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Aditivna proizvodnja v gradbeništvu - Kvalifikacija - Strukturni in infrastrukturni elementi (ISO/ASTM/DIS 52939:2022)

Additive Manufacturing for construction - Qualification principles - Structural and infrastructure elements (ISO/ASTM/DIS 52939:2022)

Additive Fertigung für das Bauwesen - Grundsätze der Qualifizierung - Struktur- und Infrastrukturelemente (ISO/ASTM/DIS 52939:2022)

Fabrication additive pour la construction - Principes de qualification - Eléments de structure et d'infrastructure (ISO/ASTM/DIS 52939:2022)

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Additive Manufacturing for construction — Qualification principles — Structural and infrastructure elements

Fabrication additive pour la construction — Principes de qualification — Eléments de structure et d'infrastructure

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The committee responsible for this document is ISO/TC 261, Additive manufacturing, in cooperation with ASTM Committee F42, Additive Manufacturing Technologies, on the basis of a partnership agreement between ISO and ASTM International with the aim to create a common set of ISO/ASTM standards on Additive Manufacturing

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Introduction

The construction sector is increasingly facing challenges with respect to labour shortages, project delays, increased lead times, excessive material use, large amounts of waste and adverse CO_2 footprint impacts. Furthermore, from a market perspective, the global construction demand is increasing especially as the housing crisis continues and infrastructure projects (whether new or sustaining existing structures) are on the increase. Additive Construction (AC) is capable of addressing all of these issues directly. Synonyms such as Additive Manufacturing (AM) and 3D Construction Printing (3DCP) are also used in the industry. Within this standard, the term Additive Construction is used.

Of recent, AC has made great strides. Printed elements could potentially prove to be more durable, more sustainable, more eco-friendly, cheaper (en masse), and faster to deliver than conventional construction approaches. However, without AC standard, approval, certification, and especially risk mitigation is unattainable.

The focus of this document is to outline the requirements necessary as a basis for production and delivery of high quality additively manufactured structures (residential or infrastructure) in the construction sector.

Important steps relating to the AC process are defined, which are to be controlled and monitored in order to ensure high quality printed structures whether on or off-site. This document is not intended to be technology or material specific, and therefore sub-processes are applicable or can be disregarded, depending on the approach used. It should be noted however, printed element(s) will need to be approved by a locally certified engineer and adhere to local/regional specifications and requirements.

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Additive Manufacturing for construction — Qualification principles — Structural and infrastructure elements

1 Scope

This document defines quality assurance requirements for Additive Construction (AC) concerning building and construction projects in which additive manufacturing techniques are used for construction. The requirements are independent of the material/materials and process category used.

This document specifies the criteria for additive construction processes, quality-relevant characteristics, and factors along AC system operations. It further defines activities and sequences within an AC cell (Additive construction site) and project.

This standard applies to all additive manufacturing technologies in building and construction (load bearing & non load bearing), structural and infrastructure building elements for residential and commercial applications and follows an approach oriented to the process.

Environmental, health and safety aspects that apply to printing facility setup, material handling, operating of robotic equipment, on-site and/or offsite printing, and packing of equipment and/or elements for shipping are not covered within this standard but should be applied based on material supplier guidelines, robotic solution operating guidelines, and local and regional requirements.

Design approvals, material property characterisation and testing are not covered in this standard.

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2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 21930, *Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services*

ISO/ASTM 52950, *Additive manufacturing — General principles — Overview of data processing*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/ASTM 52900 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
Additive Manufacturing for Construction (AMC)
process to join materials to make structural and non-structural elements/components and systems from 3D model data usually by depositing material layer upon layer as opposed to subtractive and formative manufacturing methodologies

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3.2
Additive Construction (AC)
term to describe all relevant disciplines and knowledge for the construction segment using Additive Manufacturing and 3D printing technologies

Note 1 to entry: The use of the technologies covers all relevant construction sectors, e.g. large scale real estate projects, entire buildings and building elements, civil infrastructure, and disaster relief.

Note 2 to entry: AC describes all relevant knowledge disciplines, for example: architecture, engineering, structural engineering, materials engineering, robot operator, project management, construction management, facility management, etc.

Note 3 to entry: other terms used interchangeably are: Digital Construction (DC), Construction 4.0, Advanced Manufacturing in Construction (AMC), Construction 3D Printing (C3DP) and 3D Construction Printing (3DCP).

Note 4 to entry: building materials include:

— Cementitious variations such as concrete and mortar, polymer modified pastes,

— Composite materials.

