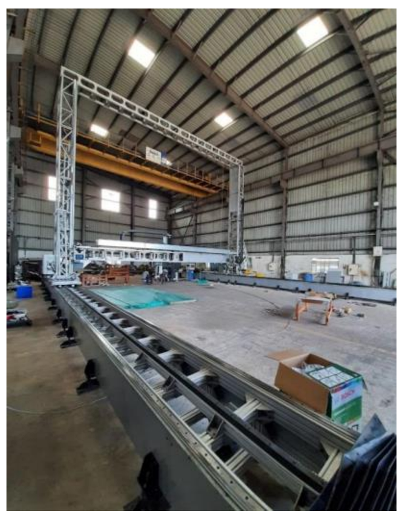
Name and Address of Certificate Holder: **M/s Tvasta Manufacturing Solutions Private Limited** Chennai, Tamil Nadu - 600119 E-mail: info@tvastagroup.in	Performance Appraisal Certificate PAC No. **1068-S/2023** Issue No. **01** Date of Issue: **18.07.2023**

BMTPC
PACS
PERFORMANCE APPRAISAL CERTIFICATION

Concrete 3D Printing Technology (C3DP)



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Performance Appraisal Certificate

For

Concrete 3D Printing Technology (C3DP)

Issued to

M/s Tvasta Manufacturing Solutions Pvt. Ltd

STATUS OF PAC

S. No.	Issue No.	Date of Issue	Date of Renewal	Amendment		Valid upto (Date)	Remarks	Signature of Authorized Signatory
				No.	Date			
1	01	18.07.2023				17.07.2024		
	01	18.07.2024				17.07.2026		

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PART 1: CERTIFICATION

1.1 Certificate Holder: M/s Tvasta Manufacturing Solutions Private Limited
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1.2 Description of System

1.2.1 Name of System - Concrete 3D Printing Technology (C3DP)

1.2.2 Brand Name - Concrete 3D Printing Technology (C3DP)

1.2.3 Brief Description

Concrete 3D printing is the technology in which concrete layers are laid one over the other using an automated robotic system. The system consists of a pump and extruder along with a print head. The entire printing process is streamlined with the help of software integrating the machine & material parameters.

Special features of the system include the following;

i. Design Freedom – A wide range of designs can be constructed which are structurally stable.
ii. Construction Efficiency – Construction time can be reduced due to the inclusion of automation during construction. Also, the manpower requirement can be reduced significantly.
iii. Automation – The process of construction is performed using robotic systems, also bringing accuracy.
iv. Labour safety – The safety of the workers can be enhanced by the use of this technology.
v. No Requirement of Formwork- The printing operation of the vertical elements does not require formwork.

1.3 Assessment

1.3.1 Scope of Assessment

The scope of the assessment included suitability of Concrete 3D Printing Technology (C3DP) for the construction of Residential Buildings up to G+2 Floors with RC structural system.

1.3.2 Basis of Assessment

The Assessment of the suitability of the construction is based on the following;

i. Assessment of various mechanical & durability parameters such as compressive strength of cubes & cylindrical cores, modulus of elasticity, stress-strain behaviour of concrete, flexural strength of concrete beams & bond strength of concrete, of 3D Printed concrete specimens, carried out at Civil Engineering Department, IIT Madras.
ii. Design Basis Report for residential building of Ground +2 Floors with 3D Printing Technology & vetting of the design & drawings by IIT Madras.
iii. Design & Construction of two 3D printed toilets for Indian Air Force at Jaisalmer, Rajasthan. Certification & Proof checking of the design & drawings by IIT Madras.
iv. Certificate of completion of 3D printed concrete structures at Chiloda, Ahmedabad, Gujarat, by Military Engineering Services.
v. Certificate from Garden Reach Shipbuilders & Engineers Ltd., Kolkata, for 3D printed site office construction at GRSE RBD Unit, Kolkata.
vi. Quality Assurance system followed by the Certificate holder.
vii. The Virtual inspection of the Set up of the Agency to review 3D Concrete Printing process, its performance, testing facilities, test results, status of quality assurance plan, certification by IIT Madras, etc. by TAC members & BMTPC Representatives.

1.4 Uses of the system

The main uses of the system are;

i. Faster construction of concrete structure using high-efficiency appliances, low material wastage & without the requirement of formwork for vertical members.
ii. Construction of customized & air-gap insulated building walls/elements, reducing heat gain through walls, as per the requirement.

1.4.1 Special Aspects of Use /Limitations

For 3D printing of modules at the site, the slab/roof needs to be cast as per the conventional method. However, the number of props can be reduced due to the walls supporting the slab's shuttering. The slab/roof can also be precast.

1.5 Conditions of Certification

1.5.1 Technical Conditions

i. Raw materials and the finished product shall conform to the requirements given in Part 2 of the document.

ii. The building to be constructed using C3DP technology shall be designed by competent structural engineers in accordance with various specifications, following relevant codal requirements, and constructed by trained persons only with technical support or supervision by qualified engineers and builders. The structural design shall include seismic loads, wind forces and other forces/loads applicable as per relevant Indian Standards. As per the requirement of the Client, vetted design of the structure will be provided by the PAC Holder.

iii. The structural engineers and building designers associated with such type of construction should be thoroughly familiar with its various structural aspects. It is also recommended that Architects and Engineers who undertake such building design and construction gain familiarity with the system, properties, and materials.

iv. The design assumptions, detailed calculations, and references to necessary and detailed design drawings shall be made available on demand if required. The structural design calculations should clearly demonstrate structural integrity and stability, including connection details.

v. The system is to provide minimum reinforcement, as required by prevalent applicable codes for multi-storied buildings.

1.5.2 Quality Assurance

The Certificate Holder shall implement & maintain a quality assurance system in accordance with the Scheme of Quality Assurance Plan (QAP) as per **Annexure 1**.

1.5.3 Handling of User Complaints

The Certificate holder shall provide quick redressal to consumer/user complaints which proved reasonable & genuine and within the conditions of warranty provided by it to customer/ purchaser.

The Certificate holder shall implement the procedure included in the QAP. As part of PACS Certification, it shall maintain data on such complaints with a view to assessing the complaint satisfaction and suitable preventive measures taken.

1.6 Certification

On the basis of the assessment given in Part-3 of this Certificate & subject to the conditions of certification, use & limitations set out in this Certificate and if selected, installed & maintained as set out in Part-1 & Part-2 of this Certificate, Concrete 3D Printing Technology (C3DP) is fit for use as set out in the Scope of Assessment.

PART 2: CERTIFICATE HOLDER'S TECHNICAL SPECIFICATIONS

2.1 General

The PAC holder shall use the System in accordance with the required specification & as per the relevant standards (Part-5).

2.2 Specifications of Raw materials

The concrete needs to be designed in such a manner that it satisfies the requirements of the printable mix.

2.2.1 Raw materials/components

Table 1 List of raw materials/components used

Sl. No.	Raw Material/ Component	Source	Specification	If quality certified in any form, state
1.	OPC – 53 Grade	India Cements	IS 12269-2013	In house testing
2.	PPC	India Cements	IS 1489 (Part 1) – 1991 Reaffirmed. 2020)	
3.	Fly ash	Dirk	IS 3812 (Part 1)-2003	
4.	Water	Municipality	IS 456 – 2000	
5.	Sand	Locally available	IS 383 – 2016	
6.	Accelerating admixture	Chryso	IS 9103 – 1999Reaffirmed. 2018)	External lab testing
7.	PCE based superplasticizer	BASF	IS 9103 – 1999Reaffirmed. 2018)	
8.	Viscosity modifying admixture	SE Tylose GmbH & Co.KG	ASTM C494/C494M	
9.	Non-structural fiber (6 to 18 mm)	Locally available		

2.3 Concrete 3D Printing Process

The machine consists of a pump, extruder along with a print head, and an accelerator mixing setup at the nozzle, as shown below (Fig. 1). The printable mix needs to satisfy the three material requirements of pumpability (ability to be pumped), extrudability (ability to be extruded), and buildability (ability to build).

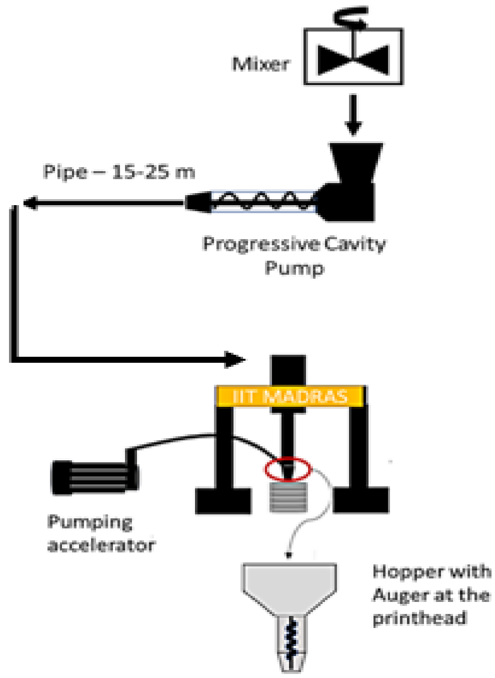


Fig. 1 Machine for 3D Printing

2.3.1 Printer

The printers used by Tvasta for executing construction projects have been designed and developed in-house to achieve optimal resource utilization and unconventional architecture. The printers have numerous subsystems that ensure its operations. These are integrated using our proprietary software to streamline the printing process.

