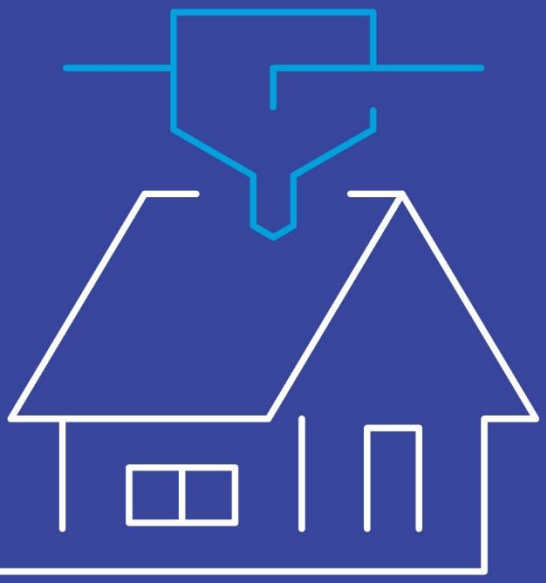
بلدية دبي
Dubai Municipality



3DCP Guideline

Guideline for 3D Concrete Printing in Design & Construction

1st Edition
June 2024

Contents

1. Executive Summary

1.1. Purpose & Scope of the Guideline

In his capacity as Ruler of Dubai, Vice President, and Prime Minister of the UAE His Highness Sheikh Mohammed bin Rashid Al Maktoum issued Decree No. (24) of 2021 regulating the use of 3D printing in the construction sector in Dubai, which supports the emirate's strategic target to ensure that 25% of new buildings are constructed using 3D printing technology by 2030.

The Decree aims also to promote Dubai as a regional and global hub for the use of 3D printing technologies. Part of a broader plan to spur economic growth and promote the adoption of advanced technologies in the emirate, the new legislation seeks to enhance efficiencies in construction projects, enhance the local industry's competitiveness, reduce waste, and attract leading companies in the sector to Dubai.

This guideline sets forth criteria for 3D concrete printing in construction. It outlines the requirements for design approval, qualifications of companies and personnel, certification of manufacturing facilities, and on-site building control standards to ensure safety, quality, and efficiency in all 3D printed projects.

This guideline applies to organizations involved in design for 3D Printing, concrete manufacturing, and construction, including the authorized contractors, consultants, and manufacturers involved in this activity.

This guideline does not, by itself, ensure the issuance of building permits for a project encompassing 3DCP methodology. However, it does provide the necessary general assessments, which are required for the evaluation and issuance of the building permits.

The purpose of the guidelines is to provide a structured framework that outlines best practices, recommendations, and standards for utilizing 3D printing technology in the creation of concrete structures. These guidelines aim to ensure safe, efficient, and high-quality implementation of 3D concrete printing throughout the design and construction processes.

1.2. Scope of the Guideline

The scope of these guidelines typically covers the following aspects:

a. **Design Considerations**: Guidelines address how to adapt traditional architectural and engineering designs for 3D printing, taking advantage of the technology's capabilities while adhering to structural integrity and aesthetics.
b. **Material Selection & Testing:** Recommendations are provided for selecting appropriate concrete mixes that are suitable for 3D printing. This involves testing materials for printability, workability, and curing behavior.
c. **Quality Control & Testing:** Guidelines cover methods for inspecting and testing printed components to verify their adherence to design specifications and to ensure structural soundness.
d. **Safety Protocols:** Safety guidelines for personnel involved in the printing process, as well as site safety during execution of works, are outlined to minimize risks.
e. **Regulatory Compliance:** Addressing any legal and regulatory requirements for 3D printed structures, including building codes and permits, is a key aspect of the guidelines.
f. **Documentation & Reporting:** Guidelines emphasize the importance of thorough documentation of the entire process, from design to completion, for future reference and accountability.
g. **Sustainability & Environmental Impact:** In some cases, guidelines may also touch upon sustainable practices associated with 3D concrete printing, such as reducing material waste and minimizing energy consumption.

Overall, this guideline aims to facilitate the adoption of 3D concrete printing in the construction industry by providing a structured approach that ensures successful project outcomes while addressing the unique challenges and opportunities presented by this innovative technology.

This guideline contains information that is proprietary to Dubai Municipality, which shall not be used in any misleading context or purposes other than compliance with the relevant requirements in the Emirate of Dubai.

Note: This guideline succeeds and shall be read in conjunction with Decree No. (24) of 2021 Regarding Regulating the Use of 3D Printing in the Construction Sector in the Emirate of Dubai.

To download the Decree, use the link below:

Decree No. (24) of 2021

2. Overview of Benefits & limitations

2.1. Benefits

a. **Design Freedom**: 3D concrete printing enables intricate and complex geometries that are hard to achieve with traditional methods.
b. **Reduced Material Waste**: Precise material deposition minimizes waste compared to traditional formwork.
c. **Speed and Efficiency:** Faster construction due to automated layer-by-layer printing, potentially reducing project timelines.
d. **Labor Savings:** Less labor-intensive than conventional construction, leading to potential cost savings.
e. **Customization:** Tailoring structures to specific needs is easier with 3D printing, allowing for optimized functionality.
f. **Sustainability:** Reduced material consumption and transportation can contribute to lower carbon emissions.

2.2. Limitations

a. **Material Development:** Developing concrete mixes suitable for printing while maintaining structural integrity can be challenging.
b. **Print Quality Control:** Ensuring consistent layer bonding and proper curing throughout the process is crucial.
c. **Regulations & Standards:** Developing and adapting building codes for 3D printed structures can be complex.
d. **Lack of Experience:** The technology is still relatively new, so there's a shortage of skilled professionals with expertise in 3D concrete printing.
e. **Equipment Costs:** Initial investment in specialized 3D printing equipment can be high, potentially limiting accessibility.
f. **Size Limitations:** Current technology may limit the size of structures that can be effectively printed.
g. **Maintenance and Repairs:** Developing methods to repair or modify 3D printed structures is an ongoing challenge.

Balancing these benefits and limitations is essential for successful implementation of 3DCP projects. 3D concrete printing guidelines will help in resolving the limitations by sharing information and best practices available within the industry.

3. Overview of 3D Concrete Printing

3.1. Definition of 3D Concrete Printing

3D concrete printing is an advanced construction technology that utilizes additive manufacturing principles to create three-dimensional objects and structures using concrete or mortar. It involves the layer-by-layer deposition of a concrete mix to build up a physical object based on a digital design.

3.2. Fundamental Concepts & Technologies

a. **Additive Manufacturing**: This concept involves adding material layer-by-layer to create objects, in contrast to traditional subtractive manufacturing methods.
b. **Digital Design**: Objects are designed using computer-aided design (CAD) software, which generates a digital 3D model that guides the printing process.
c. **Material Extrusion**: The most common technique in 3D concrete printing that involves extruding concrete material through a nozzle in three dimensions.
d. **Layer Height and Resolution**: Objects are printed layer-by-layer, with the layer height determining the resolution and surface finish of the final product.
e. **Curing**: Curing 3D printed concrete is vital for its strength and durability. The extrusion process used in 3DCP exposes a greater surface area of the concrete, creating higher potential for cracking. External curing (moist curing), internal curing, and shrinkage-reducing admixtures are various curing methods that may be used. Choosing the right method depends on project size, environment, desired properties, and cost.

