Name and Address of Certificate Holder: **M/s Larsen & Toubro Limited**
L&T Construction - Buildings & Factories, TC2 Building, PB No.: 979, Mount Poonamallee Road, Manapakkam, Chennai, Tamil Nadu, 600089
Tel: +91-44-22526000/ 22528000
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Performance Appraisal Certificate No.
PAC No.: **1059-S/2022**

Issue No. **01**

Date of Issue: **28/03/2022**

Volumetric (3D) Concrete Printing Technology (VCPT)





User should check the validity of the Certificate by contacting Member Secretary, BMBA at BMTPC or the Holder of this Certificate.

Building Materials & Technology Promotion Council
Ministry of Housing & Urban Affairs
Government of India
Core 5A, First Floor, India Habitat Centre,
Lodhi Road, New Delhi – 110 003

Tel: +91-11-2463 6705, 2463 8097; Fax: +91-11-2464 2849
E-mail: info@bmtpc.orgWeb Site: http://www.bmtpc.org

Performance Appraisal Certificate

For

Volumetric (3D) Concrete Printing Technology (VCPT)

Issued to

M/s Larsen & Toubro Limited

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	28/03/2022				27/03/2023		
		28/03/2023				27/03/2025		

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PART 1: CERTIFICATION

1.1 Certificate Holder: M/s Larsen & Toubro Limited
L&T Construction - Buildings & Factories, TC2 Building, PB No.: 979, Mount Poonamallee Road, Manapakkam, Chennai, Tamil Nadu, 600089
Tel: +91-44-2252 6000/ 2252 8000
E-MAIL : sln-pm@lntecc.com

1.2 Description of system

1.2.1 Name of system - Volumetric (3D) Concrete Printing Technology (VCPT)

1.2.2 Brand Name - Volumetric (3D) Concrete Printing Technology (VCPT)

1.2.3 Brief Description

3D Printing, also known as additive manufacturing, is an automated process that produces complex shaped geometries from a 3D Model (Computer-aided design (CAD) model) on a layer-by-layer basis. It is used in various manufacturing industries such as automobile, aerospace, medical etc.
3D Concrete printing technology (3DCP) constructs concrete structures by selectively placing a special quick-setting concrete mix using a numerically controlled robotic printer layer by layer as per a 3D CAD model. The operation can be performed with minimal human intervention/support and eliminating the need for formwork to construct walls.It is either executed on the site (Like cast In-situ) or Offsite in a centralised set-up (Like precast). In offsite 3DCP, the units or components are printed in the factory and then transported to the assembly site. In onsite 3DCP, the units are constructed at the site directly.

Special features of the system include;

- Eliminates the use of formwork
- Automated construction ensures excellent build quality and safety
- Rapid construction with significant improvement in productivity
- Cost optimisation possibilities that are constrained in conventional formwork & execution methods
- Innovative design possibilities to elevate aesthetics and convenience to end users
- Optimum usage of skilled workmen
- Highly digitised 3DCP workflow offers good predictability of the execution results
- 3D printers are lightweight systems that can be easily shifted, erected, and commissioned at job sites

1.3 Assessment

1.3.1 Scope of Assessment

The scope of assessment included suitability of Volumetric (3D) Concrete Printing Technology (VCPT) for RC structural systems and construction of Residential Buildings up to G+3 Floors.

1.3.2 Basis of Assessment

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

i. Assessment of various 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.
ii. The prototype building (G+1) of 700 Sqft. built-up area constructed by the Agency at itsKanchipuram facility, Chennai. The details of the project include structural system, printing process, construction methodology etc.
iii. Certificate for Structural stability of the above Volumetric (3D) concrete printed building & Proof Checking of the design & drawings by IIT, Madras.
iv. Certificate for Structural stability of the proposed residential building of 300 Sqft (Ground +3 floors) with 3D Printing Technology & Proof Checking of the design & drawings by IIT, Madras.
v. Quality Assurance system followed by the Certificate holder
vi. The Virtual inspection of the unit to review production process, performance and testing facilities at the unit including competence of technical personnel and status of quality assurance in the unit by TAC members & BMTPC Representatives.

1.4 Uses of the System

VCPT is a digitized version for replacing conventional concreting process at locations having facilities for mechanization and automation. The end product from this process is similar to regular concrete products and can be used with appropriate engineering at all suitable locations requiring concrete construction.

1.4.1 Special Aspects of Use /Limitations

- Basic performance and analysis behaviour shall be similar to regular concrete buildings.
- Skilled manpower with appropriate engineering and implementation techniques is required.
- Climatic conditions as required for regular concrete production will suffice. Efficiency and quality of product is further enhanced if factory like controlled environment is provided.

1.4.2 Maintenance aspects

Maintenance is required for;

- External surface having primer with external grade paint finish
- Internal surfaces having primer with Internal grade paint finish
- Wet areas having suitable water proofing with protective plastering

Maintenance frequency shall be as similar to regular conventional buildings and will be as per usage.

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 3D VCPT 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, based on structural designs including seismic loads, wind forces and other forces/loads as applicable as per relevant Indian Standards.

iii. The structural engineers and building designers associated with such type of construction should be thoroughly familiar with the 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, 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 technology is to provide for 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 Scheme of Quality Assurance Plan (QAP) given in **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 assess the complaint satisfaction and suitable preventive measures taken.

1.6 Certification

On the basis of 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, Volumetric (3D) Concrete Printing Technology (VCPT)is fit for use 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

3D concrete mix design requires paradoxical combination of concrete properties to achieve successful printing. An appropriate proportion of aggregate, cement, mineral admixtures and reinforcing fibres enables a wider particle size distribution, making it possible for the fresh mixture to achieve good mix.

The material must maintain its shape and sustain subsequent layers after extrusion. Due to difference between conventional construction methods and 3D-printing process, it is important to consider both fresh and hardened properties of materials.

Raw material components

Table 1 List of raw materials/components used

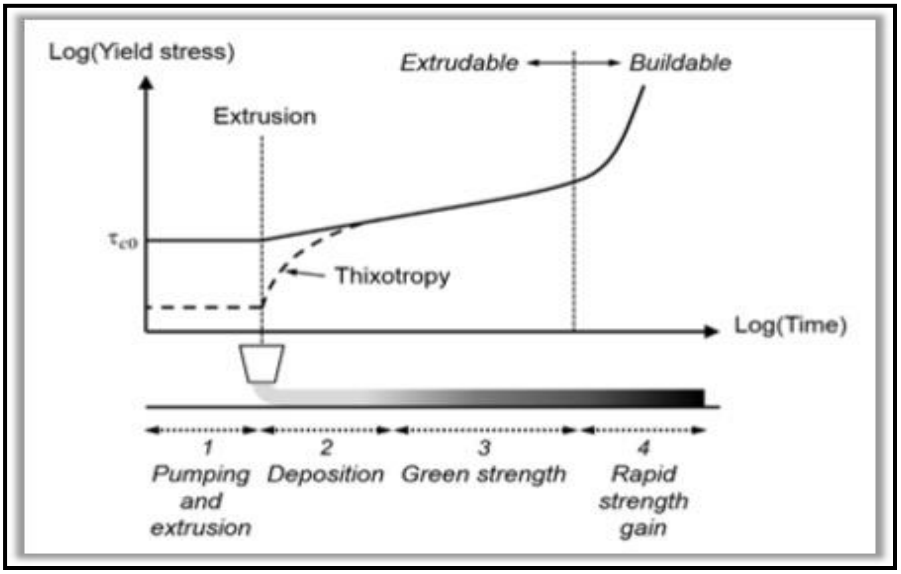
Sl. No.	Raw Material / Component	Source*	Specification	If quality certified in any form, state
1	Cement – OPC 53 Gr	Ultratech/Dalmia	IS 269	Internal Lab test
2	Fly ash	Ash tech India	IS 3812 Part1	MTC from supplier
3	Micro silica	Elkem	IS 15388	
4	Crushed sand (5mm down)	Keerapakkam L&T Crusher	IS 383	Internal lab test
5	Chemical admixture-PCE based	Euclid India Ltd	IS 9103	MTC
6	Chemical admixture- VMA	Euclid India Ltd	ASTM C494	MTC
7	Chemical admixture- shrinkage reducer	Euclid India Ltd	ASTM C 494	MTC
8	PP Fiber (Micro 6 to 12mm)	Don construction Products Ltd		
9	Water	L&T Bore well	IS 456	