The printers have been designed to follow two methods of machine movement, namely, *Gantry and Robotic Arm*.

2.3.1.1 Gantry-based Concrete 3D Printers

These printers consist of Tvasta printheads mounted on a gantry system. The printheads print the proprietary material through *screw-based extrusion*. The range of printers includes;

- ***R&D scale Concrete 3D Printer***

Research 3D Printer aiding 3D Printing with a variety of materials has been developed by the Agency, as shown below in Fig. 2, which is compatible with various materials and designs, easy and user-friendly in machine operation.

Fig. 2 Printing setup Gantry based – R&D

- ***Off-site Concrete 3D Printer***

  This printer (Fig. 3) can be used to print large-scale concrete parts that can be used individually or assembled to form a bigger structure. It implements a novel multi-pallet printing mechanism, allowing fast printing.

Fig. 3 Printing setup Gantry based – Off-site

- ***On-site Concrete 3D Printer***

  The on-Site Printer developed by the Agency is a system intended to print large-scale concrete structures such as residential buildings as shown below in Fig. 4. This printer can be assembled on-site and can be made ready to print (24/7) in a short duration of 2 days. A unique truss framework allows ease of transport and assembly. It has a real-time feedback system with sensors for precise printing of layers and an automated material supply system for dust-free operations.

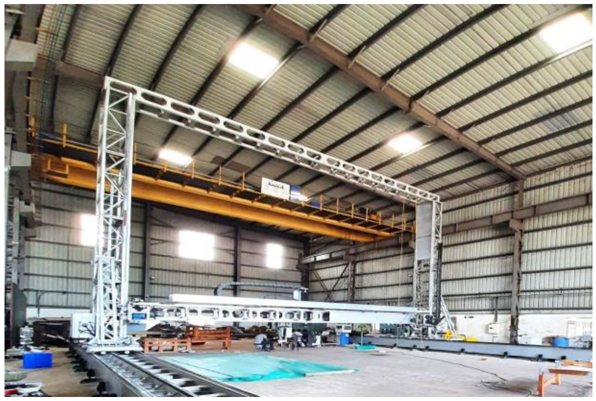


Fig. 4 Printing setup Gantry based – On-site

2.3.1.2 Robotic-Arm based Concrete 3D Printers

These printers consist of printheads developed by the Agency mounted on a robotic arm. The printheads print the proprietary material through screw-based extrusion. The range of printers include;

- ***Stationary Robotic Arm-based Concrete 3D printer***

It is 6-axis robotic arm with 3 m reach (Fig.5), equipped with a unique extrusion system that allows ease of printing and movement for both large and small-scale production. This also provides greater design flexibility, faster production times and seamless deposition of layers through advanced nozzle and smart sensor systems. The streamlined arm enables access to tight spots without potentially interfering with printing.

Fig. 5 Printing setup Robotic arm – Stationary

- ***Mobile Robotic Arm-based Concrete 3D Printer***

This printer utilizes a distinct 7th axis motion system in addition to 6 axes of a robotic arm (Fig. 6). The motion system consists of a crawler that enables printing large and small-scale structures. The printer has larger reach than a fixed robot and can be used ideally in a factory-setup for production.

Fig. 6 Printing setup Robotic arm – Mobile

2.3.2 Mixer

A batch-type mixer (Pan type planetary mixer or Drum mixer) is preferred. However, an inline continuous mixer can also be used to prepare the concrete. The dosage of admixtures needs to be optimized to reduce the probability of segregation or bleeding depending on the mixing system and parameters such as speed etc.

2.3.3 Pumps

Any commercially available screw-based positive displacement pump (Fig. 7) (with maximum particle size of 8 mm) or piston-based pump with the provision of zero dead volume can be used to pump 3D printable mix. Both pumps are used for different projects. No special modification to the available commercial pumps is required for this process.

The accelerator/chemical admixture is pumped using a commercially available centrifugal pump to the nozzle head/ extruder.

Fig. 7 Pumping system

2.4 Construction Methodology

2.4.1 C3DP System manufacturing details

The manufacture of the concrete 3D-printed building is schematically described in Fig. 8. In the first step, the concrete needs to be designed and prepared using specified raw materials. The quality check and control of the raw materials are performed as per quality assurance plan. After batching of the concrete, the quality is checked again, and the concrete is transferred to the pump for pumping. Simultaneously, the software file for the robot to function is processed. The 3D module in the form of .stl file is further sliced to form the G-code. The G-code is needed for the control of the print path. The robotic movement needs to be ensured before the initiation of the real print. The printing of the modules is controlled by both machine and material parameters.

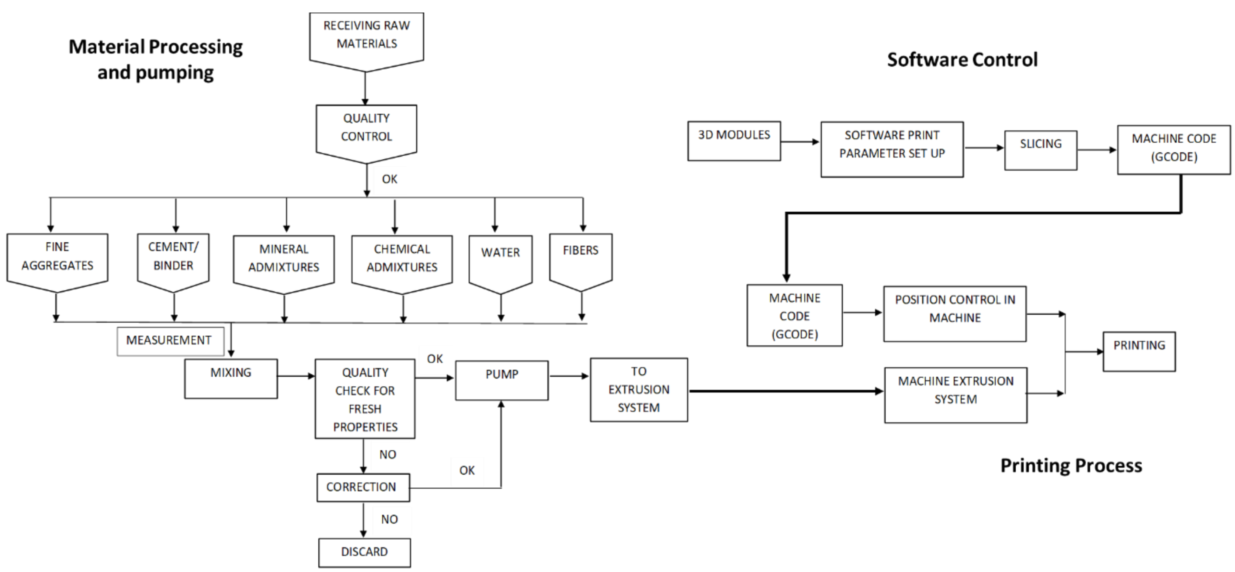


Fig. 8 Schematic diagram –Concrete 3D-printing of building

2.4.2 Construction of 3D Printed building - Structural system

Fig. 9 describes the construction process at different elemental levels of the 3D printed building. The construction is divided into six steps starting from foundation to upper storey slab/roof. The foundation can be either cast-in-situ or precast. The outer boundary of the footing can be of 3D printed elements, however, lateral support is needed during the concreting of the foundation. The foundations are designed and constructed as per the guidelines of IS 456 and NBC. The plinth beam can be cast on-site or precast plinth beam can also be used. 3D printed beams as precast plinth beams can be used following the requirements of relevant IS codes for footings (such as IS

456, IS 15916 etc.). The ground level/ plinth level floor is constructed using the cast-in-situ method.

The wall modules can be constructed in two ways - (a) The modules are printed away from the site and transported to the site, and assembled on the plinth beam and on subsequent beams of the building at different floors, and (b) The printer is installed at the site, and the modules are printed directly on the plinth beam and on subsequent beams at different floors. The construction of the first floor commences only after the full construction of the ground floor (excluding MEP and finishing), including the infill or encapsulating walls. If the walls are load-bearing, the modules constructed by either method 'a' or 'b' are joined together using tie beams and tie columns at-site while grouting the modules following cast-in-situ method. If the modules are printed as per method 'a', the panels need to be erected using manpower or machines depending upon the size of the modules. Partial grouting of the modules at the factory is possible while allowing provisions to be connected at-site. However, for both cases, the provision for connecting the modules at-site is provided and shown in Fig. 10. If the modules are printed at-site, the printer nozzle can be positioned over the last printed modules/ tie beam/ beam and printing of subsequent modules can be continued. The grouting of load-bearing components with reinforcement is done at site using cast-in-situ method. If the RC frame consists of beams and columns instead of load bearing walls, required provisions as per the dimension requirement are provided as shown in Fig. 11. These provisions can be grouted after inserting reinforcements either in the form of cages or through manual lapping of bars at-site. Cast-in-situ method is used for grouting the columns and beams at-site. Fig. 12 shows an example of the process of joining a plinth beam/ foundation wall with the column cage and provision of lateral support during column grouting. While a panel printed away from the site is shown in the picture, a similar strategy will be used for the panel printed at site over the plinth beam/ foundation wall. In the end, a cast-in-situ slab or precast slab can be used for the upper floor slab or roof. Shuttering will be required for cast-in-situ, whereas props will be required for precast until connections gain the required strength. The complete flowchart of the process flow is shown in Fig. 13.