3.3. Components of the 3D Printing Systems

a. **Printing Nozzle/Extruder:** This component deposits the concrete material layer-by-layer.
b. **Material Delivery System:** Supplies the concrete mix to the nozzle for extrusion.
c. **Control System:** Coordinates the movement of the nozzle and the printing bed based on the digital design.
d. **Power & Control Unit:** Provides the necessary power and control signals to the printing system.
e. **Digital Design Software:** CAD software that generates digital models to be printed.

4. Overview of the Printing Process & Systems

a. **Digital Design:** The process begins with creating a 3D digital model of the object to be printed using CAD software.
b. **Selecting a Printer:**
    i. **Gantry Printers:** Printers with a large frame that moves along designated paths.
    ii. **Robotic Arm Printers:** Robotic arms with specialized end-effectors are used to precisely deposit the concrete, enabling more complex geometry.
c. **Converting the Digital Design:** to readable data by 3D slicing software. The digital model is divided into thin horizontal layers using 3D slicing software, which generates instructions for the printer.
d. **Printing Setup:** The printer is calibrated along with the printing bed and a suitable nozzle/extruder are positioned at the printing location.
e. **Printing:** The concrete mix is extruded layer-by-layer according to the instructions generated by the slicing software.
f. **Curing:** The printed structure needs to undergo a controlled curing process to achieve the desired strength and durability.
g. **Post-Processing:** Depending on the project, additional processes like smoothing, support installation, rebars insertions, concrete casting, insulations, and final touches may be applied.
h. **Assembly:** If necessary, printed components are assembled to create a complete structure such as slabs, lintels, etc.

Different technologies and approaches exist within the field of 3D concrete printing, each with its own variations in terms of material composition, printing methods, and equipment. The technology is continuously evolving, offering new possibilities for architectural innovation and construction efficiency.

5. Design Principles & Requirements for 3D Concrete Printing

At the project permit stage, the submitted documents, shop-drawings, and details shall prove compliance with the approved construction method evaluated as part of the building system approval process.

In case it is not possible to implement the approved construction method in any part of the building, the new method shall be submitted for approval to the Research & Building Systems Section of Dubai Municipality.

5.1. Structural Design Considerations

Dubai Building Code shall govern the structural design of 3D concrete printed structures. Compliance with the conditions and requirements of the Building System Approval is also mandated.

5.2. Architectural Design Considerations

The architectural design of 3D concrete printed structures shall adhere to the provisions outlined in the Dubai Building Code.

5.3. MEP Design Considerations

MEP design of 3D concrete printed structures shall adhere to the Dubai Building Code. Additionally, compliance with the approved building system's conditions and specifications is mandatory.

To access Dubai Building Code, please click on the link below:

Dubai Building Code – 2021 Edition

6. Material Specifications & Testing

6.1. 3D Printing Concrete

3D Printing Concrete Mix is a proprietary cementitious material composed of cement, fibers (if applicable), supplementary cementitious materials (if applicable), fine and/or coarse aggregate, and admixtures (if applicable). 3D Printing Concrete Mixes may only be supplied by factories holding a factory certification of conformity and Conformity Mark under the Certification Scheme of 3D Printing Concrete Mix Manufacturers by Dubai Central Laboratory Department.

In case 3D Printing concrete is used as permanent shutter for reinforced concrete elements, it shall not be considered as part of the load-bearing element.

In addition to the requirements stipulated in DCLD certification scheme, the following requirements shall apply:

6.2. Compressive Strength of 3DP Concrete

Each mix design shall be tested for compressive strength according to ASTM C31 or ASTM C109. A minimum of 5 specimens shall be tested at the age of 28 days. The average 28-day compressive strength shall not be less than 17 MPa (cylinder strength) / 20 MPa (cube test).

3DP concrete specimens shall be sampled for compressive strength testing at the time the 3D printed element is constructed. A minimum of 5 specimens shall be sampled for each element. At least 3 sets (each 5 specimens) shall be sampled for continuous printing of the same mix design on each construction day. The average compressive strength of 3DP concrete shall not be less than 17 MPa (cylinder strength) / 20 MPa (cube test) at 28 days.

6.3. Shrinkage & Volume Change

Each 3DP concrete mix shall be evaluated for shrinkage cracking response at the mix design stage. A minimum of 3 specimens shall be tested for each mix design in accordance with ASTM C157.

The average strain measurements of all tests of 3DP concrete at 28 days shall be less than:

- 0.065% for mixes with fibers or with aggregate size larger than 1.25mm.
- 0.05% for mixes without fibers or with aggregate size less than 1.25mm.

6.4. Inter-layer Bond Strength

Flexural bond tests shall be carried out on three sets of 3DP concrete specimens in accordance with ASTM E518 Section 5.2 (Method A). The specimens shall be representative of the 3D printed element and cast at both minimum and maximum extrusion time intervals between layers. The test results shall be equal for both extrusion time intervals.

7. The Printing Process

The 3D concrete printing process involves several stages, including preparation, printing, monitoring, and post-processing. Here's an overview of each stage:

7.1. Preparation & Preprocessing

a. **Concrete Mix Design**: Develop a concrete mixture suitable for 3D printing, considering material properties, workability, and printability.
b. **Digital Model**: Create a 3D digital model of the structure to be printed, using Computer-Aided Design (CAD) software.
c. **Slicing**: Divide the digital model into horizontal layers (slices) to guide the printing process.
d. **Path Planning**: Generate toolpaths that specify the deposition of material for each layer, optimizing for speed and structural integrity.

7.2. Printing Strategies (Layer-by-Layer Approach)

a. **Material Deposition**: The 3D printer deposits concrete layer-by-layer, following the toolpaths generated in the preprocessing stage.
b. **Extrusion**: Most 3D concrete printers use extrusion, where a print head deposits layers of concrete onto the previous layer.
c. **Inter layer enhancements**: There may be a need to enhance the strength between the layers by making small grooves at the top of the bottom layer to moisten it by spraying water or adding wet cement slur to its surface to ensure cohesion and homogeneity with the next layer and thus cohesion between all layers. This method is also applied in the case of stopping work and reprinting.
d. **Support Structures:** Temporary support structures may be needed alongside the main structure to prevent overhangs and maintain stability during printing. Usually, support structures for 3DCP are required when printing complexes or overhanging geometries that may not be self-supporting during the printing process.

7.3. Monitoring & Control During Printing

a. **Quality Control**: Sensors and cameras can monitor the printing process in real-time, checking for any inconsistencies or defects.
b. **Material Flow**: Monitoring the extrusion process to ensure consistent material flow and proper layer adhesion.
c. **Temperature & Humidity**: Monitoring and controlling environmental conditions to prevent premature curing or material-related issues.
d. **Layer Adhesion**: Ensuring proper bonding between successive layers for structural integrity.