- or Equivalent make complying to the Specifications

2.2.1 Fresh Properties

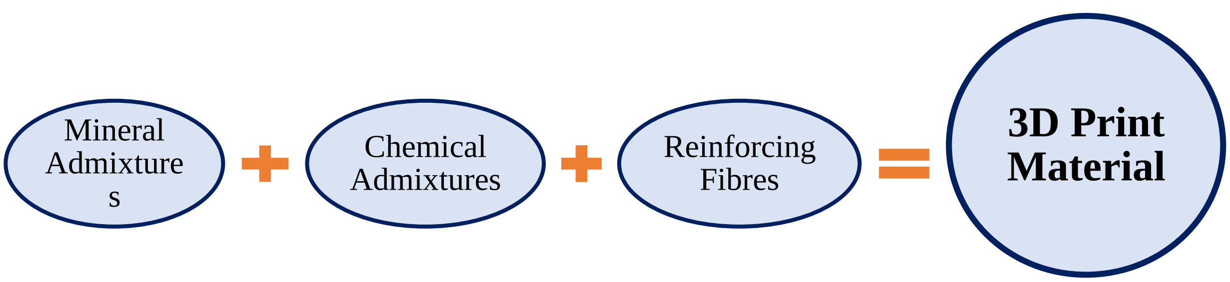
2.2.1.1 Flowability

- Evaluates the flow behaviour of fresh materials in the pumping system.
- All the components used in mixed design are main factors affecting flowability in addition to the external factors such as mixing and pumping system and ambient conditions like temperature and humidity.



2.2.1.2 Extrudability

- It is the capacity of the fresh paste to pass through the printing nozzle as a continuous and intact filament.
- A smooth grading of materials with minimum void content and high volume of cementitious paste will give better extrudability.



2.2.1.3 Buildability

- It is printed materials resistance to deformation under load.
- Fresh materials must have enough buildability to be stiff enough after extrusion to sustain its self-weight, weight from the upper layers, and the extrusion pressure.

2.2.1.4 Open Cycle Time

- Open Cycle time is identified as the time elapsed between the initial contact of dry mix and water and the time when the material is printable.
- It is related to the change of the flowability with time.

2.2.1.5 Hardened Properties

2.2.1.6 Compressive Strength

- It is expected that a reasonable and effective extrusion process strengthens the compressive properties of printed objects.
- Highest compressive strength is found in the longitudinal direction and the more voids or weakness are generated in the perpendicular or lateral direction.

2.2.1.7 Flexural Strength

- Flexural strength of printed components is also determined by loading direction.
- Highest flexural strength is expected in the loading direction.
- For testing of compressive strength and flexural strength, conduct the test on cube specimens along with cylinder and prism specifications in 3 loading directions.

2.2.1.8 Tensile Bond Strength

- Bond strength is controlled by the printing time gap between extruded layers, which is mostly a function of the structure size.
- Some specific curing methods should be adopted to hold surface moisture and reduce shrinkage of lower printed layers for better bond behaviour.

2.2.1.9 Density, Shrinkage and Cracking

- Including pump pressure, printing speed, and printing path design are the factors influencing density.
- Shrinkage and Cracking are important factors in long-term dimensional stability and cracking of structure.

After various lab research and field trials by L&T construction, an optimum concrete mix design meeting the above properties is developed, by using the locally available regular construction materials.

Characteristic Behavior of Concrete

Stage (1)
The concrete needs to maintain the workability status to facilitate ease of production, transportation and pumping from the workstation to the printer.

Stage (2)
Since there are no formwork system associated in 3DCP, as soon as the concrete is printed (i.e pushed out from the nozzle), it needs to retain the shape of the intended design profile, without freely flowing out.

Stage (3)
To ensure proper bonding between the layers, the concrete needs to maintain sufficient green status, without losing the intended design profile.

Stage (4)
Since the layers will be built on top of each other, the bottom concrete layers should get enough hardening strength to take the load of the upper layers being printed. While doing so, the concrete in the immediate bottom layers need to possess green characteristics also to ensure proper bonding.

2.3 Construction Methodology

2.3.1 VCPT System manufacturing details

3D Concrete printing technology (3DCP) constructs concrete structures by selectively placing a special quick-setting concrete mix using a numerically controlled robotic printer layer by layer as per a 3D CAD model. The operation can be performed with minimal human intervention/support and eliminating the need for formwork to construct walls.

3DCP requires comprehensive knowledge and control of 3Ms (Material, Machines and Methods) to successfully operate in a large scale and speed demanded by construction industry. The interaction between 3Ms need to be seamlessly integrated within the system to get the perfect results.

2.3.2 Manufacturing Machinery

It primarily comprises of the following three subsystems,

- Pumping system
- Positioning system (Typically, a part of 3D Concrete Printer)
- Extrusion system (Typically, a part of 3D Concrete Printer)

Pumping system:

Due to the nature of thixotropic material consistency required for 3DCP, special type of concrete pumping system is needed. Segregation of mixture ingredients, change in mixture properties are few undesirable effects that can be resulted with a wrong pumping system. The pump must also be able to keep the mixture in continuous agitation to prevent flocculation of the mixture. Based on various research trials, piston type pumps have finally been zeroed down, which are best suited for 3DCP application and able to overcome the above cited issues.

Positioning system:

Based on market research, there are two types of the positioning systems used for 3D concrete printing.

Cartesian Printers

Cartesian Printers are characterised by mechanisms that are configured to act like mutually perpendicular axis of 3D coordinate system. The positioning of the end effector is achieved by the relative motion of machine parts along one of its axis rails. The workspace of these robots is enclosed within in dimensions of the robot or conversely Cartesian robots occupies space outside its build volume. As the dimension of such robots are limited only by the length of rails along each axis, these kinds of robots can provide large workspaces for printing. The following figures showcase the variation of 3D printers in this kind of system.

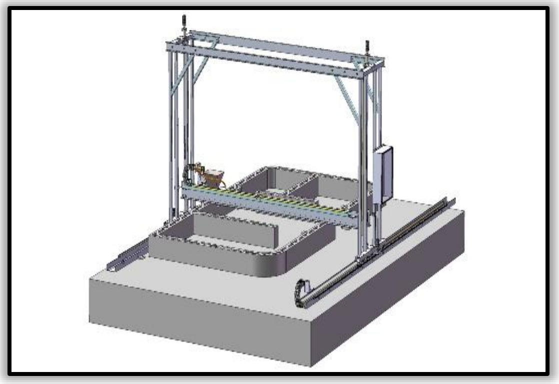


Figure 1 Cartesian Printers 1

Figure 2 Cartesian printers 2

Radial Printers

Radial Printers are located at the centre of their build volume and they build structures around them or away from them. Industrial 6 axis robots and crane like cylindrical robots belong to radial mechanism. Their primary advantage is that they come as a single unit and does not require assembly and installation like Cartesian systems at site. This enables them to be mounted on mobile platforms to act like mobile 3d printers. But unlike Cartesian systems their build volume is limited and is constrained by the reach of its mechanical arm. The following figures showcases the variation of 3D printers in this kind of system.

Figure 3 Radial printers 1

Figure 4 Radial printers 2

Extrusion system

It refers to the mechanical assembly at the end of printer head that controls how the material is extruded from the tip. The extrusion systems have control on the following variables of 3D printing.

a. Addition of admixtures for property modification at the tip
b. Control on rate of extrusion
c. Compensation for minor change in material properties in permissible ranges
d. Creating a desirable extrusion profile while depositing the material on the print
e. Forming of the deposited material for tighter dimension control of the final print.

Extrusion system can be classified as passive extrusion systems and active extrusion systems. Active extrusion will have mechanical actuators that will actively control the material flow at the tip. Passive extrusion does not have any dedicated systems for controlling material at the tip and directly depends on the pump for achieving the desired flow rate. Active extrusion system is most preferred to have better control on the printing process and concrete flow.

The agency has used a Cartesian printer with active extrusion system for its printing works.

