structure & finishing). Similarly, for Monolithic concrete construction & precast component structure, the slab cycle of each floor is considered to 11days[1], which narrows down to finish the super structure in 18 - 20 weeks or 5months (excluding substructure & finishing). For each technique, the time associated with substructure & finishing would be same for all & it can be overlapped. Hence the time comparison graph for 3 techniques is shown in figure 3.

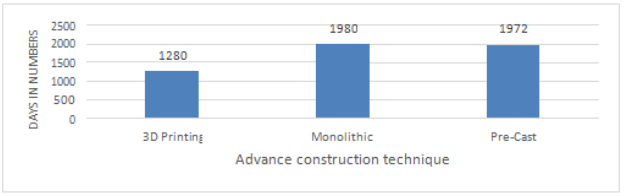

Figure 2: Time Calculation of Advance construction Techniques

RESULTS & DISCUSSION

Now, Capital Cost of construction & Time involved for each advance construction technique is when plotted for the purpose of evaluation using the formula of Internal rate of return(IRR), the ratios &

growth returns of working capital can be assessed and is shown in the table 3.3.

Table 4 IRR calculation (Numbers denotes the value in INR except for Year)

*Assumptions: Rate of Affordable housing units is considered as 12.5Lakhs [4] & Inflation rate in current market 2022 is considered as 6%.

RESULTS

As per the numbers arrived, the internal rate of return of the invested amount for 3D concrete printing is significantly higher in percentage and so as the profit (ratio of Invested amount to returns). Applying TIME VALUE OF MONEY concept, the value of money is calculated with respect to the Time. The cost of construction for every technique is in the similar range for investment of working capital but when the time factor is involved its value changes significantly. For the research, the result was generated by evaluating techniques on specific project & it can be applicable for any project to make it more economical by valuing the current capital cost. Faster process can be useful to generate Affordability in the cost. When the timeline of any project gets reduced there are various advantages associated with those such as minimization in Price escalation of materials, labor, resources, etc., and Cost inflation considered for sale value of the project (each unit) becomes minimal with short duration.

With the Growing advance construction techniques, there are always pros & cons associated with those. There various other vernacular materials such as clay which can be used in printer with many constraints as per its productivity & characteristics. Various researches along with the implementation of 3D printing with different materials have been executed across globe. Since 3D Concrete printing is developing technique across the global levels, the finance associated with various experiments shall become the base for growth & to make it commercial for implementation. However, much more scope of research can be carried out further with developing techniques.

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