7.4. Post-Processing, Curing, & Finishing

a. **Support Removal**: If support structures were used, they need to be carefully removed without damaging the printed structure.
b. **Curing**: The printed structure needs to undergo a controlled curing process to achieve the desired strength and durability. Furthermore, the curing process for 3DCP mix is often accelerated due to optimized mixtures and additives. Nonetheless, the exact curing time can range from a few hours to a few days depending on the formulations of the mix which makes it crucial to follow the manufacturer's recommendations and the industry's best practices.
c. **Surface Finishing**: Depending on the desired appearance, additional finishing processes like sanding or coating may be applied.
d. **Reinforcement**: Additional reinforcement materials like rebar or fibers can be added to enhance the structural strength if necessary.
e. **Inspection**: Thoroughly inspect the printed structure to ensure it meets quality standards before it's put into use.

It's important to note that the specific details of each stage can vary based on the 3D printing technology used, the type of concrete mixture, and the complexity of the structure being printed. Additionally, as technology and practices continue to evolve, the steps and strategies involved in 3D concrete printing may also change or improve over time.

Appendix A - Licensing Requirements for 3D Concrete Printing Activities

A.1. Engineering Staff Accreditation

1. Create an account in the Dubai Engineering Qualification System (DEQ) by entering the link:
   Dubai Engineering Qualification System (DEQ)
2. Fill in the individual record data:
   - General data
   - Qualifications
   - Practical experiences
3. Applying for the "Engineering Staff Accreditation" service and choosing the appropriate activity according to the educational degree specialization and practical experience of the engineer.
4. Book an appointment for the test (tests vary based on the activity); the test format will be Multiple Choice Questions held in testing centers.
5. After passing the exam, the certification is automatically provided in the individual record of the engineer in the DEQ system.

A.2. Register Engineering Professional Practice Certificate

1. Issuing the initial approval and trade name certificate from the Department of Economy and Tourism (the initial approval contains details of the activities required to be licensed + the license parties).
   Create an account in the Dubai Engineering Qualification System (DEQ) by entering the link:
   Dubai Engineering Qualification System (DEQ)
2. Applying for the "Register Engineering Professional Practice Certificate" service and filling in the initial approval data that was issued by the Department of Economy and Tourism.
3. The application is studied by Dubai Municipality, and upon approval, the engineering professional practice permit is automatically created and activated in the DEQ system (the full details of the record and the available services can be viewed in the system - 360 Vision).
4. After issuing the professional practice permit, the professional standards will be visible in the Health Checkup list in the DEQ system, according to the activities of the license (managers + certified engineers + office + labors) to help the license parties manage their engineering companies.

A.3. 3D Printing Activities & the Required Standards

#	Activity Code	License Type	Main Activity	Activity Name	Degree	Engineer Degree Specialization	Academic Experience	Professional Experience
1	7110213	Professional	Consultancy	Building Engineering Consultancy with 3D Printing Technology	Bachelor's	1x Civil Engineer & 1x Architectural Engineer	5 Years	5 Years
2	2395014	Industrial	Suppliers / Manufacturer	3D Printed Building Concrete Manufacturing	Bachelor's	1x Civil Engineer	3 Years	3 Years
3	4330025	Commercial	Contracting	Decoration Design & Implementation Using 3D Printing Technology	Bachelor's	1x Civil / Architectural Engineer OR 1x Civil / Architectural Diploma	3 Years (Bachelor's) OR 5 Years (Diploma)	3 Years (Bachelor's) OR 5 Years (Diploma)
4	100192	Commercial	Contracting	3D Printing Building Construction Contracting	Bachelor's	1x Civil Engineer	5 Years	5 Years

For further information regarding Licensing Requirements kindly click the link:

Dubai Engineering Qualification System Guide

Appendix B - Approval Process for 3D Concrete Printing Building Systems

B.1. 3D Concrete Printing (3DCP)

Important Information

1. The approval will be issued to 3D Printing contracting companies registered with DM Qualification Section through DEQ system and having an active license under activity code: **100192 - 3D Printing Building Construction Contracting** from Dubai Economy and Tourism (DET).
2. Structural calculations and designs will be reviewed at the permit stage for each project.
3. Final approval is issued for the 3D printing concept and methodology and is not related to a specific project.
4. Project design shall be submitted to obtain a building permit from the concerned entity.

B.2. Required Documents for New Applications

Administrative

1. The required license from Dubai Economy and Tourism (DET).
2. Registration record with DM Qualification Section.
3. List of completed and ongoing projects within the UAE or regionally (if available). The list shall, whenever applicable, include project name, description, location, plot number, area, owner, consultant, main contractor, type of elements used and project status.
4. List of key personnel including but not limited to design team, factory production team site operations team, quality control (as applicable) and their qualifications; designation, academic qualifications, professional trainings, and experience.
5. Printer operator qualification including but not limited to proof of training or certification.

Technical

1. Brief about the technology adopted, the printer and printing methodology.
2. High-resolution detailed cross-sections for printed elements including element thickness, configuration, printing layer thickness, stiffeners, etc.
3. Factory production quality control procedures (if applicable).
4. Site quality control and testing procedures.
5. Connection details between walls and other elements.
6. Materials specifications and data sheets along with the relevant test reports
7. Dubai Central Laboratory (DCL) product conformity certificates for 3D printing mortar.
8. Dubai Central Laboratory (DCL) product conformity certificates for insulation materials.

Performance

1. Details of thermal insulation for external walls and roof.

2. U-value calculations using DM U-Value Calculator for external walls and roof.
3. Acoustics test reports to be in line with Al Sa'fat requirements (All walls); test results to be submitted for each section and to be compared with Al Sa'fat requirements.
4. Method statement for MEP works.
5. Dubai Civil Defense (DCD) approval for insulation materials as well as relevant Certificate of Compliance (COC) and test reports.
6. Details of waterproofing wherever applicable.
7. Details of external finishing and insulation systems along with the application/installation process in compliance with Dubai Building Code requirements for building envelope.

Additional documents/information may be requested during the review process.

B.3. Required Documents for Renewal Applications

1. Industrial/Commercial/Professional license
2. Registration record with DM Qualification Section.
3. List of 3DCP projects (completed and ongoing) by the local company in Dubai during the last year using the below format:

Project Name	Project Description (Type, no. of floors...)	Location & Plot No.	Owner	Consultant	Main Contractor	Elements Type	Project Status (Completed / Under Construction...)

4. Updated list of key personnel including but not limited to design team, factory production team site operations team, quality control (as applicable) and their qualifications (designation, academic qualifications, professional trainings, and experience) using below format:

Name	Designation	Job Description (Responsibilities)	Experience Record (no. of years doing job in charge of)

5. Dubai Central Laboratory (DCL) product conformity certificates for 3D printing mortar.
6. Dubai Central Laboratory (DCL) product conformity certificates for insulation materials.
7. Dubai Civil Defense (DCD) approval for insulation materials.

For more information regarding building system approvals kindly refer to the service "Request to approve a new building System" or visit the website using the link here:

Request to Approve a New Building System

Appendix C - Building Permit Process for 3D Concrete Printing Projects

C.1. Project Submission & Documentation Requirements

The building permit process for 3D printing projects involves several steps to ensure project compliance with local regulations, safety standards, and other requirements. Here's a general outline of what it might involve:

C.2. Preliminary Consultation

Engage in discussions with local authorities, building departments, or relevant regulatory bodies to understand the specific requirements and regulations for 3D printing projects. This might involve meetings or correspondence to clarify any questions you have about the permitting process.