Conventional/ Precast foundation	With 3D printed outer boundary and lateral support or conventional formwork	Rebar needs to be conventionally placed for the foundation	Foundation casting shall be done as per the cast-in-situ method mentioned in relevant IS codes. For precast foundation, single footing foundations is only accepted.	Reinforcement as per IS 456 and IS 15916. Connections between grouted RC frame sections should follow IS 456, IS 15916, and IS 15917. Min reinforcement provision need to be satisfied for plain wall panels also. *Provision of tie beam and tie column is necessary for load bearing wall systems *Reinforcement placement shall be as per the suggestion of structural engineer.
		Starter rods for column/ wall		
Conventional / 3D Printed plinth beam	Precast 3D printed plinth beam can be used	Damp proof course on top of the plinth	3D Printed beams as precast beams can be used for plinth beam or the cast in-situ beam with conventional formwork can also be done.	
Ground floor slab/ Plinth level slab	Conventional slab casting	Sand filling before casting the slab		
Walls	Printed as wall modules. It can be both load bearing (part of RC frame) or non-load bearing	Modules are transported to the site and assembled as large panels	Printer is hosted at a covered place where modules are printed. Modules can be grouted at the factory also before transportation or grouted at site	
		Modules are printed on the plinth beam at site	Printer transported and installed at the site for printing modules. Foundation provision need to be provided for the printer installation.	
Columns and beams	Columns and beams	3D printed as columns and beams to be a part of RC frame. Encapsulated by 3D printed walls	Columns and beams are cast within the wall modules with help of external supports and props. The columns and beams can be grouted at factory or site with provision of connections for monolithic behaviour.	
Slab/ roof	Conventional or precast roof	3D printed as precast roof and connected at site or 3D printed and supported by shuttering and props as cast roof on-site		

Fig. 9 Construction steps for a 3D printed building

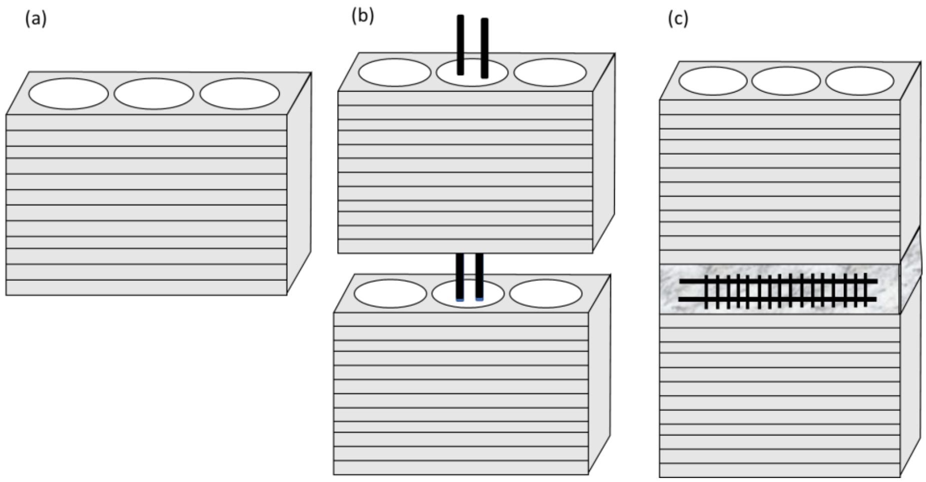


Fig. 10: (a) A single wall panel with cavities/ provisions, (b) vertically joining with rebars, (c) Tie beams to connect the horizontal modules. The vertical reinforcement and the tie beams/ beams will be joining all the modules together

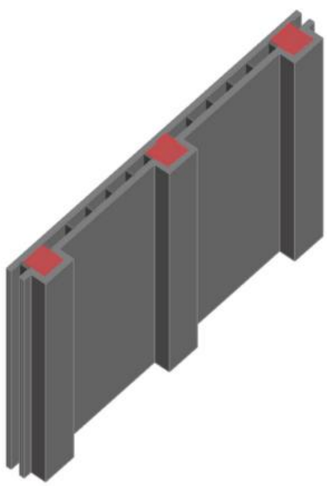


Fig.11 Provision of column and beam in the printed encapsulating wall

Provision to Join panels with footing wall/ plinth beam

Column reinforcements at different wall provisions

Lateral support during grouting of column/beam

Fig. 12: Joining column with footing/ plinth beam (left), column reinforcement at selected positions (center), Lateral support while concreting column (right)

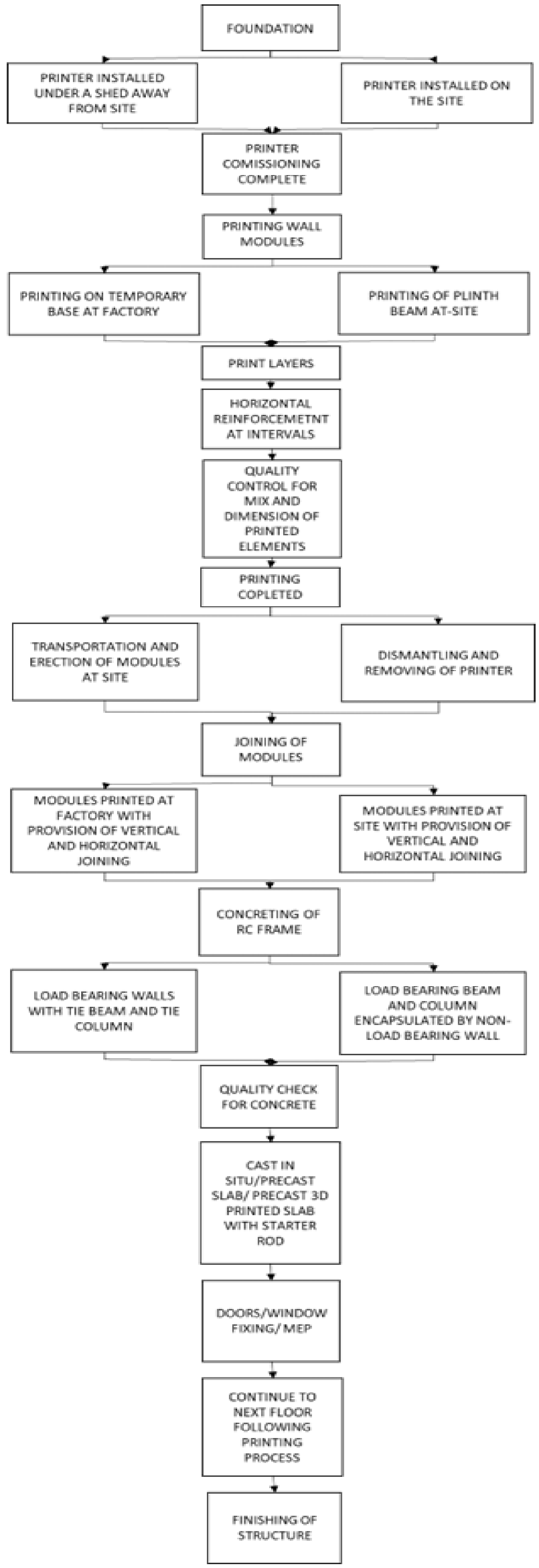


Fig. 13 Construction steps followed for the 3D printed building

The Manual/ Instruction for construction using 3D printing is attached at **Annexure-2.**

Curing protocol

The curing protocol needs to follow IS 456. Curing shall initiate just after the starting of printing or near the initial set of the material to avoid plastic shrinkage cracks. 21 days of curing is prescribed to avoid drying shrinkage cracks for 3D printed wall panels.

2.4.3 Manufacturing Machinery

Table 2 Manufacturing Machinery

S. No.	Date of installation	Name of machine and ID No	Make	Capacity	Capability	Number of machines	Does the unit have maintenance schedule	Remarks
1	2	3	4	5	6	7	8	9
1	Dec 2021	Robotic Arm Off Site Concrete 3D Printer - RT001	Tvasta	2.5m reach	Off-site	1	Yes	
2	Mar 2022	Robotic Arm Off Site Concrete 3D Printer - RT002	Tvasta	2.5m reach	Off-site	1	Yes	
3	Apr 2023	Robotic Arm On Site Concrete 3D Printer - RT101	Tvasta	4m reach	On-site	1	Yes	
4	Apr 2023	Robotic Arm On Site Concrete 3D Printer - RT102	Tvasta	4m reach	On-site	1	Yes	
5	Aug 2021	Gantry Based Off Site Concrete 3D Printer - PD101	Tvasta	4mx10mx2m	Off-site	1	Yes	
6	Oct 2022	Gantry Based Off Site Concrete 3D Printer - PD201	Tvasta	2mx2mx2m	Off-site	1	Yes	
7	Apr 2023	Gantry Based Off Site Concrete 3D Printer - PD202	Tvasta	8mx10mx3m	On-site	1	Yes	
8	Mar 2023	Gantry Based Off Site Concrete 3D Printer - PD203	Tvasta	4mx10mx2m	Off-site	1	Yes	
9	Mar 2022	Gantry Based Onsite Concrete 3D Printer - OT001	Tvasta	8mx10mx8m	On-site	1	Yes	
10	Sep 2021	Gantry Based Off Site Concrete 3D Printer - RD001	Tvasta	1mx1mx.5m	R&D	3	Yes	
11	Aug 2021	Small Pan Mixer	Tvasta	100kg	Off-site & On-site	4	Yes	
12	Sep 2021	Big Pan Mixer	Tvasta	300kg	Off-site & On-site	8	Yes	
13	Sep 2021	Small PC Pump	Tvasta	2.5m^3	4.75 mm Aggregate	5	Yes	
14.	Dec 2021	Big PC Pump	Tvasta	6m^3	10 mm Aggregate	4	Yes	

PART 3: BASIS OF ASSESSMENT & BRIEF DESCRIPTION OF ASSESSMENT PROCEDURE

3.1 Assessment

The assessment has been done as per the provisions of the standards listed in Part-5 of this Certificate.