Note 5 to entry: intrinsic to the current definition is a high degree of robotic automation, a low degree of human intervention during the construction process, and minimal waste due to as-needed material delivery systems.

Note 6 to entry: as of this writing in 2022, the field of AC is rapidly evolving, and novel materials and methods are very likely to become included in this definition.

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3.3
AM System Operations
plant/solution which maps the Additive Construction System in operation for end applications

EXAMPLE Industrial AC service provider or internal department of larger company, or an AM Cell solution with an end-to-end approach.

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3.4
Layer deposition
application of a single layer

3.5
AC Cell
printing solution deployed on site for in-situ printing (includes material mixing and placement systems)

3.6
Material deposition device
assembly including delivery mechanism for material and/or binder and deposition nozzle(s)

3.7
Physical production
the physical totality of the build space, elements located on the build space, and production related support structures in the build space of the system

3.8
Virtual production run
computer/digital simulation of the physical production run (build job)

EXAMPLE Printing simulation.

3.9
Dry production run
process of running the build program with no materials to verify the first layer toolpath and other critical points of the program; and can be part of calibration process

EXAMPLE Toolpath

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3.10
Construction process
process encompassing all digital and physical construction steps through to completion of the final part, including the quality control

3.11
MEP
acronym used in the construction sector and stands for "Mechanical, Electrical and Plumbing"

3.12
Printed element
construction 3D printed component that gets incorporated into a building or structure, is a complete infrastructure component

EXAMPLE Walls, columns, beams, etc.

3.13
Printability
ability of the material to be easily delivered to the print head, processed by the print head (e.g. extrudability) and meet layer shape, stability, buildability requirements, and if applicable pumpability

3.14
Extrudability
ability of the material to smoothly be ejected through the printing nozzle without inducing any blockage of the conduits or significant damage to the material quality

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3.15
Layer Shape Stability
ability of the deposited layer to preserve its shape and withstand the increasing loads coming from superposed/subsequent layers with controlled deformation

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3.16
Buildability (Print Stability)
ability of a print to preserve vertical and lateral stability under increasing loads coming from superposed/subsequent layers with controlled deformation

4 Constructability, Assessment and Review

4.1 General

Verification of the AC element requirements shall be performed before the data preparation. The results shall be transferred in a definite sequence with associated production specifications including specific requirements in respect to the quality control (for load and non-load bearing elements). It is recommended that any asset monitoring and/or management be based on locally applicable standards/codes/regulations which could be based on numerical verification analysis.

If the production request is incomplete (for example missing technical drawing) or an initial commissioning is associated with restrictions, the customer shall be notified in an effort to correct the problem.

Figure 1 shows the individual steps for checking the feasibility and qualification phase as a pre-requisite for the serial production with AC.

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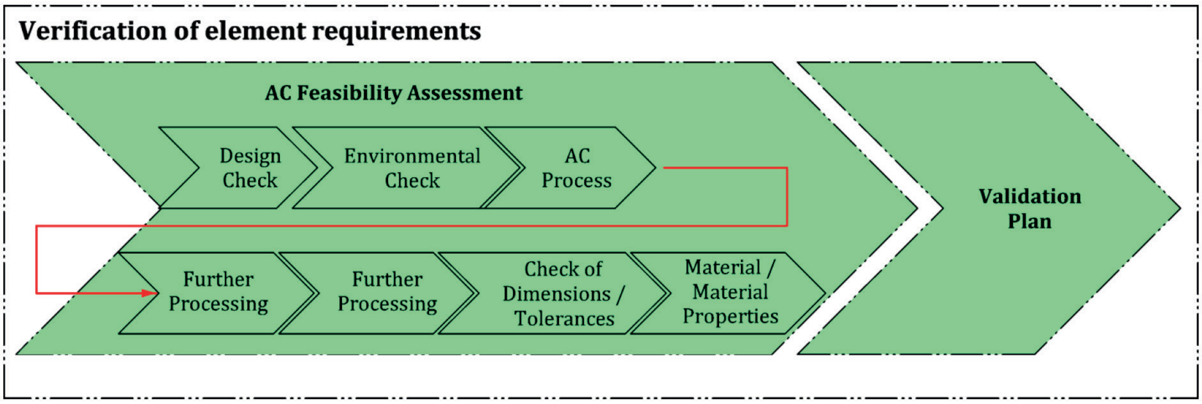

Figure 1 — Steps involved in verification of AC element requirement

4.2 AC feasibility assessment

The AC feasibility shall be checked by suitable personnel (e.g., technology experts or instructed persons), the necessary production competence is only available in the direct AC environment. It is important to include all element requirements in the feasibility check.