C.3. Building System Approvals

A building system approval must be acquired from the Research and Building Systems Section before beginning the building permit process.

C.4. Project Documentation

Prepare detailed project documentation, which includes architectural and engineering plans, structural calculations, materials specifications, and other relevant details. These documents should accurately reflect the 3D printing technology and methods to be used.

C.5. Permit Application Submission

Submit a building permit application to the appropriate regulatory authority. This application typically includes the project documentation, proposed construction timeline, information about the technology used, and any required fees.

C.6. Plan Review

The regulatory authority reviews the submitted documents to ensure compliance with Dubai Building Code, zoning regulations, safety standards, and other applicable requirements. This review involves different disciplines, such as structural, architectural, MEP, fire safety, and more.

C.7. Modifications & Clarifications

During the plan review, you might be asked to make modifications to your project documentation to address any issues or concerns raised by the regulatory authority. You may need to provide additional information or clarify certain aspects of the project.

C.8. Approval & Issuance

Once the review process is complete and your project documentation is deemed compliant, you'll receive approval for your building permit. This approval might come with conditions or requirements that you need to adhere to during construction.

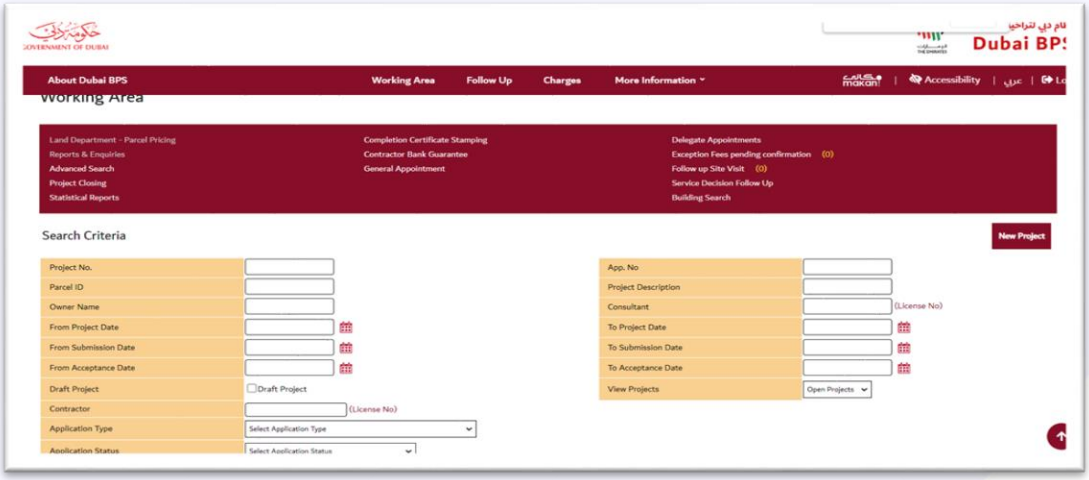
C.9. Permit Fees & Payments

Pay any required permit fees before construction begins. The fees are usually based on the scope and complexity of the project.

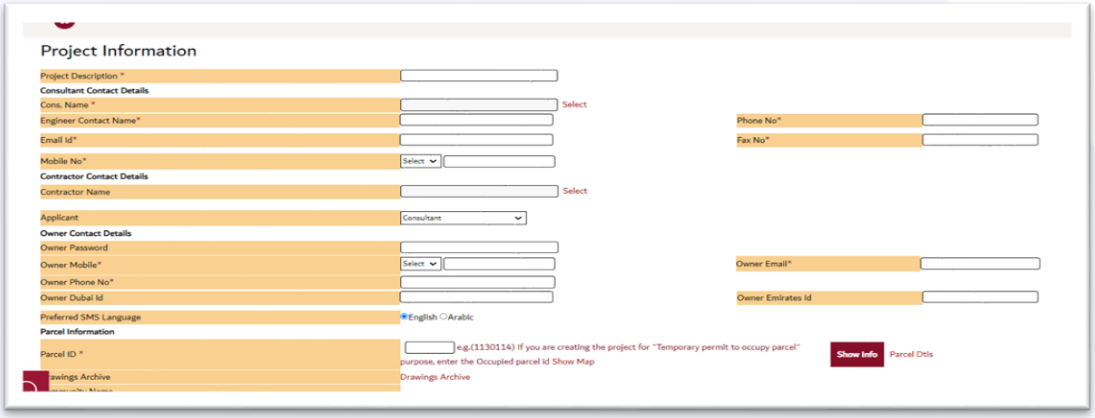
It's important to note that the specific requirements can vary depending on the location, the size and nature of the project, and any unique regulations related to 3D printing, yet the process is like any new submission submitted on the BPS website.

C.10. Building Permit System process

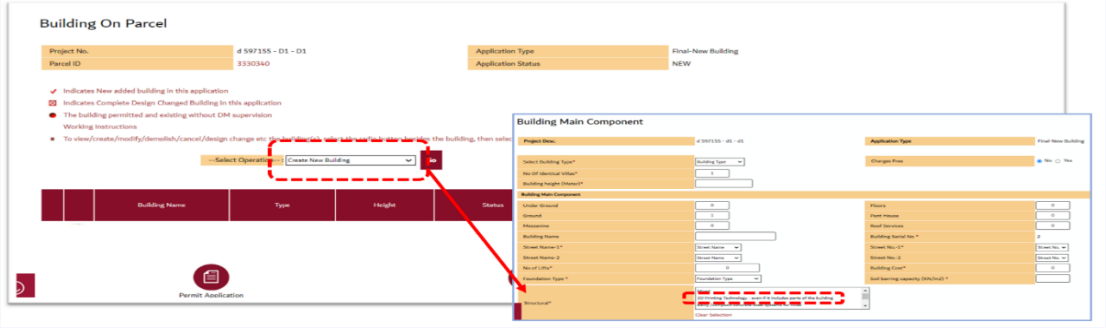
- Accessing the system
- Create New Project in the working area page:



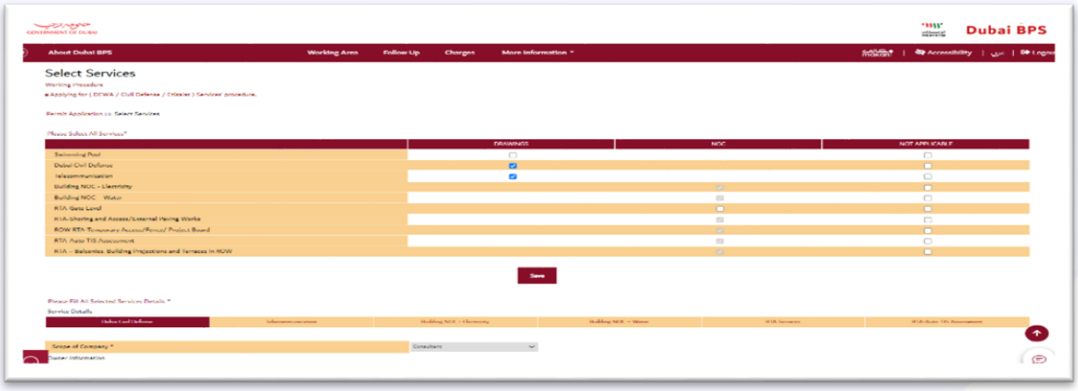
- Fill in the project information:
  - Create New Project
  - Fill in the project information.
  - Create new application.