3.2 Material assessment performed

The material assessment of 3D Printing Concrete was carried out in Civil Engineering department, IIT- Madras. The assessment of various parameters of 3D Printed concrete specimens such as compressive strength of cubes & cylindrical cores, Modulus of elasticity, Stress strain behaviour of concrete, Flexural strength of concrete beams, were conducted.

The Summary of assessment results are as below;

i. **Pumpability and open time**

The fresh-state properties of concrete are required for the mix to be pumpable. Additionally, the open time of the mix is important to retain workability. The open time is defined as the maximum time allowed for pumping. The properties of the mix assessed are shown in Table 3.

Table 3 Fresh state properties of the printable concrete

Test	Code provision	Values (Mean)	Unit	COV* (%)	Remarks
Slump flow	IS 1199 (Part 6) -2018	450	mm	10	
Flow table	ASTM C1437-20	200	mm	5	
Initial setting time	IS 1199 (Part 7)-2018	4	hours	10	Without accelerator
Final setting time		9	hours		
Open time		3	hours	5	

** Coefficient of Variation*

ii. **Extrudability and Buildability**

The extrudability and the buildability become critical at the fresh state for the construction of the designed structures. The mix pumped should attain the desired geometry and carry the loads during printing without deviating from the designed geometries. In the printing system, a separate extrusion system is provided with an accelerator mixing setup to assist with on-demand rheological and mechanical control of the mix. The extruded material is analysed as per Table 4.

Table 4 Test for Pumpability and early age compressive behavior

Test	Code provision	Values (Mean)	Unit	COV (%)	Remarks
Pressure bleed test – API filter	ASTM C1741 – 18	1.7	%	5	Weight of Forced bleed water/ Weight of sample
Uniaxial compressive stress	IS 2720 (Part 10)-1991Reaffirmed.2020)				The h/d value was modified to 0.5 The strain rate considered for the test was 60%/ min
Stress corresponding to 5% strain at age of 30 minutes		8	kPa	15%	
Secant modulus at 5% strain at age of 30 minutes		160	kPa	15%	

iii. **Mechanical and Durability properties of cast concrete**

The mechanical properties of the concrete mix are evaluated following the existing standards to determine the mechanical and durability properties of the printable concrete mix (Table 5). The data obtained from the tests are considered for design.

Table 5 Mechanical and durability properties of cast printable concrete

Tests	Code Provision	Value (Mean)	Unit	COV (%)	Remarks
Hardened state properties - Mechanical – Printable concrete					
Cube compressive strength – printable concrete	ASTM C109/109M-21			10%	M35 Grade of Concrete
7 days		24.5	MPa		

28 days		40	MPa		
Split tensile strength – printable concrete	IS 516 (Part 1/Sec1)-2021				1/10th of compressive strength
28 days		3.5	MPa	10	
Elastic modulus – printable concrete	IS 516 (Part 8/Sec 1)-2020				About 5000 f_{ck}
28 days		26	GPa	4	
Flexure strength – printable concrete	ASTM C348-21				About 0.7 f_{ck}
28 days		4.2	MPa	5	
Durability – Printable concrete					
RCPT – printable concrete	ASTM C1202-22				Very Good/ Good as per ASTM C1202-22
28 days		300-1400	Coulombs		
Water absorption	IS 3495 (Part 2)-2019				
28 days		6	%	15	
Water Porosity					
28 days		12	%	15	

iv. Load-bearing structures - Properties of concrete cylinder and prism with printed shell and grouted core

The mechanical properties of the printed hollow beam and cylinder grouted with the same grade of material are evaluated for compression and flexure strength (Fig. 14). The relevant codes used for testing are mentioned in Table 6. The structural components used in the construction are primarily grouted. Hence, the values obtained from this subsection can be directly used as the measure of characteristic and flexural strength of the RCC concrete to be used for structural purposes. The cylinders have an external diameter of 150 mm and a height of 300 mm. The grouted part in the cylinder has a diameter of 70 mm. The beam has dimensions of 700 mm x 150 mm x 150 mm with 40 mm thick printed layers.

Fig. 14 Printed beam and cylinder with grout

Table 6 Technical specifications – Printed cylinder and beam with grouted concrete

Printed Cylinder and Beam strength – grouted					
Tests	**Code provisions**	**Value (Mean)**	**Unit**	**COV (%)**	**Remarks**
Cylinder compressive strength- grouted					
28 days	IS 516 (Part 1/Sec 1)- 2021	35	MPa	5	>0.8 f_{ck} (f_{ck} is 35 MPa)
Beam flexure test – grouted- three-point loading					
28 days	IS 516 (Part 1/Sec 1)- 2021	4.4	MPa	5	Greater than 0.7 f_{ck} as per IS 456-2000

v. **Hollow shells and non-load bearing - Properties of extracted samples from printed concrete**

The property of the printed shell is further evaluated by extracting specimens from the printed shell. The values can be used to design the hollow shells for non-load-bearing components of the building.

As shown in the schematic diagram (Fig. 15), the property of the printed segments is evaluated by extracting cubes and prisms from 3D-printed walls. The length (L): thickness (T): height (D) ratios for the extracted samples are either considered as 1:1:1 for cubes or 1:0.33:1 for the prism segments (following the h/t ratio mentioned for the prism strength test in IS 1905-1987) as shown in Fig. 16.

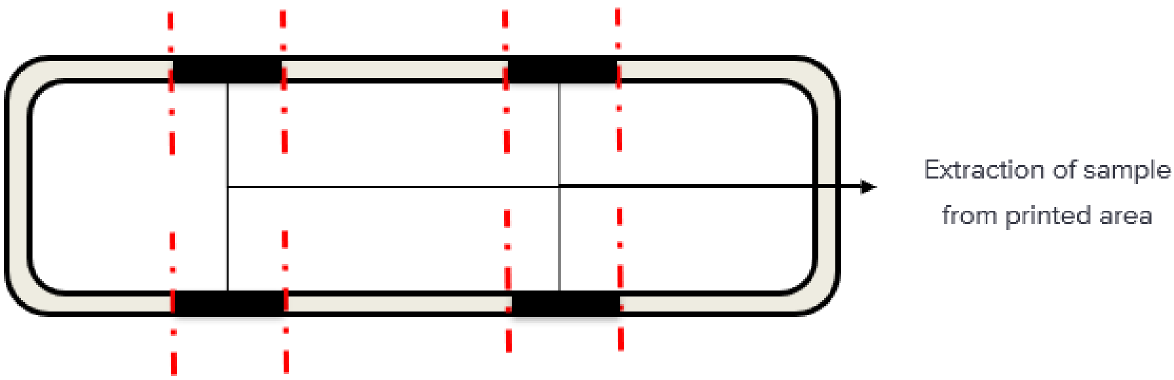


Fig. 15 Schematic diagram: Extraction from printed wall segment

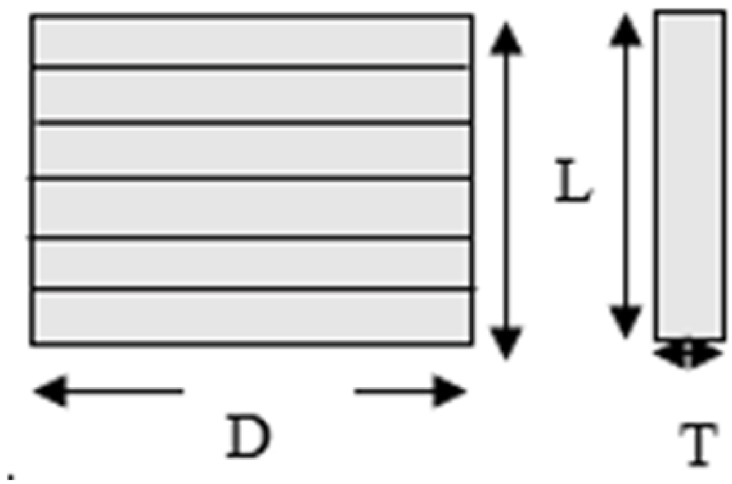


Fig. 16 Extracted sample: Dimension

The sample extraction process is shown in Fig. 17. At first, larger segments were cut out from the walls, and the inner core was extracted out. The inner core was further cut into prisms and cubes. The cubes and prisms with different layer orientations (0° to 90° with base) were extracted and tested.