1. **Design check**: the process-relevant design directives should be consulted to evaluate the design's AC feasibility. In addition, process-relevant AC restrictions such as minimum wall thicknesses shall also be taken into consideration.

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2. **Environmental Check**: for the environmental dimension, material selection and design stages are regarded as crucial to the sustainability performance of a built element throughout its life cycle. It is important to perform a sustainability assessment of the building material or the building product itself, according to ISO 21930 following a *cradle-to-grave* approach of a life cycle analysis (LCA) and track macro-indicators, for both internal use and to elaborate Environmental Product Declarations (EPDs) of building products after validation.

   Core indicators to use are:

   — Global warming potential (CO_2 equivalent emissions) - greenhouse gas (GHG) emissions that have a potential impact on the climate.

   Other relevant indicators may be:

   — Pollution potential: Freshwater resources that have a potential impact on the depletion of freshwater resources;

   — Fossil fuel depletion potential (oil equivalent): consumption of non-renewable raw materials and non-renewable primary energy;

   — Ozone depletion potential (CFC-11 to air): release of gases that have a potential impact on the stratospheric ozone layer;

   — Amount of waste generated by type: total volume of non-hazardous and hazardous wastes that has a potential impact on the generation of waste for disposal acidification potential (SO_2 to air) - potential impact on the acidification of land and water resources;

   — Freshwater eutrophication potential (P to freshwater): potential impact on the eutrophication of water bodies.

3. **AC process**: it is also necessary to check whether the desired element, and element properties to be attained, are AC feasible with the process parameters already qualified, or whether adaptations are necessary to attain AC feasibility. This should fall under the responsibility of the AC engineer. AC

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Specific Process category risks need to be evaluated to achieve dedicated component requirements. Refer to Table A.1 - *AC Technology and Material Legends* for specific processes and materials.

4. **Further processing**: if a further (semi-)automated manufacturing step occurs, it is necessary to check whether the design is appropriate for this, if auxiliaries cannot be used. If subtractive or finishing processes are then carried out in order to attain the required manufacturing tolerances, corresponding design details shall be provided as early as the data processing, if necessary.

5. **Check of dimensions/tolerances**: the tolerances specified in the design shall be attainable in the selected AC process. Post-treatment, this shall be taken into account before the start of the AC process.

   EXAMPLE 1 Any special considerations for reinforcement and/or MEP integration, starting/stopping/skipping in the AC process.

6. **Material/Material properties**: the AC feasibility shall be considered beyond the selected technology, depending on the material over the entire AC process. The specified material properties shall be incorporated here. Local standard tolerances for fire load, tension, shrinkage, creep, etc. should be followed.

   EXAMPLE 2 Materials that exhibit different AC constraints.

An individual element evaluation shall then be conducted in order to define the necessary measures for quality assurance. Based on the method for quality assurance already implemented as well as the risk analysis for the relevant application, it is necessary to check whether separate measures for element-related quality control are necessary (see 7.4).

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4.3 Validation plan

The requirements of the direct manufacturing environment include the qualification plan for the series element. The prerequisite is qualification of the material for a definite AC process. A qualification plan shall be formulated for the elements and associated test methods according to the relevant work and/or procedural steps as specified by the customer. The element(s) production is validated in a one to three stage process (see A.2 or ISO/ASTM 52901). Each phase is successfully completed upon signing by suitable personnel.

The methodical recording of the element requirements can be derived from (e.g., ISO/ASTM 52901). This makes it possible to derive which validations can be necessary beyond this document.

5 Infrastructure of the AC cell

The following requirements are relevant for the infrastructure of the AC cell:

1. **Equipment:** all equipment used should comply with local regulations and EHS (Environmental, Health and Safety) standards. As by standards accepted by local jurisdictions. Some examples are listed below:

EN 12001	Conveying, spraying and placing machines for concrete and mortar — Safety requirements
EN 12629-1	Machines for the manufacture of constructional products from concrete and calcium-silicate — Safety — Part 1: Common requirements
EN ISO 4413	Hydraulic fluid power — General rules and safety requirements for systems and their components
EN ISO 4144	Pneumatic fluid power — General rules and safety requirements for systems and their components
EN ISO 12100	Safety of machinery — General principles for design — Risk assessment and risk reduction

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