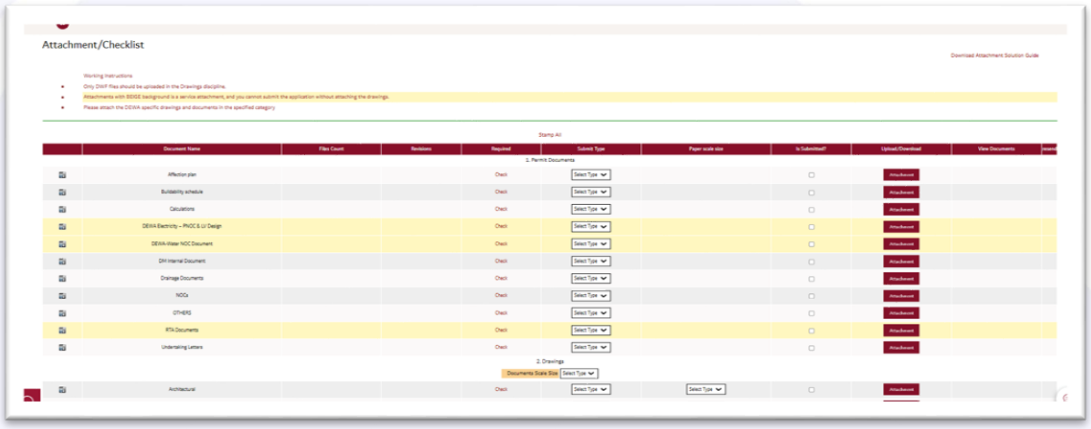
- Fill in the application information in the following order:
  - Add the building card details and choose (3d printing technology) as shown:



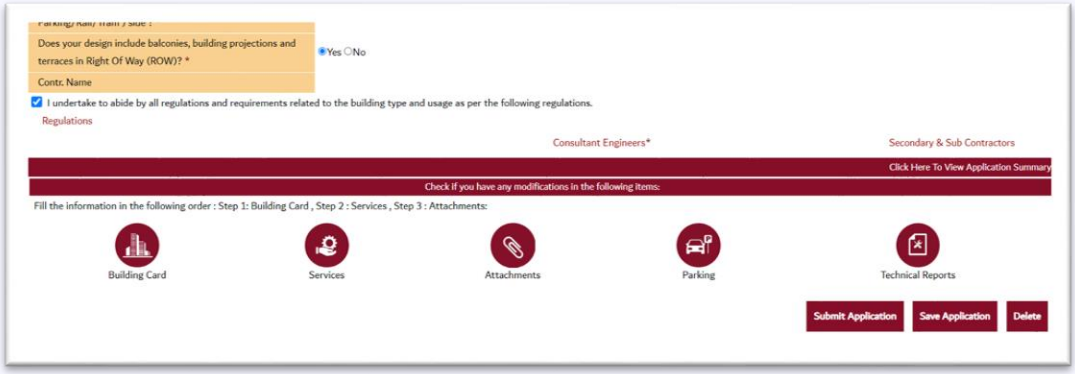
- Fill the services details



- Attach document and drawings:



- Submit the permit application:



For further information a link is provided for the New Building Permit service on DM website, which includes permit section procedures to obtain the permit certificate:

Apply for a New Building Permit

Appendix D - Structural & Occupational Safety Process for 3D Concrete Printing Projects

D.1. Site Preparation & Mobilization

Before commencing the construction works of 3D printing the project, the main contractor shall comply with the following obligation:

1. Obtaining permits, approvals, and NOCs from the concerned departments.
2. Preparing the mobilization drawings locating the places of temporary site office, material stores, workers rest area, and preparing the necessary passages for the movement of machinery and equipment used in 3D printing process.
3. Obtaining the necessary approvals from the concerned Departments before occupying neighboring plot or right of way.
4. Preparing a safety plan and risk assessment before starting work, including all major and secondary activities, enumerating potential risks resulting from the use of 3D printing equipment and materials, such plan shall be approved by the engineer.
5. Install the temporary fence and the project sign board, which must include the following information:
    a. Hotline number and Dubai Municipality logo
    b. Parcel ID
    c. Building permit number
    d. Permit details
    e. Project type (3D printed building)
    f. The owner's name
    g. Name of the consultant
    h. Name of the main contractor
    i. Name of the 3D printing subcontractor

D.2. Execution of 3D Printing Works

In addition to what is stipulated in the regulations and legislation regulating buildings construction, the engineer and contractor shall comply with the following requirements and conditions:

1. All levels shall comply with approved drawings.
2. Excavation and soil improvement works (if any) shall comply with approved drawings, considering that soil bearing capacity at foundation level should be confirmed prior submitting a request for a structural inspection of the foundation works.
3. Execution of building components, including foundations, columns, concrete slabs, and 3D printed elements according to approved drawings, specifications, and engineering principles.
4. Commitment to follow the method of statement stipulated in the approved drawings for implementing 3D printing elements.
5. Concrete products shall be cured for the required period according to the specifications specified by the manufacturer of the concrete mix used for 3D printing.
6. The contractor shall submit a request for a structural inspection of buildings executed using 3D printing technology at the following stages:
   a. Before casting the foundations, slabs, and for shoring system (if any), according to the procedure followed for conventional buildings.
   b. Before starting 3D concrete printing work.
   c. After completing the 3D concrete printing elements work.
7. If the building contains pre-cast 3D concrete printing elements, loading and off-loading requirements and approved installation procedure shall be followed.
8. When implementing building elements using the technology of 3D concrete printing, the following considerations shall be followed:
   a. Complying with technical specifications and engineering principles and taking necessary precautions to ensure the quality of structure.
   b. Commitment to implementing the construction details in accordance with the construction methodology stipulated in approved drawings.
   c. Adherence to the implementation of 3D printed concrete elements as per the dimensions, thicknesses, the height of each layer, and the time interval between them according to the approved drawings.
   d. Complying with technical specifications and engineering principles regarding structural connections of 3D printed concrete elements according to the approved methodology.

9. For any amendments or additions required, they must not be started before revising the drawings from the concerned department.

10. A quality control plan and inspection of 3D concrete printed elements should be developed to ensure their safety and integrity of the structure.

11. In case of any technical defects developed, appropriate remedial method of statement shall be prepared and approved by the engineer with the necessity to inform the concerned department. If these defects affect the structural safety and integrity of the building, the engineer must approve the method statement from the concerned department.