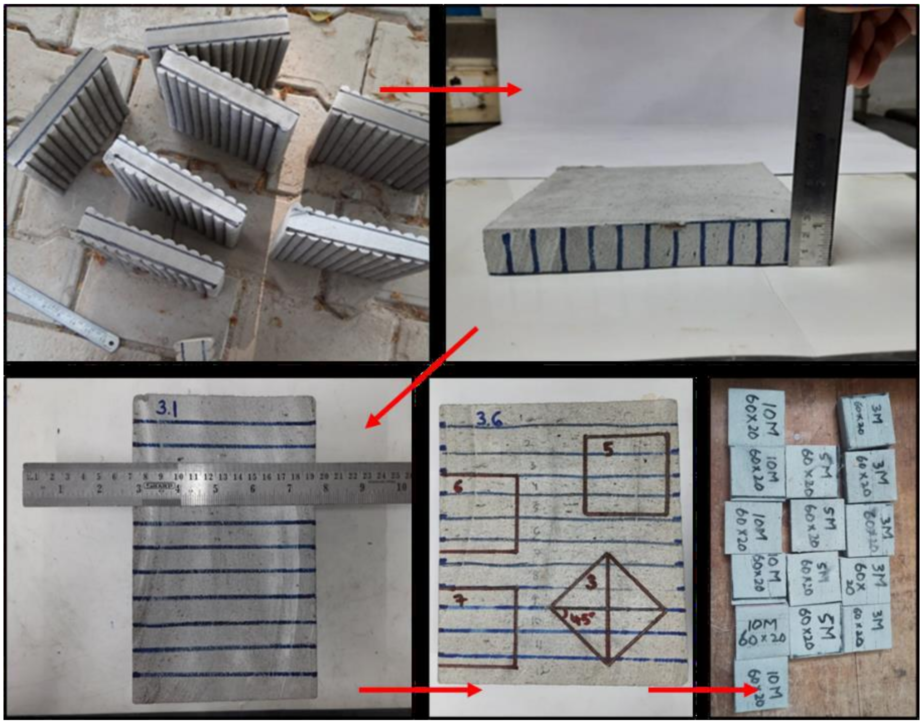


Fig. 17 Sample extraction - printed panels

The mechanical properties of the composite and the bond properties were evaluated using the extracted samples of the printed walls (Fig. 18). The properties are mentioned in the following Table 7.

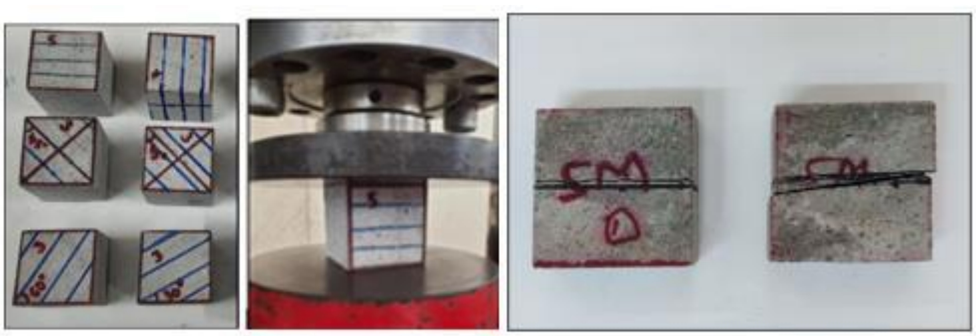


Fig. 18 Extracted element – Cubes with different orientations and bond strength

Table 7 Technical Specifications – Extracted samples

<table>
<tr><th colspan="7">Extracted cubes and prisms Printed Wall</th></tr>
<tr><th colspan="2">Tests</th><th>Code provisions</th><th>Values (Mean)</th><th>Units</th><th>COV (%)</th><th>Remarks</th></tr>
<tr><th colspan="7">Flexure test on prisms extracted from printed wall</th></tr>
<tr><td colspan="2">28 days</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Loading parallel to bond</td><td rowspan="2">IS 1237-2012</td><td>3</td><td>MPa</td><td>15</td><td rowspan="2">Can be used as bond flexure strength</td></tr>
<tr><td colspan="2">Loading perpendicular to bond</td><td>7</td><td>MPa</td><td>15</td></tr>
<tr><th colspan="7">Compressive strength of cubes extracted from printed wall</th></tr>
<tr><td colspan="2">28 days</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Bond Orientation</td><td>0° with base with vertical joint in the loading face</td><td rowspan="3">ASTM C109/109M-21</td><td>35</td><td>MPa</td><td>5</td><td rowspan="3">Can be used for determining compressive strength of the printed shells for non-load bearing components</td></tr>
<tr><td>0° with base with vertical joint in the face adjacent to the loading face</td><td>33</td><td>MPa</td><td>5</td></tr>
<tr><td>90° with base</td><td>27</td><td>MPa</td><td>5</td></tr>
</table>

vi. **Non-load bearing modules - Properties of 3D printed concrete blocks with different hollow area percentage**

The compressive strength of 3D printed prisms (Fig. 19) with different hollow area percentages is tested. The obtained values can be used for the non-load-bearing hollow components to be used in the structure. The blocks with 57% hollow area also showed a compressive strength of about 24 MPa (Table 8), presenting their suitability to be used as blocks for non-load-bearing walls.

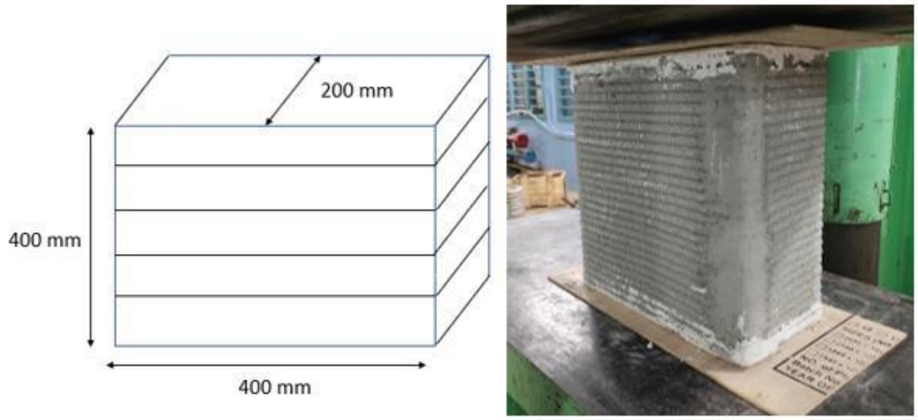


Fig. 19 Compressive strength test of 3D printed prism

Table 8 Technical specifications – non-load bearing modules

Tests		**Code provisions**	**Values (Mean)**	**Units**	**COV (%)**	**Remarks**
Compressive strength for different hollow area						
28 days						
Hollow area percentage	12%	Loading rate - IS 516 (Part 1/Sec 1)– 2021 Prism size-IS 1905-1987	30	MPa	15	
	23%		28	MPa	15	
	26%		26	MPa	15	
	57%		24	MPa	15	

3.3 List of works executed by the Agency using Concrete 3 D Printing Technology

S. No.	**Building/ Structure**	**Date of Completion**	**Client**	**Current Status**	**Photos**
1.	India's First 3D Printed House at IIT Madras, Chennai	24.09. 2021	Habitat for Humanity	In Service	
2.	3 Number of Doffing Unit at various locations in Tamil Nadu	15.10.2021	Saint Gobain	In Service	

3.	Sanitary Block for Air Force Station Jaisalmer, Rajasthan	26.02.2022	MES (Air Force)	In Service	
4.	Guest House for Air Force at Chiloda, Gujarat	13.05.2022	MES (Air Force)	In Service	
5.	Modular Site Office at GRSE, Kolkata	23.12.2022	GRSE	In Service	
6.	Bus Stand at Mumbai	27.08.2022	Godrej & Boyce	In Service	
7.	BPCL Boundary Wall at Krishnapattam, Andhra Pradesh	5.06.2021	Harerama Harekrishna Enterprises (BPCL)	In Service	
8.	Anant Siras Statue at Chennai	10.11.2022	India Cement	In Service	
9.	M.A.Chidambaram Stadium Boundary wall at Chennai	28.03.2023	TNCA	In Service	

3.4 Quality Assurance system followed by the certificate holder

The Quality Assessment system has been developed for C3DP Building, by the Agency which includes: a) Plan for raw material testing, b) Ensuring quality of concrete during the printing processes (c) Quality check for printer (d) Quality assurance during erection. Further, the scope of quality assurance plan has been divided into two components namely structural works & Architectural works. The overall weightages have been given to the two components with further break for various sub-components. The provisions of contract specifications related to quality aspects have also been covered. The Quality Assurance system has been included at **Annexure-1**.

3.5 Site Inspection

The setup of the Agency was reviewed by the members of TAC & Officers of BMTPC via video conferencing on May 08, 2023 & interaction were held with technical personnel of the Agency. The agency demonstrated various printers, printing operation, testing results, quality assurance measures adopted, certification by IIT Madras and various projects undertaken.

PART 4: STANDARD CONDITIONS

This certificate holder shall satisfy the following conditions:

1 The certificate holder shall continue to have the product reviewed by BMBA.
2 The product shall be continued to be manufactured according to and in compliance with the manufacturing specifications and quality assurance measures which applied at the time of issue or revalidation of this certificate. The Scheme of Quality Assurance separately approved shall be followed.
3 The quality of the product shall be maintained by the certificate holder.
4 The product user should install, use and maintain the product in accordance with the provisions in this Certificate.
5 This certificate does not cover uses of the product outside the scope of this appraisal.
6 The product is appraised against performance provisions contained in the standards listed in Part-V. Provisions of any subsequent revisions or provisions introduced after the date of the certificate do not apply.
7 Where reference is made in this Certificate to any Act of Parliament of India, Rules and Regulations made there under, statutes, specifications, codes of practice, standards etc. of the Bureau of Indian Standards or any other national standards body and the International Organization for Standardization (ISO), manufacturer's company standards, instruction/manual etc., it shall be construed as reference to such publications in the form in which they were in force on the date of grant of this Certificate (and indicated in Part V to this Certificate)
8 The certificate holder agrees to inform BMBA of their distributors / licensees whenever appointed by him and agrees to provide to BMBA a six monthly updated list thereof.
9 The certificate holder agrees to provide to BMBA feedback on the complaints received, the redressal provided, and the time taken to provide redressal on complaint to complaint basis as soon as redressal is provided. BMBA agrees to provide the certificate holder the user feedback received by it, if any.
10 If at any time during the validity period, PAC is unable to fulfill the conditions in his PAC, he should on his own initiative suspend using the PAC and notify Chairman, TAC the date from which he has suspended its use, the reason for suspension and the period by which he will be able to resume. He shall not resume without the prior permission of BMBA. He shall also inform, simultaneously, his agents, licensees, distributors, institutional, government, public sector buyers, other buyers and all those whom he has informed about his holding the PAC. He shall also inform all those who buy his product(s) during the period of suspension. He shall provide to BMBA at the earliest the list of who have been so informed by him.
11 In granting this Certificate, BMBA takes no position as to:
    (a) The presence or absence of patent or similar rights relating to the product;
    (b) The legal right of the Certificate holder to market, install or maintain the product;

(c) The nature of individual installations of the product, including methods of workmanship.