2.3.3 The Equipment/Machineries used for 3D Concrete Printing

Sl No	Date of installation	Name of machine and ID No	pMake	Capacity	Capability	No of machines	Does the unit have maintenance schedule	Remarks
1	2	3	4	5	6	7	8	9
1	01/10/2019	3D Printer	BOD1	6m height	Concrete Printing	1	Yes	Hired
2	01/10/2019	Batching Plant	Stetter	30 Cum/Hr	Concrete production	1	Yes	
3	NA	Concrete Pump	Turobosol	10 Cum/Hr	Concrete Pumping	2	Yes	

2.3.4 VCPT Process Flow Chart

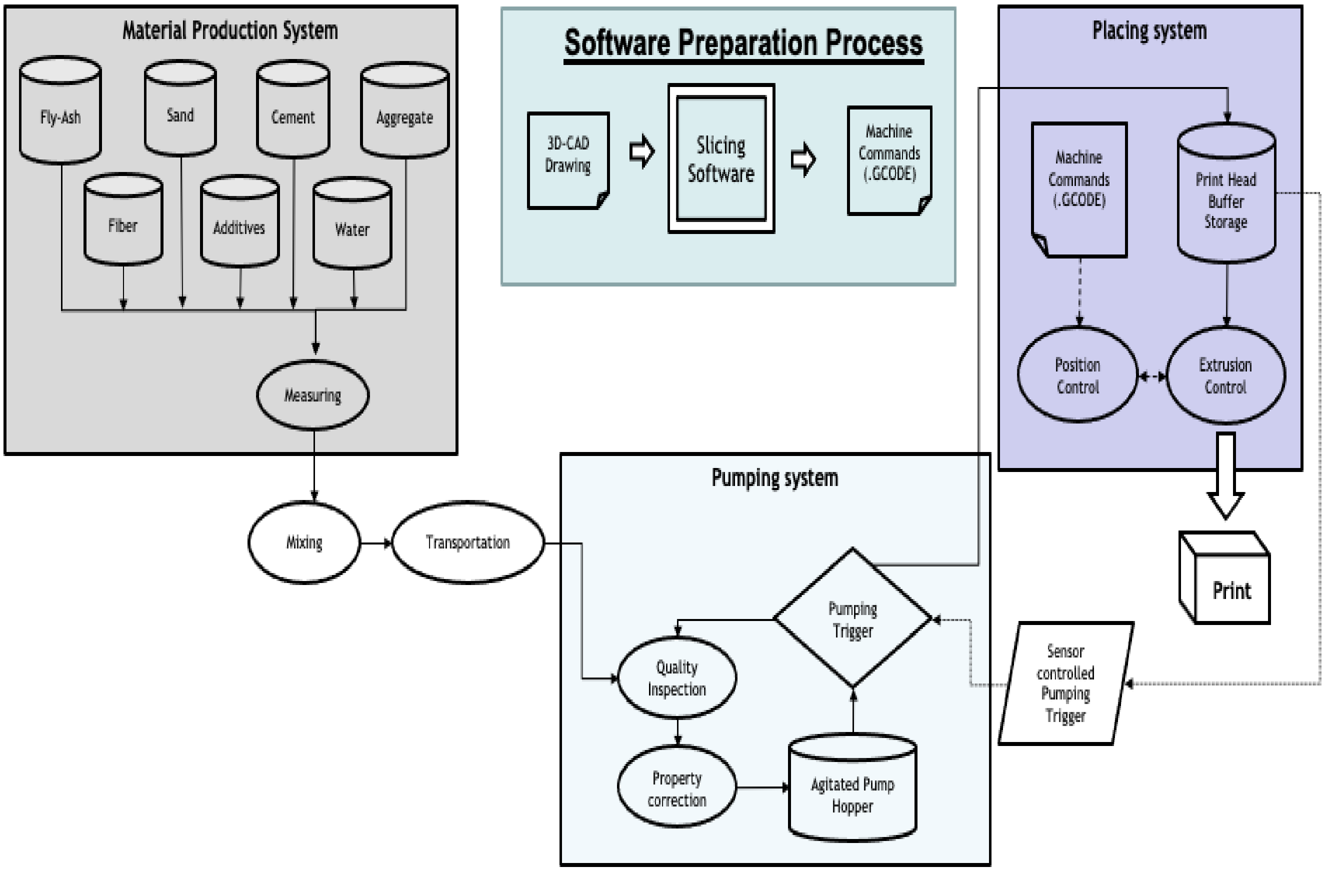


Figure 3 VCPT Flow process chart

2.3.5 VCPT Construction Process

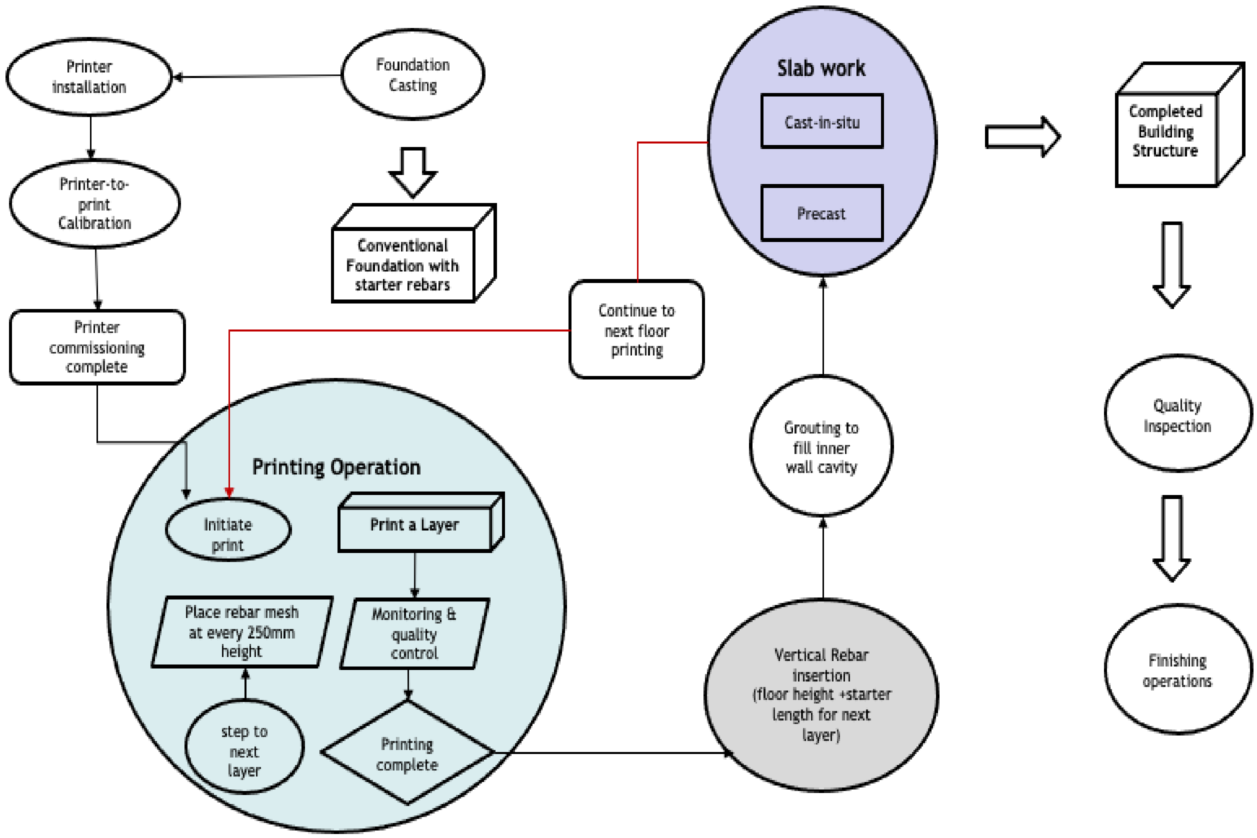


Figure 4 1.3.4 VCPT Construction Process

The construction process has been covered in detail at **Annexure-2**: Mock-up building (G+1), Tamilnadu. The conceled MEP services features are now considered as a standard feature in most affordable housing schemes. The technology should be aligned with options to provide concealed services options, if required by the architect/client.

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

3.1 Assessment

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

3.1.2 Laboratory tests performed

The Research & Testing centre of L&T, carried out evaluation of basic structural properties of 3D Printed concrete specimens & submitted the report in this regard. 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 & bond strength, were conducted.