D.3. Raw Materials & Mixtures Used

The following requirements shall be adhered to regarding the materials and mixtures used for 3D concrete:

1. All materials used in 3D printing shall be certified by Dubai Central Laboratory and have the marks of conformity.
2. Use of permitted materials in the preparing of mixtures, and the provide proof of the integrity of such materials such as tests reports or certificates.
3. Manufacture mixtures within the ratios and approved mix design for 3D concrete printing.
4. Ready mix 3D concrete printing shall meet the standards and specifications of green buildings (as applicable).
5. Provide material performance test results that satisfies the requirements and approved standards.
6. A trial mix for printable 3D materials shall be designed to satisfy the requirements; such mix shall be approved by the engineer, with the necessity to maintain test results at the site.
7. The contractor shall not use mixtures supplied from outside the emirate on the construction site, unless the following conditions are met:
    a. It has been proven that the mixtures are not available in the emirate's markets, or that they are insufficient.
    b. Obtaining the approval of the concerned department, before supplying mixtures to the construction site.
    c. Conducting tests that prove that the mixtures are prepared within the proportions and standards necessary for printing the building and its elements, and that they have sufficient technical specifications in conformity with the standards, regulations and engineering specifications approved in the emirate.
    d. Obtaining a letter of exemption from Dubai Central Laboratory indicating the aforementioned conditions have been met.

D.4. Effective Supervision by the Engineer

This chapter addresses the role of the Engineer in achieving effective supervision to verify the integrity of execution of the works and their conformity with the approved drawings, specifications, technical standards, and engineering principles. The engineer shall inspect the following requirements:

1. Conformity of the executed works with the approved structural and architectural drawings.
2. Conformity of the executed works with engineering principles, technical specifications, and approved execution methodology.
3. Carry out structural inspection of all horizontal and vertical structural members before casting, in addition to the shoring works (if applicable).
4. The required tests for the structural elements and printed parts and their fulfillment of the required results according to the standards.
5. Inspect and approval of printed members and ensure their integrity and that they are free from technical defects.
6. Audit of the construction materials used and ensure that they receive the conformity certificates from Dubai Central Laboratory

D.5. Safety Standards & Requirements for 3D Printing Technology

This chapter explains the necessary requirements and arrangements to be followed during all stages of execution and construction using 3D printing technology which includes design, supervision, and implementation of work to preserve the lives and safety of workers.

Printing Equipment & Vocational Training

The contractor shall consider the following requirements:

1. Obtaining a safety certificate for machinery and equipment used in 3D concrete printing technology from accredited third party.
2. Obtaining a safety certificate for operators of machinery used in 3D concrete printing technology from accredited third party.
3. Follow the instructions and recommendations contained in the user guide included with the printers.
4. Providing a certificate from the manufacturer of printers on site.
5. Conduct training for an adequate number of technical staff, including engineers and technicians, to operate printers.
6. Providing the necessary number of technical staff needed on the site in proportion to the nature and size of the project, in accordance with the requirements stipulated in the construction safety guide of under construction sites.
7. Instructing and training workers on site about the precautions when dealing with or working near printers.

Working Environment for Printers

1. The contractor shall follow the state of meteorology daily during the execution of the work to ascertain the different weather factors of temperature, wind speed, and rainfall forecast to avoid negative impacts on the implementation of the 3D printing technology and accordingly take the necessary precautionary measures to avoid compromising the safety of individuals, methods, and printed elements.
2. The risk assessment plan should include the precautions to be taken from the contractor to prevent the impact of weather factors on the printed mix and the work of printers on the site and how to address the adverse effects of weather factors if they occur.
3. In case of weather fluctuations from winds, rains or storms that may affect the safety of printed items, the Engineer must submit a report to the concerned department indicating the technical status of printed members and their structural integrity.

Temperatures

1. The contractor shall monitor the weather temperature daily and ensure that it does not exceed the permitted limits according to the printer's specifications and requirements and the methods used in the printing process.
2. The contractor shall observe the maximum permissible temperature of operation in accordance with the recommendations of the Special Guidance for Construction Materials used for the 3D printing process.
3. The contractor shall use appropriate methods to reduce the temperature of the atmosphere by providing air conditioning and insulated place around the printer places in case the temperature exceeds the permitted limits.

Rainfall

1. The contractor shall take the necessary precautions during the work of the printers in case of anticipated rainfall, appropriate protections shall be provided to prevent the negative impact of rainfall on printing procedure and printed members during or after printing.
2. The contractor shall stop operating printers at the site in case of heavy rainfall that may affect the safety of printers and printed members.
3. The Engineer shall examine the printed elements in case of direct exposure to rainfall intensity to assess their condition and the extent of damage caused by the impact of the rain.

Wind

1. The contractor should provide a wind speed measuring device at the site.
2. The contractor should take the necessary precautions by providing appropriate protections to prevent the impact of the wind on the work of the printers.

3. The contractor must stop the work of printers at the site in case the wind speed exceeds the allowable rate according to the manufacturer's manual of printer.
4. The contractor should consider the impact of sand and dust on the operation of printers and take precautions to prevent damage to printers.

Vibrations

1. The contractor should coordinate the work on the site to avoid synchronizing the vibrating work with the work of the printers on the site.
2. The contractor must stop the work of the printers in case the vibration rate resulting from the work of the adjacent equipment exceeds the permitted limits in accordance with the recommendations of the Manual of Printers.
3. If the printed elements are exposed during or after implementation to vibrations, the engineer must inspect to ensure that the printed items are not damaged.
4. The passage of machinery and heavy equipment near the printers' premises is prohibited and the contractor must take precautions to prevent the equipment from reaching the printers' working zone.

Safety Precautions for Construction Materials Used for Printing

1. The contractor should follow the recommendations of the guide on how to handle the construction materials used in the printing process.
2. The contractor must provide appropriate stores for construction materials used for 3D printing work to protect them from the influence of different weather conditions.
3. Materials used for printing work shall not be dumped directly on the ground and must be placed on dry and elevated floor over the ground.
4. Safety precautions should be taken during the loading and handling of materials used by printing.
5. The contractor should use suitable tanks to store cold water and ice used by lowering the temperature of the mixtures used in 3D printing process.
6. Workers and printer operators must wear suitable protective equipment to prevent harmful effects of printing materials.

General Safety Precautions During Implementation of 3D Printing

1. The contractor is required to submit a setting out plan showing the general layout, identifying the location, movement and paths of printers and machinery during the work plan to prevent overlap between the scope of the printers' work.
2. The contractor shall take the necessary precautions to remedy and repair any failure that may occur with printers or the operating system with the development of an alternative plan to ensure continuity of work and it should be approved by the Engineer.

3. No excavation work is permitted near the printers' working zone, provided that the distance between the excavation edge and the printer position shall not be less than 3 meters or as provided for in the manual of the printer.
4. The contractor must ensure that solid flooring is made up of concrete or material that is suitable for the standing and stability of printers without inclination or settlement below it and ensuring that the soil is compacted to a suitable degree.
5. The contractor must not allow non-specialized persons to be present in the printers' work area.
6. Movement of loaded cranes above the operating range of printers, printed elements and facilities is prohibited.
7. The contractor must install safety barriers around the printers' working zone and provide guidance and warning boards.
8. The contractor must provide safe pathways free of obstacles to ensure the safe movement of printing equipment.
9. The contractor must provide the necessary means of protection to prevent materials falling and flying from buildings under construction adjacent to the printers' workplaces.
10. Any flammable work should not be carried out near the printers' working areas (such as welding).