12 BMTPC and the Board of Agreement of BMTPC (BMBA) take no position relating to the holder of the Performance Appraisal Certificate (PACH) and the users of the Performance Appraisal Certificate (PAC) respecting the patent rights / copy rights asserted relating to the product / system / design / method of installation etc. covered by this PAC. Considerations relating to patent / copy rights are beyond the scope of the Performance Appraisal Certification Scheme (PACS) under which this PAC has been issued. PACH and users of this PAC are expressly advised that determination of the Claim / validity of any such patent rights / copy rights and the risk of infringement of such rights are entirely the responsibility of PACH on the one hand and that of the users on the other.

13 It should be noted that any recommendations relating to the safe use of the product which are contained or referred to in this Certificate are the minimum standards required to be met with when the product is installed, used and maintained. They do not purport in any way to restate or cover all the requirements of related Acts such as the Factory Act, or of any other statutory or Common Law duties of care, or of any duty of care which exist at the date of this Certificate or in the future, nor is conformity with the provisions of this Certificate to be taken as satisfying the requirements of related Acts.

14 In granting this Certificate, BMTPC and BMBA does not accept responsibility to any person or body for any loss or damage, including personal injury, arising as a direct or indirect result of the use of this product.

15 The certificate holder indemnifies BMBA, its officers and officials involved in this assessment against any consequences of actions taken in good faith including contents of this certificate. The responsibility fully rests with the certificate holder and user of the product.

16 The responsibility for conformity to conditions specified in this PAC lies with the manufacturer who is granted this PAC. The Board (BMBA) will only consider requests for modification or withdrawal of the PAC.

17 The PAC holder shall not use this certificate for legal defense in cases against him or for legal claims he may make from others.

Place: New Delhi
Date of issue: 18/07/2023

Chairman TAC & for and on behalf of Member Secretary, BMBA

PART 5: LIST OF APPLICABLE STANDARDS AND CODES

Standard No.	Title
Loads and Structural Design	
IS:456-2000	Plain and reinforced concrete- Code of practice
IS:875-1987 (Reaffirmed 018/2020)	Code of practice for design loads (other than earthquake) for Buildings and structure (Part 1 to Part 3)
IS:1904-2021	General requirements for design and construction of foundations in soils — Code of practice
IS:1893 (Part-1)-2016	Criteria for earthquake-resistant design of structures (Part 1: General provisions and building)
SP:34-1987	Handbook of concrete reinforcement and detailing
Materials and Mix design	
IS:269-2015	Ordinary Portland cement - Specification
IS:1489 (Part 1) -2015	Portland pozzolana cement - Specification, Part 1: Fly Ash based
IS:3812 (Part 1)-2013	Pulverized fuel ash - specification (Part 1 for use as pozzolana in cement, cement mortar and concrete)
IS:383-2016	Coarse and fine aggregate for concrete – Specification
IS 9103-1999 (Reaffirmed 2018)	Concrete admixtures – Specification
IS:10262-2019	Concrete mix proportioning - Guidelines
ASTM C494/ C494M-19	Standard specification for chemical admixture for concrete
Fresh and Hardened properties of Concrete	
IS:1199- 2018 (Part 1 to 9)	Fresh concrete-Methods of sampling, testing and analysis
ASTM C1437-07	Standard test method for flow of hydraulic cement mortar
ASTM C1741-18	Standard test method for bleed stability of cementitious post-tensioning tendon grout
IS 10086-2021	Moulds for use in tests of cement, concrete, and pozzolana-Specification
IS 2720 (Part 10)-1991 (Reaffirmed 2020)	Methods of test for soils (Part 10 determination of unconfined compressive strength)
ASTM C109/109M-21	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube Specimens)
IS: 4031 (Part 7)-1988 (Reaffirmed 2019)	Method of physical test for hydraulic cement (Part 7 Determination of compressive strength of masonry cement)
ASTM C348-21	Standard test method for flexural strength of hydraulic-cement mortars
IS:516 (Part 1/Sec 1)-2021	Hardened concrete - methods of test: part 1 testing of strength of hardened concrete: section 1 compressive, flexural and split tensile strength

Durability	
ASTM C1202-22	Standard test method for electrical induction of concrete's ability to resist the chloride ion penetration
Reinforcements	
IS:800-2007	General construction in steel - Code of practice
IS:1786-2008	High-strength deformed bars and wires for concrete reinforcement - Specification
IS:1566-1982 (Reaffirmed 2020)	Specification for hard-drawn steel wire fabric for concrete reinforcement
IS:432 (Part 2)-1982 (Reaffirmed 2020)	Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement (Part 2 Hard-drawn steel wire)
Modules testing	
IS 1237-2012	Cement concrete flooring tiles – Specifications
IS 1905-1987: 2002	Code of practice for structural use of unreinforced masonry
ASTM C1314-22	Standard test method for compressive strength of masonry prisms
Precast code	
IS 15916-2020	Building design and erection using prefabricated concrete - Code of practice
IS 15917-2020	Building design and erection using mixed/ composite construction-Code of practice
IS 11447-1985 (Reaffirmed 2018)	Code of practice for construction with large panel prefabricates
IS 3414-1968: 2000	Code of practice for design and installation of joints in buildings
IS 10297-1982: 2008	Practice for design and construction of floors and roofs using precast reinforced/prestressed concrete ribbed or cored slab units

Applicable part of NBC 2016

Volume	Section	Sub-section	Name
1	Part 5		Building Materials
	Part 6	1	Loads, Forces, and Effects
		2	Soils and Foundations
		4	Masonry
		5A	Plain and Reinforced Concrete
		7	Prefabrication, Systems Buildings and Mixed/ Composite Construction
2	Part 9		Plumbing services

CERTIFICATION

In the opinion of Building Materials & Technology Promotion Council's Board of Agreement (BMBA), **Concrete 3D Printing Technology (C3DP)** is satisfactory if used as set out above in the text of the Certificate. This Certificate **PAC No. 1068-S/2023** is awarded to **M/s Tvasta Manufacturing Solutions Pvt. Ltd, Chennai.**

The period of validity of this Certificate is for a period of two year i.e. from **18/07/2024** to **17/07/2026** as shown on Page 1 of the PAC. This Certificate consists of a cover page and pages 1 to 49.

Dr. Shailesh Kr. Agrawal
Chairman, TAC
& Member Secretary, BMBA
Building Materials and Technology Promotion Council
Ministry of Housing and Urban Affairs, Govt. of India
Core 5A, 1st Floor, India Habitat Centre
Lodhi Road, New Delhi-110003

Embossing Seal of BMBA

BUILDING MATERIALS AND TECHNOLOGY PROMOTION COUNCIL
BMTPC PACS
BMBA
BMTPC BOARD OF AGREEMENT
NEW DELHI

On behalf of BMTPC Board of Agreement, Chairman, Technical Assessment Committee (TAC) of BMBA & Member Secretary, BMTPC Board of Agreement (BMBA) Under Ministry of Housing and Urban Affairs, Government of India

Place: New Delhi, India

Date: 19/09/2024

PART 6: LIST OF ABBREVIATIONS

BMBA	Board of Agreement of BMTPC
BMTPC	Building Materials and Technology Promotion Council
CPWD	Central Public Works Department
ED	Executive Director of BMTPC
IO	Inspecting Officer
MS	Member Secretary of BBA
PAC	Performance Appraisal Certificate
PACH	PAC Holder
PACS	Performance Appraisal Certification Scheme
SQA	Scheme of Quality Assurance
TAC	Technical Assessment Committee (of BMBA)

Performance Appraisal Certification Scheme - A Brief

Building Materials & Technology Promotion Council (BMTPC) was set up by the Government of India as a body under the Ministry of Housing &Urban Poverty Alleviation to serve as an apex body to provide inter-disciplinary platform to promote development and use of innovative building materials and technologies laying special emphasis on sustainable growth, environmental friendliness and protection, use of industrial, agricultural, mining and mineral wastes, cost saving, energy saving etc. without diminishing needs of safety, durability and comfort to the occupants of buildings using newly developed materials and technologies.

During the years Government, public and private sector organizations independently or under the aegis of BMTPC have developed several new materials and technologies. With liberalization of the economy several such materials and technologies are being imported.

However, benefits of such developments have not been realized in full measure as understandably the ultimate users are reluctant to put them to full use for want of information and data to enable them to make informed choice.