The specimens were tested with load applied both parallel to printing direction & in perpendicular to the printing direction, and the consolidated test results are summarized below;

Summary of test results at 28 days

Sl. No.	Name of Tests	Test results	
		Parallel to printing	Perpendicular to printing
1.	Cube compressive strength, MPa	53.0	49.7
2.	Equivalent cube compressive strength ofcores, MPa	43.2	48.0
3.	Modulus of elasticity, MPa	36800	
4.	Stress-strain test	Average peak stress = 61.70 MPa Average Peak strain = 0.00281	
5.	Pullout Test	Bond stress at 0.025 mm slip = 1.76 MPa Bond stress at 0.25 mm slip = 12.5 MPa	
6.	Two-point load test on beams of span 400 mm and a/d≈1, MPa	6.8	5.8

7.	Two-point load test on beams of span 2000mm and a/d≈2, MPa	2.7	
8.	Two-point load test on beams of span 400mm and a/d=1, MPa	6.0	5.7
9.	Two-point load test on beams of span 2000mm and a/d=1, MPa	2.4	

3.1.3 Mock-up Building (G+1) & its Certification

The building (G+1) of 700 sqft. Built-up area has been constructed by the Agency at its Kanchipuram facility, Chennai using Volumetric (3D) concrete printing technology.

The Agency approached IIT Madras for structural stability Certificate & proof checking of technology concept, structural design & drawings. IIT, Madras certified the same with following remarks;

Certificate for Stability of Structure

i. Building has been visually inspected & designed as per relevant latest Standards &design Codes (Dead, Imposed & Wind loading as per IS 875-2015 Code, seismic loading as per IS-1893-2016 & design as per IS-456-2000) with sound engineering practices.

ii. The stability of structure against earthquake is ensured & the said structure serves the purpose for which it is intended.

Proof Checking of the Building Design & Drawing

Based on the site visit, various discussions and scrutiny of Volumetric (3D) Concrete Printed Technology concepts, design documents and drawings, the views of the IIT, Madras faculty are mentioned below:

i. Design Concept and construction methodology adopted are consistent with relevant Indian code of practice.
ii. Junction details, load path as well as force transfer at the junction and design calculation for the project are found to be in order.
iii. Similar design and detailing can be adopted for affordable housing construction in all seismic zone and all wind speed zones in India. However detailed design need to be carried out for a specific project.

3.1.4 Proposed Building (G+3) using 3DCP Technology, its Certification of Structural Stability & Proof Checking of Design by IIT, Madras

The Agency has proposed residential building of 300 sqft (Ground +3 floors) with 3D Concrete Printing Technology, as per the details below;

S No.	Tower Description	Total No of Block(s)	No of Floors	No. of Units
1	G+3 Residential Building at Chennai	1	G+3 (8 Units per Floor)	32

The building is to be designed as RCC Structural wall (3DCP) and RCC/ Precast slab, in accordance with the relevant Indian Code of Practice for civil works i.e. IS: 456, IS: 875, IS: 1893-2016, IS: 4326 and IS -13920-2016 with up to date revisions. Monolithic RC wall (3DCP) & slab system is used for residential towers founded on raft/Isolated footings. Typical floor to floor height is 3.0m.

The Agency submitted technology concept, design documents & drawings to IIT, Madras. Based on the same, the Institution has certified the Structural stability of the proposed structure & proof checked the design with remarks same as above building (G+1 Prototype). The Design basis reports along with IIT, Madras Certification & Remarks have been submitted by the Agency.

3.1.5 Quality Assurance system followed by the certificate holder

The Quality Assessment system has been designed for 3DCPT Building, by the Agency which includes measuring the 3D Printing process and finishing works against workmanship standards and specifications. The scope of quality assurance plan has been divided into two components namely structural works & Architectural works. The overall weight ages 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**.

3.1.6 Site Inspection

The set up of the Agency was visited by the members of TAC &Officers of BMTPC via video conferencing on 2nd December, 2021& interaction were held with technical personnel of the Agency. The agency through videos demonstrated the construction of Prototype building, various design & drawings, testing results, certification by IIT, Madras, etc.

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: 28/03/2022

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

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

PART 5: LIST OF APPLICABLE STANDARDS AND CODE

S.No.	Code	Description
1.	IS-875 (Part 1) – 1987	Code of Practice for Design Loads (other than earthquake) for buildings and structures – Unit weights of buildings materials and stored materials
2.	IS-875 (Part 2) – 1987	Code of Practice for Design Loads (other than earthquake) for buildings and structures – Imposed loads
3.	IS-875 (Part 3)- 2015	Code of Practice for Design Loads (other than earthquake) for buildings and structures – Wind loads
4.	IS-875 (Part 5) – 1987	Code of Practice for Design Loads (other than earthquake) for buildings and structures – Special loads and load combinations
5.	IS: 456 – 2000	Code of Practice for Plain and Reinforced Concrete
6.	IS: 1893 (Part 1) – 2016	Criteria for Earthquake resistant design of structures
7.	IS 13920- 2016	Code of Practice for Ductile Design and Detailing of RC Structure subjected to Seismic Forces
8.	IS 516-1959 (RA 2018)	Methods of tests for strength of concrete
9	IS 383 : 2016	Coarse and Fine Aggregate for Concrete - Specification (Third Revision)
10	IS 269 - 2015	Ordinary Portland cement - Specification (Sixth Revision)
11	IS 3812 (Part 1)-2013	Pulverized fuel ash - Specification: Part 1 For use as pozzolana in cement, cement mortar and concrete
12	IS 9103-1999 (RA 2018)	Specification for Concrete Admixtures (First Revision)
13	IS 15916 : 2010	Building Design and Erection using Prefabricated Concrete — Code of Practice
14	IS15917 : 2010	Building Design and Erection using Mixed/ Composite Construction — Code of Practice
15	IS 11447 : 1985 (Reaffirmed 2003)	Code of Practice for Construction with Large Panel Prefabricates

CERTIFICATION

In the opinion of Building Materials & Technology Promotion Council's Board of Agreement (BMBA) **Volumetric (3D) Concrete Printing Technology (VCPT)** is satisfactory if used as set out above in the text of the Certificate. This Certificate **PAC No.** 1059-S/2022 is awarded to **M/s Larsen & Toubro Limited, Chennai.**

The certificate has been renewed further and its validity is from 28-03-2023 to 27-03-2025.

This Certificate consists of a cover page and pages 1 to 44.

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

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:

PART 6: LIST OF ABBRIVIATIONS

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 BMBA
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 – ABrief

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 under-standably 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

A1. Objectives of quality assurance plan

Building Quality Assessment System (BQUAS) has been designed with three objectives:

- To have a standard quality assessment system for 3DCP Building.
- To make quality assessment objective by:
  - ✓ Measuring the 3D Printing process and finishing works against workmanship standards and specifications.
  - ✓ Using sampling approach to suitably represent the whole project.
- To carry out the quality assessment systematically within reasonable cost and time.

A2. Scope of quality assurance plan

The scope is divided into two main components:

Structural works

a. 3D Printing
b. Steel reinforcement
c. Precast Slab
d. Screed
e. Finish Concrete
f. Structure Quality Tests – Concrete and Rebar

Architectural works

g. Internal finishes – Floor, Internal Walls, Ceiling, Doors & Windows
h. Roof
i. External Wall
j. Functional tests – Tests such as 3DCP joint water tightness test, window water-tightness & wet area water-tightness.

A3. Scoring weightages

Overall weightage

COMPONENTS	Housing	Other types of building
Structural Works	35%	40%
Architectural Works	65%	60%
Total Score	100%	100%

Structural weightage

Elements	Weightage %
1. 3D Printing Process	40
2. Rebar	15
3. Finished Concrete	35
4. Structure Quality	
a. Concrete Quality	5
b. Steel Reinforcement Quality	5
Total	100

Architectural weightage

Elements	Weightage %
1. Internal Finishes	
○ Floor	10
○ Internal Wall	25
○ Ceiling	5
○ Door	5
○ Window	5
2. Roof	5
3. External Wall	15
4. Functional Test	
○ 3DCP Joint Water Tightness Test	10
○ Field Window Water Tightness Test	10
○ Wet Water Area Water Tightness Test	10
Total	**100**

A4. Quality standards for Structural works:

1	3D Printing Wall Tolerance & Finished Concrete	
	Type of Dimension Measured	Permissible Tolerance (mm)
	Dimension Up to 3m 3m to 4.5m 4.5 to 6m Each additional 6m	 +/- 3 +/- 6 +/- 9 +/- 3
	Straightness or bow (deviation from intended line) Up to 3m 3m to 4.5m 4.5m to 6m Every subsequent 6m	 6 9 12 6
	• Alignment, Plumb & Level • Departure from any point • Plumb • Level	 10mm max 3mm/m, max 20mm floor to floor & 40mm for entire building +/-10mm of mean level
	Flatness of surface	6mm per 1.5m
	Openings: • Size • Location	 +10 +/- 25
2	Reinforcement	
a	Main & Secondary rebars	1. According to structural drawings (numbers / sizes) 2. Spacing of bars not more than the specified
b	Anchorage & lap lengths	1. Required lap length not less than the specified
c	Cover provision	1. According to specifications with tolerance of +5mm
d	Links, stirrups and trimming bars	1. According to structural drawings (numbers/sizes) 2. Spacing of links not more than the specified
e	Rebar Condition	1. Rebar's must be securely and properly placed, as per the approved drawing. 2. Rebar's must be free from concrete dropping, corrosion, etc
3	Structure Quality Concrete cube test	 1. For every pour of concrete, test cube results at 28 days must satisfy the passing criteria as specified in the contract.