The contractor and engineer must periodically review and adhere to the updated regulations, laws, and circulars.

Appendix E - Certification of 3D Printing Concrete Mix Manufacturers

E.1. Definitions of Terms & Abbreviations

For the exclusive use of this guideline, the following terms, phrases, abbreviations, and definitions, shall apply in addition to those given in the applicable standards/normative references and the General Rules of Certification as per Factory Assessment Scheme DM-DCLD-RD-DP21-2001(IC).

Term	Definition / Explanation
DM Certification Body	Certification and Quality Control of Products Section. A section within Dubai Central Laboratory Department – Dubai Municipality (Refer also herein as DCLD-CQPS), responsible for certification of Products/Processes and Services.
Product	The 3D Printing Concrete Mix [A proprietary cementitious material that consists of cement, fibers, and supplementary cementitious materials (if applicable), fine and/or coarse aggregate, and admixtures (if applicable)].
Process	The process for producing/manufacturing the 3D Printing Concrete Mix
Applicant/Client	The Manufacturer (Factory) producing the 3D Printing Concrete Mix
Factory Production Control System – FPC (Product Quality Assurance Plan)	A documented system, agreed upon by both the Applicant/client and DM certification body, to ensure continuous compliance of the certified Product/Process /Service with the certification requirements.
Quality Management System - QMS	The Documented Quality Management System, in line with the requirements of ISO 9001, which is implemented and followed by the application/client.
Authorized Auditor	The approved auditor by DCLD-CQPS either internal within DCLD- CQPS or external (Approved Conformity Assessment bodies' auditor or an approved auditor based on a signed contract with DCLD-CQPS).
Process Parameters	Set of operating parameters and system settings used during the design/ manufacturing process of the 3D Printing Concrete Mix.
DCLD Certification	The Factory Certification of Conformity and the Conformity Mark issued by DCLD to the applicant after satisfactory conformance with the certification requirements.

E.2. Scope

The 3D Printing Concrete Mix manufacturing process includes but not limited to 3D Printing Concrete Mix manufacturing process in addition to the mix design and the quality control monitoring from the incoming raw materials to the finished designed 3D Printing Concrete Mix.

The factory certification of conformity and DCLD Conformity Mark under the scope of this guideline are granted to the applicant and will cover the 3D Printing Concrete Mix manufacturing process including the type of the 3D Printing Concrete Mix being assessed satisfactorily as per below requirements.

The data below does not by itself permit the use of the 3D printing method in the construction sites. However, it does provide the necessary general conformity assessment criteria, which are required for the evaluation and issuance of the factory certification of conformity and DCLD Conformity Mark to the applicant.

E.3. DCL Certification Requirements

1. Application

1.1. Any applicant/client as defined within this guideline shall apply to DM Certification Body to obtain factory certification of conformity and the DCLD Conformity Mark.

1.2. The Applicant/client shall submit his application online through DM Portal as guided by DM Certification body and approve all terms of reference as set within the application.

1.3. The applicant can submit different 3D Printing Concrete Mix in one application for assessment and approval.

2. 3D Printing Concrete Mix - Technical & Management Requirements

2.1. Quality Management System

The applicant/client shall have a Quality Management System that is aligned to the requirements of ISO 9001 standard.

Note: Having a certificate of ISO 9001 is not mandatory. However, the structure of the client's QMS shall be in line with its requirements.

2.2. Required Facilities and resources.

The applicant/client shall have and or ensure the following:

2.2.1. Full control and monitoring of the necessary facilities and resources to design and produce the 3D Printing Concrete Mix covered by the application for certification, which includes the 3D printing the 3D Printing Concrete Mix manufacturing process and monitoring of set control process parameters up to the quality of the finished product.

2.2.2. Detailed quality control procedures for all steps within the process of manufacturing of the 3D Printing Concrete Mix including the design and trials.

2.3. Production & Quality Control

The applicant/client shall operate and/ or follow a defined FPC (Factory Production Control system) to ensure that the product as defined continues to comply with the requirements of certification. It shall include but not limited the following:

2.3.1. Procedure for competency and qualification of all personnel involved in the manufacturing of the 3D Printing Concrete Mix process and intended application.

2.3.2. Procedure for selection and evaluation of all raw materials used in the manufacturing of the 3D Printing Concrete Mix.

2.3.3. As applicable, a procedure for maintenance, control, and calibration of monitoring devices and all equipment used in the manufacturing and control of the 3D Printing Concrete Mix.

2.3.4. As applicable, a procedure for the 3D Printing Concrete Mix design in accordance with the performance required for the elements to be 3D printed.

2.4. All Records Related to Technical & Management Requirements Shall be Maintained.

3. Initial Audit

3.1. Quality Management System Audit

3.1.1. Initial audit shall be carried out by duly authorized auditor(s) in line with the guidelines of ISO 19011- Guidelines for Auditing Management Systems, which will cover auditing the applicable clauses of the quality management system to verify its compliance with the requirements of ISO 9001, in addition, to verify the implementation of DM Certification Body requirements.

3.1.2. Where deemed necessary; the audit could also be carried out remotely as per [DM-DCLD-RD-DP21-2098 (IC) Guidelines for Remote Audit], or as per the related approved guidelines, which are followed by the approved outsourced CAB.

Note: An independent certification to ISO 9001 issued by a QMS certification body recognized by DM Certification Body may be considered as having satisfied this requirement. However, DM Certification Body may still opt to carry out a verification audit to confirm that the factory is complying with the requirements of the certification schemes and rules, mainly the areas of

production and monitoring stages of product realization, quality control and final product testing and evaluation.

3.2. Production & Quality Control Audit

3.2.1. Authorized auditor shall audit the applicant/client's implementation of a factory production control (FPC) system; to ensure that the 3D Printing Concrete Mix conforms to the declared performance characteristics. The FPC system shall comply with the below provisions (clauses 3.2.2 and 3.2.3) in addition to those under clause [2.3] above.

3.2.2. It shall consist of procedures, inspections, and tests to control all aspects of design and manufacturing from checking raw materials up to delivery and acceptance by the client of the finished product.

3.2.3. The FPC system shall cover the following:

A. Personnel

The applicant/client shall be able to demonstrate that the personnel assigned to carry out tasks that will affect the quality and conformity of the finished product have the appropriate competencies, responsibilities, and authorities.

- Tasks and responsibilities shall be documented.
- Competencies and training records are maintained including the qualifications of the operators and all other personnel involved in the process of the 3D Printing Concrete Mix.
- Training needs are identified, and training plans are prepared and implemented.

B. Equipment

The client shall be able to demonstrate that equipment influencing the manufacturing of the 3D Printing Concrete Mix is verified/ and or calibrated, inspected, and properly maintained. Maintenance, calibration, and inspection procedures shall be documented. All related records shall be retained for a period defined in the applicant/client FPC procedure.

C. 3D Printing Concrete Mix Design Process

The FPC system shall ensure compliance with the design brief; identify the procedures for checking the calculations and those relevant to the individuals responsible for the design. The records shall be sufficiently detailed and accurate to demonstrate that the product design has been carried out satisfactorily.