In order to help the user in this regard and derive the envisaged social and economic benefits the Ministry of Housing &Urban Poverty Alleviation has instituted a scheme called Performance Appraisal Certification Scheme (PACS) under which a Performance Appraisal Certificate (PAC) is issued covering new materials and technologies. PAC provides after due investigation, tests and assessments, amongst other things information to the user to make informed choice.

To make the PACS transparent and authentic it is administered through a Technical Assessment Committee (TAC) and the BMTPC Board of Agreement (BMBA) in which scientific, technological, academic, professional organizations and industry interests are represented.

The Government of India has vested the authority for the operation of the Scheme with BMTPC through Gazette Notification No. 1-16011/5/99 H-II in the Gazette of India No. 49 dated 4th December, 1999.

Builders and construction agencies in the Government, public and private sectors can help serve the economic, development and environmental causes for which the people and Government stand committed by giving preference to materials and technologies which have earned Performance Appraisal Certificates.

Further information on PACS can be obtained from the website: www.bmtpc.org

Annexure 1

Quality Assurance Plan

I. Quality Plan for Raw Materials

Test Parameters	In House / 3rd Party	IS/BS/ASTM Standards	IS/BS/ASTM Acceptance Standards	Frequency of Testing
FINE AGGREGATE				
Sieve Analysis, Fineness Modulus	In house	IS 2386 (Part 1)-1963 : 2002) (Reaffirmed 2021)	IS 383-2016	Once a week
Materials less than 75 Microns by weight				Once a week
Moisture Content				1 time per day prior to starting of production
Specific gravity		IS 2386 (Part 3)-1963 : 2002) (Reaffirmed 2021)		Once a week
Water absorption				Once a week
CEMENT				
Chemical Parameters:				
Ratio of % of lime to % of Silica, Alumina and Iron Oxide	3rd Party	IS 4032-1985 : 2005) (Reaffirmed 2019)	IS 269-2015	Every new aggregate source
% Alumina to Iron Oxide				
Magnesia				
% Sulphur content as SO3				
In soluble residues				
Total Loss on Ignition				
Physical Parameters:				
Fineness test 90% by sieving	In house			Every batch
Fineness Specific	3rd Party	IS 4031		

Test Parameters	In House / 3rd Party	IS/BS/ASTM Standards	IS/BS/ASTM Acceptance Standards	Frequency of Testing
Surface - Blain's air permeability		(Part 2)- 1999		
Consistency	In house	IS 4031 (Part 4/5/6)- 1988 (Reaffirmed 2005)		
Initial setting time			IS 269-2015	
Final setting time				
Compressive strength at 3, 7 & 28 days				
FLYASH				
Chemical Parameters:				
Total Loss on Ignition	3rd Party	IS 1727-1967 (Reaffirmed 2018)	IS 3812 (Part 1)-2013	Once in every new source of supply Every batch
Chloride content		IS 4032-1985 (Reaffirmed 2019)		
Sodium Oxide				
Lime content				
$SiO_2+Al_2O_3+Fe_2O_3$ percentage by mass		IS 1727-1967 (Reaffirmed 2018)	IS 3812 (Part 1)- 2013	
SiO_2 percentage by mass				
MgO percentage by mass				
Total Sulphur as SO_3				
Physical Parameters:				
Fineness- Specific Surface 45 Micron sieve	3rd Party	IS 1727-1967 (Reaffirmed 2018)	IS 3812 (Part 1)- 2013	
Compressive strength at 3, 7 & 28 days				
Specific gravity	In house			
Soundness by Autoclave test	3rd Party			

Test Parameters	In House / 3rd Party	IS/BS/ASTM Standards	IS/BS/ASTM Acceptance Standards	Frequency of Testing
Lime reactivity				
Fineness Specific Surface - Blain's air permeability				
Water				
pH	3rd Party	IS 3025 (Part 11)-2022	IS 456-2000	Once per source and after Rain
Acidity		IS 3025 (Part 22)-1986 (Reaffirmed 2019)		
Alkalinity		IS 3025 (Part 23)-1986 (Reaffirmed 2019)		
TDS				
Sulphates		IS 3025 (Part 24/ Sec 1)-2022		
Chlorides		IS 3025 (Part 32)-1988 (Reaffirmed 2019)		
Suspended Solids		IS 3025 (Part 17)-2022		
CHEMICAL ADMIXTURES				
Ash content by mass	3rd Party	IS 9103-1999	IS 9103-1999	Material Test Certificate
pH	3rd Party			
Dry material content by mass				
Chloride content				
Specific gravity				
Relative density				

II. Plan for 3D printable Concrete and Grout RCC Concrete

S. No.	Materials	Test Parameters	In House / 3rd Party	IS/BS/ASTM Standards	IS/BS/ ASTM Acceptance Standards	Frequency of testing
1	Fresh Concrete Properties	Flow table, slump cone test	In house	ASTM C1437-20/IS 1199 (Part 6) 2018		Every batch
		Temperature				
		Initial setting time		IS 1199 (Part 7) 2018		Once in a week
		Final setting time				
2	Hardened Concrete Properties	Cube compressive strength at 3,7 and 28 days		IS 516 (Part 1 / Sec 1)-2021	IS 456-2000	Every day
		Printed cube and cylinder compressive strength at 7 & 28 days				Once in a week
		Flexural strength		IS 516 (Part 1/Sec 1)- 2021		
		Young's modulus for stress-strain behavior		IS 516 (Part 8)-2020		
		Compressive strength with respect to different time interval of printing				
3	Steel reinforcement	Tensile strength	3rd party	IS 1608 (Part 1)-2008	IS 1786-2008	Material Test Certificate and One test for every 100 M.T
		Elongation				
		0.2% Proof stress				
		Bend and rebend test				
		Chemical test				

III. Quality check for Printer during operation

Apart from the concrete components, the printer position, orientation, levelling, and inclination need to be checked at the time of installation and also after every 3 days of operation. The printer shall be maintained once a week.

IV. Quality standards for Structural construction and 3D printing

The quality needs to be assured during the erection of the building as per the following:

Quality assurance during printing and construction

<table>
<tr><th></th><th>Tolerance (standards)</th><th>Frequency</th></tr>
<tr><td>3D printed Walls/ columns</td><td>IS 456- 2000
IS 15916 - 2020</td><td>After 3 meter of printing in vertical direction/ or 1 floor</td></tr>
<tr><td>Slab/ beam formwork</td><td rowspan="4">IS 456 - 2000</td><td>During placement</td></tr>
<tr><td>Placing of reinforcement</td><td>During placement of rebar/ before concreting</td></tr>
<tr><td>Compaction and curing</td><td>After concrete pouring and curing monitored for 14 days</td></tr>
<tr><td>Cover concrete</td><td>After placement of rebar</td></tr>
<tr><td>Non-structural joints</td><td>IS 15916 - 2020</td><td>During erection</td></tr>
<tr><td>Structural Connections</td><td>IS 15916 - 2020
IS 11447 - 1985(Reaffirmed2018)
IS 456 - 2000</td><td>During connection of elements/ modules</td></tr>
</table>

V. Scope of quality assurance plan

The scope is divided into 3 major components:

i. 3D Printing and structural works
- 3D printing wall and lintel elements
- Cast in-situ / precast slabs, beams
- Structural reinforcements
- Screed and finishing work
- MEP integration
- Structural quality test for concrete and reinforcement

ii. Erection and logistics

iii. Architectural and finishing works

- Internal finishes – Painting, Floor, Internal Walls, Ceiling, Doors & Windows
- Roofing
- External Wall- painting
- Functional tests – Tests such as 3DCP joint water tightness test, window water-tightness & wet area water-tightness.

MANUAL / INSTRUCTIONS

The method of construction using 3D printing comprises of multiple phases.

Phase 1 - Designing
Step 1: Architectural Design

The architectural design of the project is developed based on client's requirements.

Fig. M1 Renders of the project

Step 2: Conversion to 3D printable format

Based on the architectural drawing, the structure is split into different modules that are more suitable for 3D printing.

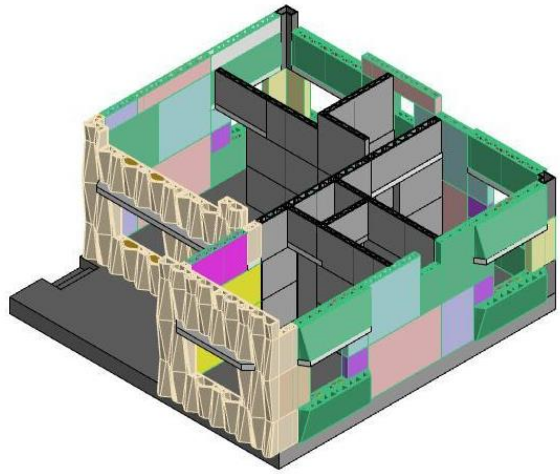
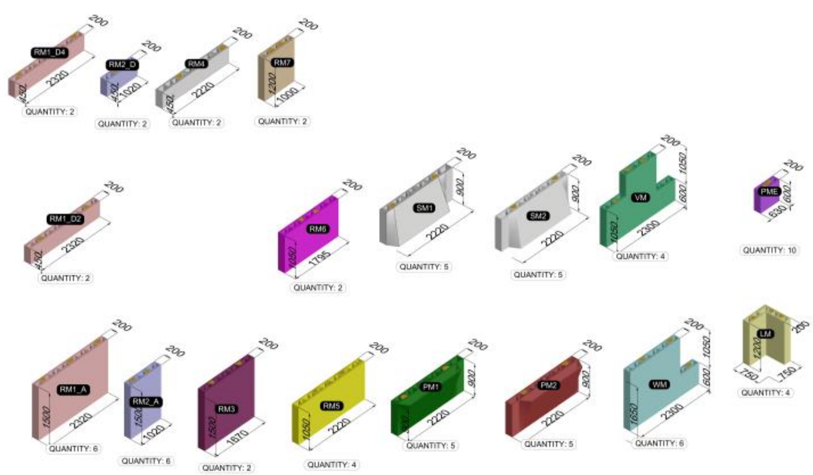


Fig. M2 Conversion of architectural drawing to 3D printable files

Step 3: Printing and Execution Strategy

The splitting of structure into modules will undergo numerous iterations based on different technical requirements.