	Reinforcement (Rebar)	The summary of test reports must be endorsed by the project's structural QP (Qualified Person) 1. To pass the tensile strength test for all the reinforcement bars used according to the contract specifications. The summary of test reports must be endorsed by the project's QP (Qualified Person) 2. All the welded steel fabric used to comply with the contract specifications. 3. No non-conforming reinforcement detected through test records has been installed in the structure.

A5. Quality standards for architectural works

Internal Finishes

	Item	Standards
1 1a	Floor General Requirements	1. Finishing • No stain marks • Consistent colour tone 2. Alignment & evenness • Evenness of surface (not more than 3mm per 1.2m) • Falls in wet areas should be in right direction • No ponding in falls for wet area • For staircases, the variance in lengths of threads and risers must not exceed 5mm; nosing must be straight • Skirting size and joint aligned with floor if of same material 3. Cracks & Damages • No visible damage / defects 4. Hollowness / Delamination • No hollow sound when tapped with a hard object • No sign of delamination 5. Jointing • Consistent skirting thickness • No visible gap between wall & skirting
1b	Screed Finish	1. Surface should not be unduly rough or patchy 2. No visible trowel marks 3.Expansion joints should be provided at interval as stated by Architect/ Structural Engineer
1c	Tiled Finish	1. Consistent colour and neat pointing 2. No hollow sound when tapped with a hard object

		3. Joints are aligned and consistent with skirting and wall tiles 4. Consistent joint size 5. Lippage between 2 tiles should not be more than 0.5mm
2 2a	Internal Walls General requirements	1. Finishing: • No stain marks • Consistent colour tone • No rough / patchy surface 2. Alignment & Evenness: • Evenness of surface (not more than 3mm per 1.2mm) • Verticality of wall (not more than 3mm per m) • Walls meet at right angles (not more than 4mm over 300mm) • Edges (wall to wall) to appear straight and aligned 3. Crack & Damages • No visible damage / defects 4. Hollowness / Delamination • No hollow sound when tapped with a hard object • No sign of delamination 5. Jointing • Straightness of corners and joints
2b	Plaster Finish	1. Surface evenness (not more than 3mm over 1.2m) 2. No hollow sound when tapped with a hard object 3. Surfaces should not be unduly rough or patchy, especially no brush/trowel marks
2c	Tiled Finish	1. Tile joints aligned and with consistent joint size 2. No hollow sound when tapped with a hard object 3. Consistent colour and neat pointing 4.Lippage between 2 tiles should not be more than 0.5mm
2d	Painting	1. Substrate – see plaster finish 2. Surfaces are evenly painted 3. Good opacity, no patchiness resulted from touch up works 4. Free from peeling, blister and chalkiness 5. No discolouration and fading
3 3a	Ceilings General requirements	1. Finishing • No stain marks

		• Consistent colour tone • No patchy surface 2. Alignment & Evenness • Overall surface should be smooth, even, not wavy • Straightness of corners 3. Crack & Damages • No visible damage, eg. spalling, leaks, cracks, etc 4. Roughness • No rough surface 5. Jointing • Consistent, aligned and neat
3b	Skim Coats/Boarded Ceiling	1. Not patchy, with no pin holes and with no trowel marks 2. Formwork joints are grounded smooth 3. Paintworks with good opacity and with no brush marks 4. Access door joints should be sharp and in consistent width
3c	False Ceiling / Grid System	1. Alignment of rails should be visually straight 2. Surface should be overall level and even 3. Chipped surfaces or corners should be seen
4 4a	Doors General requirements	 1. Joints & Gap • No visible gaps between door frame and wall • Consistent & neat joints • Consistent gap between door leaf and frame and not more than 5mm • No visible gaps within door leaf and door frame 2. Alignments & Evenness • Alignment / level with walls • Door frame and leaf to flush • Door and frame corners maintained at right angles • No rattling sound when door is closed 3. Material & Damages • No stain marks and any visible damage • No sags, warps on door leaf • Fire stop provided where necessary • Door joints and nail holes filled up, properly sanded down and with good paint finish (including on top and bottom of door leaf and consistent in colour • Glazing clean and evenly sealed with gasket • No sign of corrosion for metal frame • Consistent colour tone

		4. Functionality • Ease in opening, closing and locking • No squeaky sound during swinging the leaf 5. Accessories Defects • Lock sets with good fit and no stains • No sign of corrosion in ironmongery • No missing or defective accessories
5 5a	Windows General requirements	1. Joints & Gap • No visible gap between window frame and wall • Consistent gap between window leaf and frame and not more than 5mm (timber window only) • No visible gaps between window leaf and frame • Neat joint between window and wall internally and externally 2. Alignments & Evenness • Alignment / level with wall openings • Window leaf and frame corners maintained at right angles 3. Material & Damages • No stain marks and any visible damage / defects • Louvre windows with glass panels of correct lengths • Glazing clean, evenly sealed with putty or gasket for aluminum windows 4. Functionality • Ease in opening, closing and locking • No sign of rainwater leakage • No squeaky sound during swinging the leaf 5. Accessories Defects • Lock sets with good fit and aligned • No sign of corrosion • No missing or defective accessories • Countersunk screws levelled and flushed. No over-tightened screws • Stainless steel screws at hinges for swing window

Roof

	Items	Standards
1 1a	Construction General requirements	1. Stain / Painting • No stain marks

		• Good paint works 2. Rough / Uneven / Falls • Look smooth and with no tools marks • Even and level, no potential in stripping • Good falls in right direction 3. Cracks / Chip / Damage • No visible damage / defects 4. Joint / Sealant / Alignment • Consistent joint width, neat and aligned 5. Chokage / Ponding • No sign of chokage and ponding 6. Construction • No sign of leaking • Proper dressing for any protrusion • Neat & secured installation of fixtures
1b	Flat Roof	1. Ponding less than 3mm 2. Surface to level to avoid tripping 3. Proper dressing for any protrusion 4. Openings to be sealed to prevent pest invasion 5. Clean and no stain marks
1c	Waterproofing (exposed)	1. Should be evenly installed, no sharp protrusion 2. Complete adhesion to base 3. Good laps at joints and proper vertical abutment details 4. No leaking and sign of damage to membrane / coating 5. Clean and no mortar stains 6. No paint defects
1d	Gutters	1. No ponding and chokage 2. No cracks, chips and any other visible damages/defects 3. Gutter inlet to be covered to prevent chokage where practical 4. Clean and no cement stains

External Walls

	Items	Standards
1 1a	External Wall General requirements	1. Evenness / Roughness • Overall surface should be even, not wavy & not patchy 2. Staining • No visible stain marks • Good paint woks 3. Crack & Damages • No visible damage / defects

		4. Alignment • External features visually in alignment • Corners of wall maintained at right angle and straight • Consistent joint width, neat and aligned
1b	Plaster Finish	1. As above
1c	Tiled Finish	1. Tile joint aligned and between 2-4mm wide unless specified 2. Plumb tolerance and evenness of surface (3mm / 1.2m)
1d	Painting	1. Substrate - see plaster finish 2. Surfaces are evenly painted; no patchiness due to touch up work 3. Good opacity, no discolouring and free from peeling

Functional Test / Water Tightness Test (WTT)