All design records shall be retained for a period defined in the applicant/client FPC procedure.

D. Constituent Raw Materials & the Finished 3D Printing Mortar.

The applicant/client shall have a system for verifying and ensuring that constituent/raw materials, in addition to the resulting 3D printing Concrete Mix, conforms to the specifications in accordance with acceptable set limits and tolerances that are specified in the internal set specifications and FPC.

The specification for the constituent/raw materials shall include, but not limited to all the following FPC procedures:

- Purchasing and sales procedures established, documented, and implemented.
- Incoming raw materials inspection and quality control procedures of both raw materials and finished product.
- Product identification system and traceability are maintained.
- All procedures are followed, and related records are maintained.

E. Manufacturing Process

The client shall maintain detailed documented procedures for the manufacturing process of the product in compliance with the relevant provisions in this guideline.

F. Non-Conforming Products

The applicant/client shall have written procedures that specify how to deal with non-conforming product/process. Such events shall be recorded as they occur, and these records shall be kept for the period defined in the manufacturer's written procedures.

4. Product & Material Evaluation

4.1. All quality control tests shall be defined in the FPC plan and conducted on the raw materials and the product.

4.2. All tests must be performed during DM certification body initial, or surveillance audit based on the official declaration submitted by the client/applicant. These tests must be performed on both freshly printing 3D Concrete Mix and hardened 3D printing Concrete Mix (as applicable) at a specified age in accordance with declared testing Methodologies /Standards.

4.3. The following tests shall be carried out during the initial audit and evaluation on the 3D printed Concrete Mix:

a. Dry Bulk Density
b. Adhesion
c. Capillary Water Absorption
d. Workability Test.
e. Flexural strength test.
f. Compressive strength test.
g. Stiffness

h. Water Absorption Test.
i. Chloride Migration Test.
j. Chloride Content
a. Sulphate Content

4.4. The 3D printing Concrete Mix manufacturer shall carry out a trial mixes during the initial audit and perform required tests as per the declared parameters to assure product conformity and compliance.

4.5. The manufacture of the 3D printing Concrete mix shall have a full listing of the quality control tests to be carried out on different raw materials, with an established acceptable set of control limits, tolerances and test methods followed.

4.6. The applicant/client is fully responsible for ensuring consistency and conformance of the 3D printing Concrete Mix as per this guideline and any other relevant rules and provisions set by Dubai Municipality.

4.7. The 3D printing Concrete Mix design might be further verified by DM certification body in any of its approved independent laboratories.

E.4. Granting the DCLD Certification

1. Conditions for Granting the Factory Certification of Conformity & the DCLD Conformity Mark to Applicant

1.1. The applicant/client shall be granted the factory certification of conformity and authorized to use the DCLD Conformity Mark. Once the results of the initial audit (Clause [3] – Section 1) and the product evaluation (Clause [4] Section 1) show conformity to the requirements specified in the General Rules and this general guideline.

2. Issuance of the Factory Certification of Conformity & DCLD Conformity Mark

2.1. If the conditions mentioned in clause [1.1] above have been complied, and the applicable fees have been paid, the applicant/client shall be issued the factory certification of conformity and a Scope of Certification that covers the scope of activities for which the client has been assessed and found in conformance with this specific guideline and any additional provisions set by Dubai Municipality

2.2. The applicant/client shall also be authorized to use the DCLD Conformity Mark, wherever applicable; in accordance with the Terms and Conditions for the use of the mark, (refer to clause [1.4 below]).

2.3. The factory certification of conformity and the authorization of the use of the mark shall be valid for [1] one year and may be renewed subject to continuing compliance with the certification requirements and satisfactory results of the periodic surveillance audit.

3. Responsibilities of the Certified Applicant / Client

3.1. The applicant/client shall ensure that his product/process for which the DCLD Certification has been granted, always conforms to the requirements of the General Rules and this general guideline and shall maintain - to the satisfaction of DM certification body- the approved factory production control system.

3.2. The applicant/client shall give the duly DM authorized auditors, access during working hours, without prior notification, to the premises of the factory or any other locations of the certified products' activity, for the purpose of evaluating the materials, production processes, finished products, quality assurance facilities, records, and others, in accordance with the requirements of this guideline and any other relevant requirements set by Dubai Municipality.

3.3. The applicant/client shall inform the DM certification body in writing of any change of management, transfer of plant site, modification in the product, manufacturing process or factory quality management system.

3.4. Upon transfer of the plant site, the DCLD certification shall be deemed valid only after the audit at the new site has been satisfactorily completed.

3.5. Any infraction stated in the Terms and Conditions for the use of DCLD Conformity Mark shall constitute sufficient grounds for suspension, withdrawal, and termination of the DCLD certification in accordance with DM-DCLD-RDDP21-2070 (IC) Suspension, Withdrawal and Termination of Certification.

3.6. Any dispute that may arise in connection with the Terms and Conditions of the certification scheme shall be settled in accordance with DM-DCLD-RD-IC-0026 – Guidelines/Appeals Disputes and Complaints Procedure

3.7. The applicant/client shall pay all applicable fees related to the certification process.

4. Use of the DCLD Conformity Mark

4.1. The design and use of the DCLD Conformity Mark shall be in accordance with DM-DCLD-RD-DP21-2069 (IC) Terms and Conditions for the Use of the DCLD Mark

4.2. The applicant/client shall submit samples of label/tag showing the DCLD Conformity Mark, for approval by the DCLD-CQPS. The proposal shall include drawings and/or diagrams showing the location and size of the marking.

4.3. The authorization to use the DCLD Conformity Mark is non-transferable.

E.5. Surveillance

1. DCLD-CQPS or their authorized auditor shall carry out periodic surveillance to ensure consistent compliance with the requirements of this certification scheme as per DM-DCLD-RD-DP21-2096(IC) Surveillance of Certified Clients under the Factory Assessment Scheme.
2. If applicable, the surveillance shall include testing of the product in accordance with the independent testing plan that has been agreed upon between DM certification body and the applicant/client.

8. Normative References and Standards

1. ISO 9001, Quality Management Systems - Requirements
2. ISO 19011, Guidelines for Auditing Management Systems
3. DMS-026, Technical Requirements for the operation of Ready Mixed Concrete Plants, Dubai Central Laboratory Department (DCLD), Dubai Municipality
4. ISO/ASTM 52900, Additive manufacturing — General principles —Terminology
5. ACI 304: Guide for Measuring, Mixing, Transporting, and Placing Concrete
6. BS EN 206: Concrete - specification, performance, production and conformity
7. ICC-ES AC 509, Acceptance Criteria for 3D Automated Construction Technology for 3D Concrete Printed Walls
8. ASTM C31, Standard Practice for Making and Curing Concrete Test Specimens in the Field
9. ASTM C109, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)
10. ASTM C157, Standard Test Method for Length Change Of Hardened Cement Mortar And Concrete
11. ASTM E518, Standard Test Methods for Flexural Bond Strength of Masonry

Note: Equivalent standards can be considered subject to the review and approval of the respective departments at Dubai Municipality.