1. ***Site Conditions:*** To determine the critical junctures of construction, site visit is conducted and required information is obtained.
2. ***Structural Engineering:*** A structural drawing is developed, incorporating the reinforcement details, based on the architectural and printable design files.
3. ***Strategy:*** The printing schedule is prepared based on information obtained in the previous steps and the capability of the printer. This is essential as the printed modules need to be provided adequate time for curing.



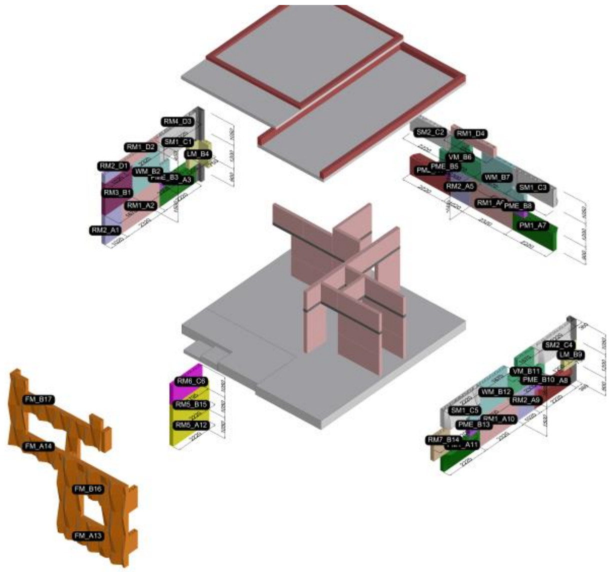


Fig. M3 Printing strategy

Phase 2 - Printing

In the second phase of this methodology, the production of the modules is undertaken.

Step 1: Printing

In this step, the actual printing of the designated modules is performed based on the printing strategy developed in the previous phase. The layers are deposited one over another to construct the designed structure.

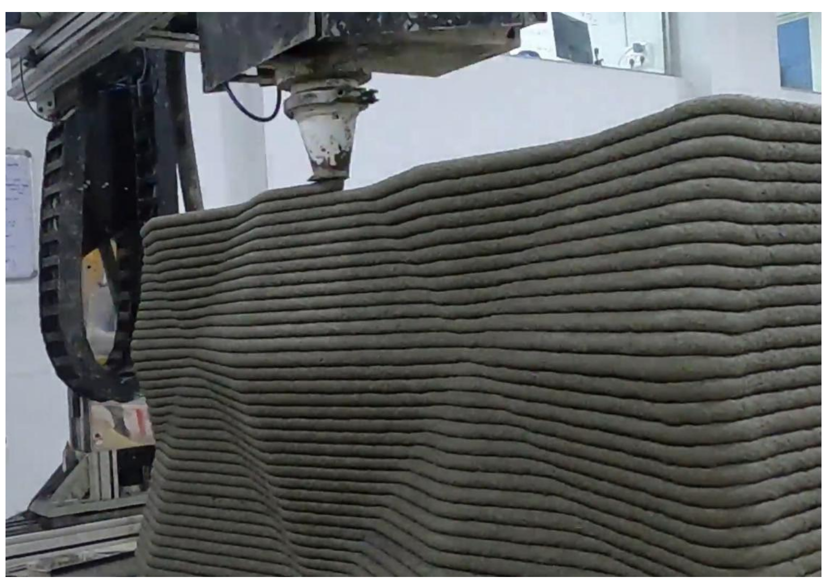


Fig. M4 Printing of modules

Either the printer is hosted under a shed where modules are printed like panels and blocks. These modules are transported to the site and assembled. Otherwise, the printer is deployed at the site to print the modules layer by layer over the plinth beam/ foundation wall.

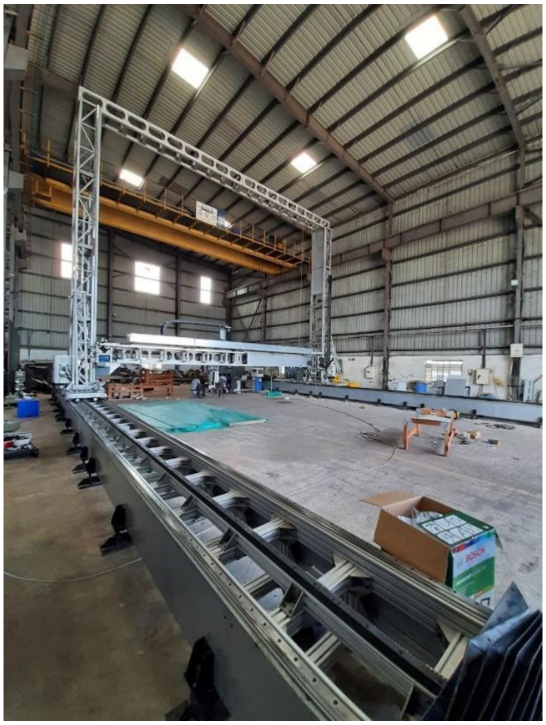


Fig. M5 Large scale Printer

Fig. M6 Printing at site

Step 2: Curing

The printed modules are allowed to be cured following IS 456.

Step 3: Primary Quality Check

The modules are scrutinized for defects and mismatches among other quality criteria. Steps are taken to reprint modules, in case faults are detected. Even if the modules are printed on the site, demolition and reprinting is done to ensure quality of the structure.

Phase 3 - Assembly of printed blocks/panels

For the modules printed away from the site, an additional process of assembly is required. The modules are partially grouted and transported to the site and placed over the foundation wall or plinth beam. If the modules are printed on the plinth beam, the printed runs around the starter bars.

Step 1: Starter rods from plinth

The starter rods are shown in the following figure.

Fig. M7 Bars from plinth

Fig. M8 Printing around the bars

Step 2: Transportation of Modules

The adequately cured modules are transported to the site location through reliable logistics partners.

Fig. M9 Transportation of modules

Step 3: Unloading and Secondary Quality Check

The transported modules are carefully unloaded at designated locations at site. This is followed by a secondary quality check to ensure that the modules are not damaged.

Step 4: Placing

The modules are assembled at the site once the foundation is completed. This step follows the execution strategy formulated during the first phase.

Fig. M10 Assembly of modules

Phase 4 - Structural members casting

Step 1: Grouting of column or tie column and beam or tie beam at site

Once the modules/blocks are stacked, the rebars are inserted through the provided provisions to connect the modules. If the modules are load bearing, tie columns and tie beams are provided. If the modules are non-load bearing, a column and beam provisions are provided. The RC frame is grouted at site.

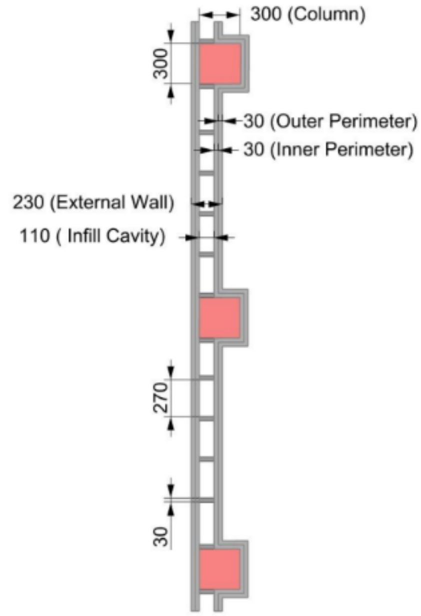


Fig. M11 Columns encapsulated by walls

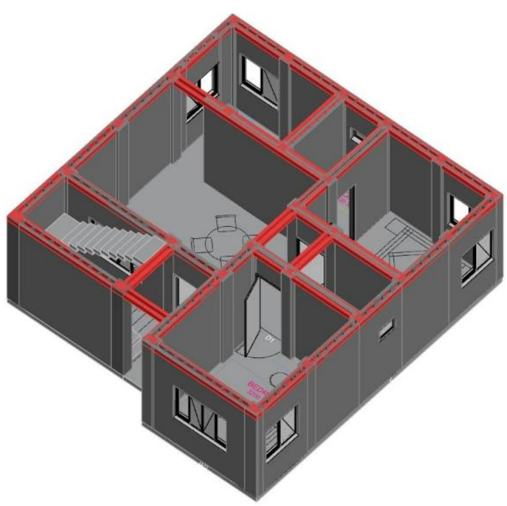


Fig. M12 Typical RC frame integration for 3D printing of structure at 1st Floor lvl. of one building

Phase 5 – Finishing

The finishing of the structure is undertaken simultaneously with the assembly. This involves grouting at joints between modules if required, apart from other conventional finishing processes.

Fig. M13 Finished structure