	Items	Standards
1	External Joints	1. WTT parameters: • Nozzle output : 10 litres / minute • Nozzle velocity : 2m / second • Nozzle inclination : approx. 60 degree at a distance of 1.2m from the wall • Spray duration : not less than 1 hr • Nozzle position : to be placed in line with the vertical joint and at level with horizontal joint 2. No dampness or seepage appears at the joint or internal side of any part of the building during spraying and after completion of the spraying.
1b	Window Frame / concrete interface	1. WTT parameters: • Nozzle output : 10 litres / minute • Nozzle velocity : 2m / second • Nozzle inclination : 90 degree • Nozzle position : 1m away from the interface/joint • Spray duration : 20 minutes 2. No dampness or seepage appears at the joint or internal side of any part of the building during spraying and after completion of the spraying.
1c	Wet Area (bathroom, toilets, flat Roof)	1. WTT to be carried out prior to any tiling works 2. No sign of leakage after ponding wet areas over a minimum period of 24hrs 3. Water ponding depth shall be at least 25mm

A6. Inspection test Plan

#	Material	Tests performed	In House/ 3rd Party	IS/BS Test Standard	IS/BS Acceptence standard	Frequency
1	FINE AGGREGATES	Sieve Analysis, Fineness Modulus	In House	IS 2386 (Part 1): 1963	IS 383 : 2016	Twice a week
		Material Less than 75 Micron by Weight	In House	IS 2386 (Part 2): 1963	IS 383 : 2016	Twice a week
		Moisture Content	In House			1 Time per Shift prior to start of concrete production and additionally if rain
		Specific gravity	In House	IS 2386 (Part 3): 1963		At the time of source approval and thereafter
		Water absorption	In House	IS 2386 (Part 3): 1963		At the time of source approval
2	CEMENT	**Chemical Requirements:**				MTC
		Ratio of % of lime to % of silica, Alumina, Iron Oxide	3rd Party	IS 4032 : 1985	IS 269 : 2015	
		% of alumina to iron oxide	3rd Party	IS 4032 : 1985	IS 269 : 2015	
		Magnesia	3rd Party	IS 4032 : 1985	IS 269 : 2015	
		% of Sulphur content as SO3	3rd Party	IS 4032 : 1985	IS 269 : 2015	
		Insoluble residue	3rd Party	IS 4032 : 1985	IS 269 : 2015	
		Total Loss on ignition	3rd Party	IS 4032 : 1985	IS 269 : 2015	
		Physical requirements:				
		Fineness test 90 % by Sieving	In House			Every Batch
		Consistency	In House	IS 4031 (Part 4):2000		
		Initial setting time	In House	IS 4031 (Part 5):1988	IS 269 : 2015	
		Final setting time	In House	IS 4031 (Part 5):1988	IS 269 : 2015	
		Compressive strength at 3, 7 & 28days		IS 4031 (Part 6):1988	IS 269 : 2015	

#	Material	Tests performed	In House/ 3rd Party	IS/BS Test Standard	IS/BS Acceptence standard	Frequency
3	FLYASH	**Chemical Requirements:**	3rd Party			Once per Six Months
		Loss on ignition	3rd Party	IS 1727 : 1967	IS 3812 (Part 1&2) : 2013	
		Chloride content	3rd Party	IS 12423	IS 3812 (Part 1&2) : 2013	
		Sodium Oxide	3rd Party	IS 4032	IS 3812 (Part 1&2) : 2013	
		SIO2 + Al2O3 +Fe2 O3 percentage By mass	3rd Party	IS 1727 : 1967	IS 3812 (Part 1&2) : 2013	
		SIO2 Percentage by Mass	3rd Party	IS 1727 : 1967	IS 3812 (Part 1&2) : 2013	
		MGO percetage by Mass	3rd Party	IS 1727 : 1967	IS 3812 (Part 1&2) : 2013	
		Total Sulpher as SO3	3rd Party	IS 1727 : 1967		
		Physical requirements:				
		Fineness - Specific surface 45 Micron sieve	In House	IS 1727 : 1967	IS 3812 (Part 1&2) : 2013	Every Truck Load
		Compressive strength at 28days	3rd Party	IS 1727 : 1967	IS 3812 (Part 1&2) : 2013	Once per Six Months
		Specific Gravity	3rd Party	IS 1727 : 1967	IS 3812 (Part 1&2) : 2013	
		Soundness by Auto clave test	3rd Party	IS 1727 : 1967	IS 3812 (Part 1&2) : 2013	
		Lime Reactivity	3rd Party	IS 1727 : 1967	IS 3812 (Part 1&2) : 2013	
		Finess Specific Surface - Blaine's Air Permeablity	3rd Party	IS 1727 : 1967	IS 3812 (Part 1&2) : 2013	
4	Chemical Admixture	Ash content By mass	3rd Party	IS 9103	IS 9103	MTC
		Dry Material Content By mass	3rd Party	IS 9103	IS 9103	
		Chloride Content	3rd Party	IS 9103	IS 9103	
		PH	3rd Party	IS 9103	IS 9103	
		Relative density	3rd Party	IS 9103	IS 9103	
		Specific Gravity	3rd Party		IS 9103	
5	Water	PH	3rd Party	IS 3025 (Part 11):1983	IS 456	Once Per Source & after Monsoon
		To neutralize 100ml of water using Phenopthalein Indicator	3rd Party	IS 3025 (Part 22,23):1986	IS 456	
		To neutralize 100ml of water using Mixed Indicator	3rd Party	IS 3025 (Part 22,23):1986	IS 456	
		Organic Content	3rd Party	IS 3025 (Part 18):1984	IS 456	
		In-Organic Content	3rd Party	IS 3025 (Part 18):1984	IS 456	
		Sulphates	3rd Party	IS 3025 (Part 24) :1986	IS 456	
		Chlorides	3rd Party	IS 3025 (Part 32):1988	IS 456	
		Suspended Solids	3rd Party	IS 3025 (Part 17) :1984	IS 456	
6	Fresh Concrete printing paste	Workability - Mini Slump Cone		IS 1199:1959		
		Temprature				
		Intial Setting Time		IS 8142: 1976		
		Visual - Bleeding , Segregation				
	Harden concrete printing paste	Sampling cubes in Plant for 3 days, 7 days, 28 days strength	In House	IS 515	IS 456	
		Cube / Cylinder compressive strength check	In House	IS 515	IS 456	
		Flexural Strength of Beams	In House			
7	Reinforcement	Weight per running meter	Measurement		IS 1786:2008	MTC / One test per every Lot of 100 T
		0.2% Proof stress (N/sq mm)	3rd Party	IS 1608 Part 1:2008	IS 1786:2008	
		Tensile strength (N/sq mm)	3rd Party	IS 1608 Part 1:2008	IS 1786:2008	
		Elongation (%)	3rd Party	IS 1608 Part 1:2008	IS 1786:2008	
		Bend test	3rd Party		IS 1786:2008	
		Re bend test	3rd Party		IS 1786:2008	
		Chemical test	3rd Party		IS 1786:2008	

#	Material	Tests performed	In House/ 3rd Party	IS/BS Test Standard	IS/BS Acceptence standard	Frequency
8	Micosilica	**Physical requirements:**			IS 16714	MTC
		Specific Gravity	3rd Party	IS 1727 : 1967	IS 16714	
		Specific surfacing by Blaime's Permeibility	3rd Party	IS 1727 : 1967	IS 16714	
		Slag Activeness Index	3rd Party	IS 1727 : 1967	IS 16714	
		Residue on 45 Micron sieve	3rd Party	IS 1727 : 1967	IS 16714	
		Compressive stength	3rd Party	IS 4031 Part 4 &6	IS 16714	
		Chemical Requirement				
		Si o2 percent by mass	3rd Party	IS1727	IS 1538	
		Moisture Content percent by mass	3rd Party	IS15388	IS 1538	
		Loss of ignitiaon percent by mass	3rd Party	IS1727	IS 1538	
		Alkalies as NA2 oLoss of ignitiaon percent by mass	3rd Party		IS 1538	
		Physical requirements:				
		Specific surfacing by Blaime's Permeibility	3rd Party	IS 1538 Annex A	IS 1538	
		Oversize % 45 Micron sieve	3rd Party	IS 1727 : 1967	IS 1538	
		Oversize % 45 Micron sieve , variation from average	3rd Party	IS 1727 : 1967	IS 1538	
		Compressive stength at 7 Days as percent of controlled sample	3rd Party	IS 1727 : 1967	IS 1538	
9	Fiber	Polypropelene fiber (micro fiber 6 to 12mm length)				MTC

Figure 5 Inspection test Plan

A7. Assessment Approach

Assessment shall be done through Site Inspection and Testing, as per the details below;

	Site Inspection	Test (Lab or Field Test)
Structural Works	○ 3 D Printing ○ Rebar ○ Finished Concrete	○ Concrete Quality ○ Steel Reinforcement Quality
Architectural Works	○ Internal Finishes ○ Roof ○ External Wall	○ WTT – 3DCP Joint Areas ○ WTT – Windows ○ WTT - Wet Areas

Annexure 2

Mock-up building

In order showcase the feasibility and advantages of VCPT technology, L&T Construction has 3D printed a G+1 building at its Chennai facility. The key highlights of 3D Printed G+1 Building are listed below,

1. It is the first G+1 building successfully 3D concrete printed in India. As per the details available in public forum, it is the second G+1 building 3D printed across the Globe.
2. The building is a replica of a typical mass housing project.
3. The building has been 3D printed with in-house developed “concrete mix”, instead of present industry practise of using pre-packed mortar. The concrete mix was designed using locally available regular construction materials only. The maximum grain size of aggregate used is 5mm.
4. The building has been printed with both horizontal and vertical rebar, in accordance with the prevailing Indian Codal complied design of RC buildings.
5. 100 x 30 x 3mm weld mesh is used for horizontal distributor.
6. 8mm TMT bar is used for vertical reinforcement
7. The building walls have been 3D printed on the job site (i.e similar to cast in-situ construction).
8. The slabs have been casted using conventional cast in-situ ply based construction. It is also possible to use precast slabs.
9. The substructure is conventional cast-in-situ concrete.
10. The entire printing has been executed in an “Open to sky” construction site environment.
11. The building printing has been completed in 106 printing hours, considering the fact that various data capturing requirement and testing were involved. However, the printing timelines can be considerably reduced, during large scale continuous printing.

The following section explains the details of the construction methodology adapted by L&T Construction for the successful 3D printing of G+1 Building.

Project description

Volumetric(3D) Concrete Printing Technology (VCPT) basedG+1 building (mock-up) was built in the engineering workshop at the company’s Kanchipuram facility, Tamilnadu. The building was built as a part of a study to use this technology to improve speed and scale, especially for mass housing projects. The total built up area of the building is 700 square feet. The actual photograph of the building is appended below.

Figure 6 Actual photograph of prototype project constructed by L&T to deonstrate the 3D printing technology.

Based on the design validation established vide this proposal and successful demonstration by printing India's first G+1 3D printed building, L&T Construction recommends the implementation of Volumetric (3D) Concrete Printing Technology (VCPT) for construction applications.

Structural System

G+1 building consists of structural wall in superstructure and strip foundation. The member size and geometry were selected to suit 3D printer capabilities. The concrete layer dimensions that can be printed depend upon the printer nozzle size. The printer (COBOD) is set to print concrete layer up to 45 mm wide and 15-20 mm thick according to the requirements. There are no limitations on member geometry since the printer nozzle would follow the geometry from 3D digital model.

Foundation

The Strip footing constructed using conventional method. The strip footing used as a substructure with 720 mm wide with thickness of 200mm.The reinforcement provided in the strip footing is 8@150mm c/c in both the directions.

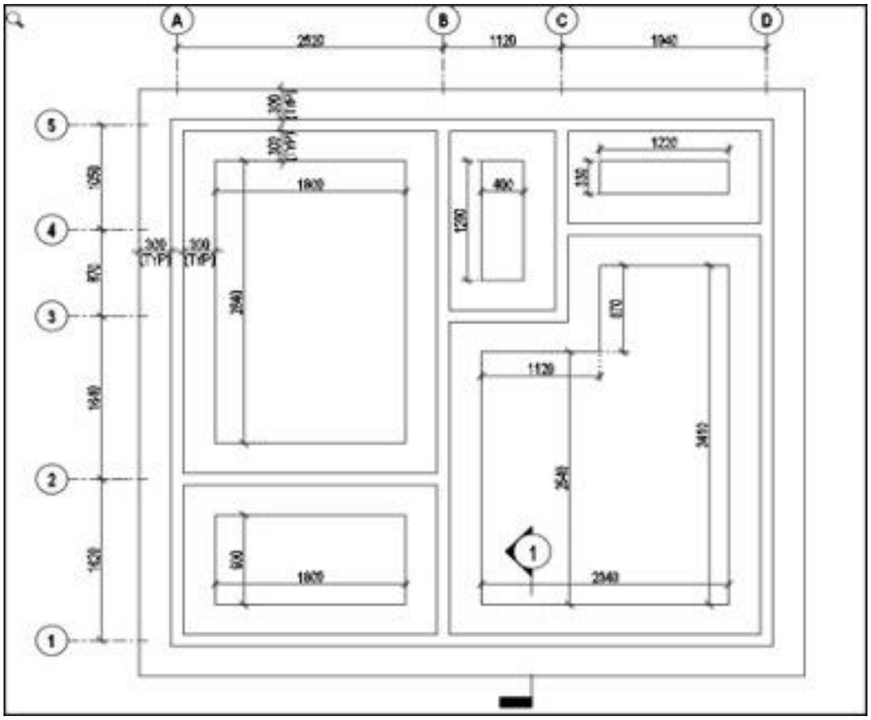


Figure 7 Strip foundation details

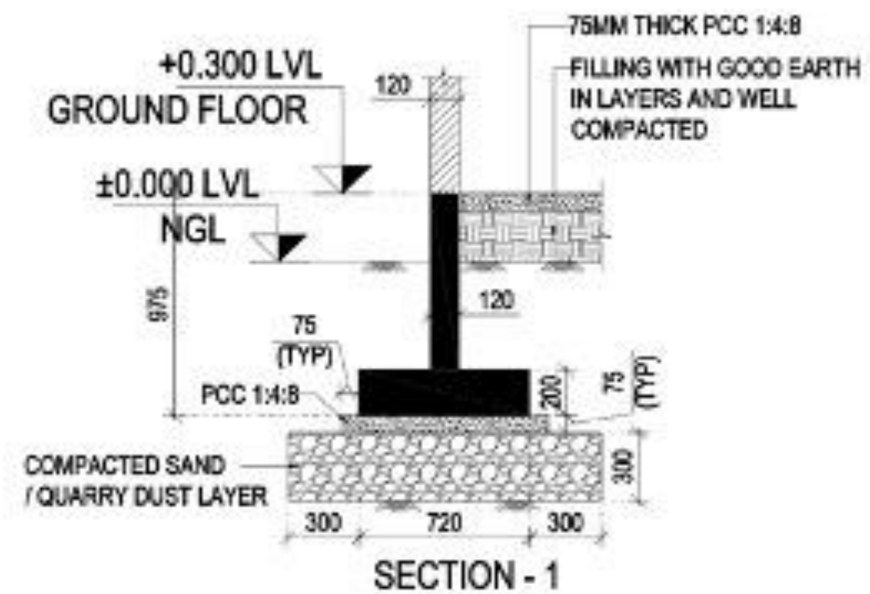


Figure 8 Strip foundation section

Walls

Walls of the G+1 building are printed by 3D printer. Walls are intended to resist both gravity loads and lateral loads. The wall's total thickness is 120 mm, in which there are two outer layer 45 mm thick and inside grout of 30 mm is filled with the same material. Hence 45+45+30 = 120 mm. Minimum reinforcement (8 @250 mm c/c) is provided in both horizontal and vertical direction to take care of any shrinkage and cracks. Hence, the end product wall is like a regular RC wall, only with the casting process difference. Each wall is divided into 3 segments. The height of each segment is 1m.

Figure 9Wall Configuration – As cast picture

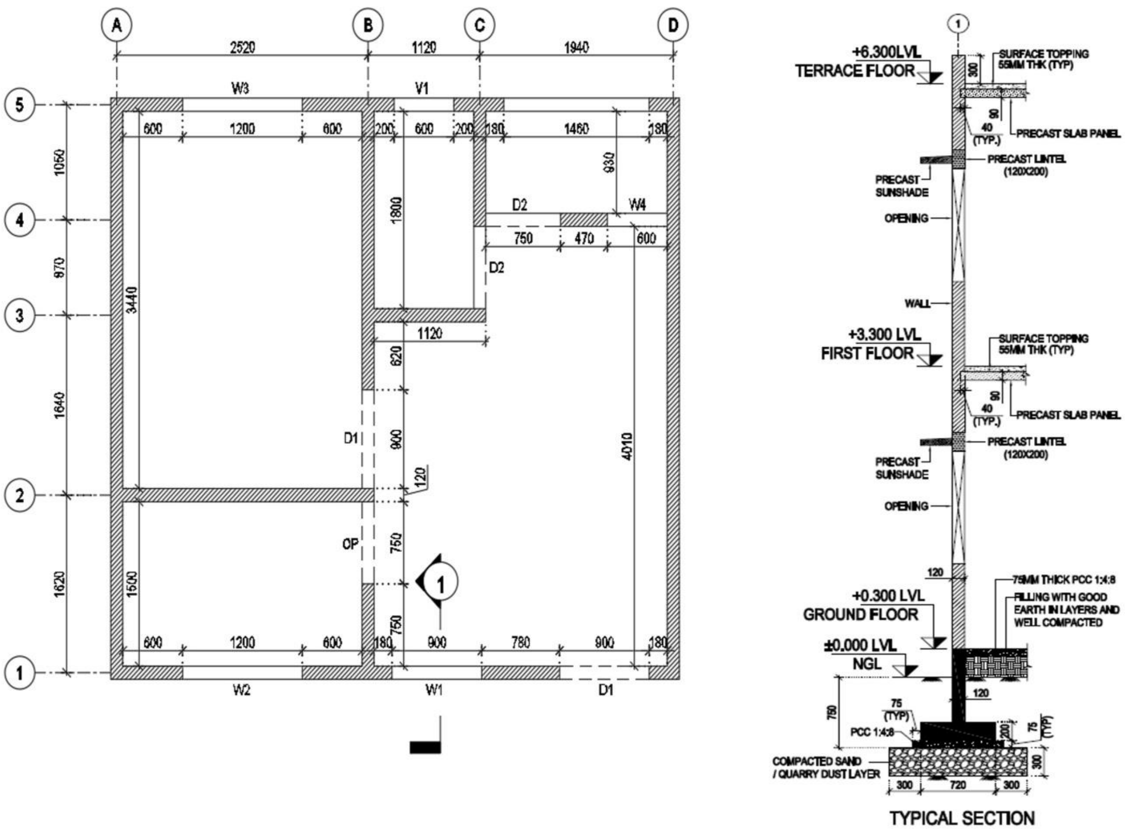


Figure 10 3D Printed Wall Numeration Drawing

Printing Process

1. There are 4 stages of printing to finish a floor.
   a. Printing with start rebars in place (Max possible height of 400mm)
   b. Continuous normal printing for a height of 2850mm
   c. Printing of Lintel level layers as an exception that spans from 2100 mm to 2200 mm.
   d. Printing of the top layer from 2850 mm to 3000mm

2. Printing of initial 400mm is done with a specially designed nozzle to ensure that the machine parts does not interfere with the protruding starter rebars at the bottom. This must be done with great care and vigil as there is high risk of machine running into a rebar if the rebar has strayed away from its initial position due to some human errors.

Figure 11 Wall printing photos

3. Normal printing can commence once the print has built-up above the starter rebar levels. It is advisable to use a different nozzle at this stage without offsets to reduce the risk of errors. This is a system dependant attribute.

4. The dimensional conformance of the built wall must be always monitored. This can be automated with profile sensors or camera mounted on top of the print head.
5. Any deviation in material behaviour can be corrected during live operation if the behaviour is in the permissible range of printability.
6. If the material property is found to deviate beyond the permissible range of printability, printing shall be stopped, and material shall be retuned back to its original state.

7. In the event of temporary pause of printing the system shall ensure that wetness of top layer is always maintained until printing is resumed. This can be done by sprinkling of water or with mist spraying.
8. In the last stage of printing a floor (ie. from 2850mm to 3000mm) only the exterior skin of the outer wall of the building is printed. These layers behave as the external formwork while slab activities are carried out later.

Reinforcement

Figure 12 Reinforcement Strategy

1. During G+1 building printing, 100mm wide weld meshes with 30mm pitch is used as horizontal distributors.
2. Horizontal distributors are placed at an interval of 250mm vertically, as per the approved design. Dedicated team members in-charge of reinforcement places the pre-cut weldmesh sheet on top the printed layers such that the sheets rest evenly on the inner and outer skin of the printed wall.
3. The weld meshes are overlapped at corners, wall intersection and wherever the continuity of reinforcement must be ensured.
4. Special care is taken to while placing the weldmesh sheets at starter bars so as to ensure that the starter bars does not deviate from their position while the weld meshes are inserted through them.
5. Weld mesh sheets of this dimension look like an array with three rows where one row rest on inner skin of the wall and the last row rest on the other skin of the wall. The centre row thus takes care of aligning the vertical rebars that are placed at a later point in the printing.
6. Vertical rebar 8mm dia are inserted from the top of the wall through the centre gap once the printing of the whole wall height is complete.
7. The insertion is done at an interval of 250mm along the length of the wall, as per the approved design.

8. The weld meshes placed at appropriate interval routes the vertical rebars to its exact location so that lapping with the starter bars at the foot is ensured.

Grouting Works

1. After completion of walls 3D Printing to the required floor height, the concrete grout (Liquid form 3D print concrete mix) is uniformly filled across the gap between 3D Printed walls.
2. During the testing, it was found that a homogenous bonding behaviour between 3D printed wall and grouted portion.

Lintel Works

1. At the lintel level, printing is performed normally with few additional considerations.
2. Once the lintel height is reached temporary formworks in the shape of plates are placed in the window or door area. These plates are supported by props that transfer load to the windowsill or floor.
3. Alternatively, compliant window and door frames can be directly placed at this stage to serve as the formwork for printing further on top of it.

Slab

Due to the layer-by-layer vertical formation method of construction, horizontal members like slabs cannot be 3D printed in a job site. Alternately, Slab works can be executed either one of the following methods. Live loads and finishes load along with self-weight are present on the slab, and these are then transferred to walls.

a. Pre-cast Slab members: The off-site precast slab members can be directly erected on top of 3D printed concrete walls, as per the prevailing approved construction design and methods.
b. Cast In Situ Slab: The slab can be casted in-situ using formwork system, as per the prevailing approved construction design and methods.

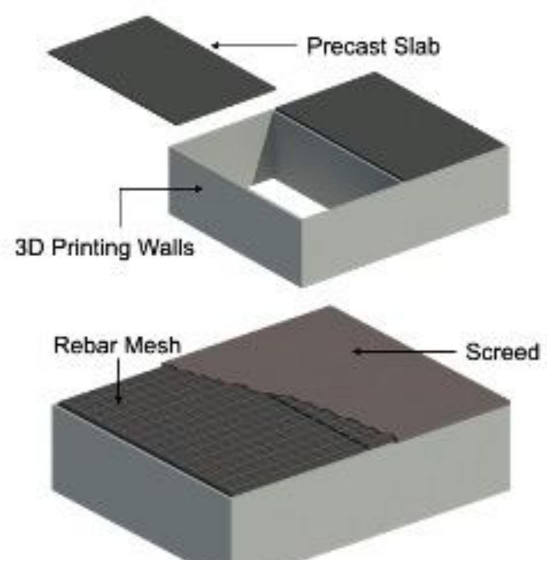


Figure 13 Option A: Pre-cast Slab

Figure 14Option A Contd . . .

L&T construction has constructed cast-in-situ slab of 100mm thick and further 50mm screeding (Option b).

Slab to Wall Interconnection:

Please refer to **Annexure – 3** for Slab to wall interconnection methodology drawing.

3D Concrete Printer used for the building

L&T Construction has used a fully automatic gantry type 3D Concrete printer for the printing of G+1 building. The printer was imported from M/s COBOD, Denmark.

Once 3D model drawing (.STEP file) and initial reference (XYZ Co-ordinates) are fed to the printer, it automatically takes over the entire printing operation, like an autonomous intelligent robot. Control variables like print speed, concrete extrusion speed, XYZ axis positioning etc can be adjusted “on the go” during the printing process.

3D Concrete printer photograph is appended below.

Figure 15 COBOD Fully automatic 3D Concrete Printer

(Ref.: https://cobod.com/wp-content/uploads/2020/09/BOD2-Specifications-1.pdf)

Slab to wall interconnection methodology drawing

Annexure 3