

DEFINING DEMONSTRATOR PROJECTS FOR DIGITAL FABRICATION (DFAB) ADOPTION IN ARCHITECTURE, ENGINEERING AND CONSTRUCTION (AEC)

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Abstract

Digital Fabrication (DFAB) proposes to increase productivity and digitalisation in Architecture, Engineering and Construction (AEC). Demonstrator projects are used to showcase novel DFAB innovations to disseminate knowledge, learning, and attract future investment to support their transfer from research to commercialisation. Currently, no unified definition of what constitutes a DFAB demonstrator in AEC exists, thus, this paper aims to address that. This offers distinction to the phenomenon reflecting its real-world context, subsequently effecting how humans think and act on it. A definition is proposed based on analysis from literature and interviews to inform future studies on DFAB demonstrator projects in AEC.

Introduction

Architecture, Engineering and Construction (AEC) is the world's largest industry by share of gross domestic product. However, it is also ranked as one of the lowest in terms of productivity and digitalisation (Ribeirinho *et al.*, 2020). The complexity of AEC sets it apart from other industries (e.g., manufacturing, automotive) due to the individuality of each built asset's design and construction needs based on unique (site) conditions and stakeholder requirements (Garcia De Soto *et al.*, 2018). One systemic innovation proposed as a solution to increase productivity and digitalisation in AEC is Digital Fabrication (DFAB). DFAB is pushing the boundaries of creativity, design and construction of the built environment and is seen as a building block of realising the digital transformation of AEC into Construction 4.0 (Graser, 2023). Examples of DFAB in practice include the MX3D Printed Bridge, a robot printed steel structure once located in Amsterdam's Red Light District in the Netherlands (Figure 1); and DFAB House, the world's most comprehensive demonstration of DFAB in the AEC domain (Figure 2).

DFAB is “a fabrication or building process driven by the seamless conversion of design and engineering data into fabrication code for digitally controlled tools” (Gershenfeld, 2012, cited in Kaseman and Graser, 2020, p. 189). A relatively new field of innovation, DFAB was initiated to AEC in Japan in the 1980s with the deployment of robotics systems to automate and standardise the construction of buildings (Kaseman and Graser, 2020). It is described as a system-level innovation



Figure 1: MX3D Printed Bridge, Amsterdam, The Netherlands (Arup, 2025)

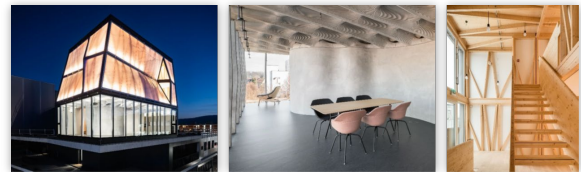


Figure 2: DFAB House, Dübendorf, Switzerland (Graser, 2023)

that combines digital design with advanced manufacturing technologies to automate construction activities and enhance the quality of built assets (Ng, Graser and Hall, 2023). Today, it is seen as a potential solution to solve some of the AEC industry's most pressing issues, such as the need to build more sustainably (Khadim *et al.*, 2023), increase productivity in light of a stagnant workforce (Mischke *et al.*, 2024), and increase digitalisation (Alsharef *et al.*, 2024) to increase efficiency. Digital technology adoption has been found to have positive effects on economic, social and environmental performance (Li *et al.*, 2022).

Despite the positive outlook for DFAB, it has yet to achieve mainstream adoption across the AEC industry due to a “large gap between research feasibility and industry adoption” (Graser, Kahlert and Hall, 2021, p. 853). This gap is often related to socio-technical factors such as business models and processes, integration into existing practices, product architecture and organisational structures (Graser, Kahlert and Hall, 2021). Ng *et al.* (2022) offer several reasons for this including the need for a new level of systemic thinking to seamlessly integrate the design and construction processes that requires “more detailed knowledge, participation, and computation than

traditional craft production”, and the lack of understanding of DFAB as a “*standardized process or an integrated digital system*” (Ng et al., 2022, p. 1).

Demonstrator projects

Demonstrator projects are one way the prevailing challenges of integrating DFAB into AEC praxis are being addressed. They constitute a phase in technology development that provides a vehicle to showcase technologies, methods and processes beyond the research boundary to attract interest and further investment with the goal of transferring innovations to industry and commercialisation. Moultrie (2015) describes demonstrator projects as *boundary objects* acting as a mediator between different social actors. They typically embody some level of risk (e.g., technical, production, commercial, operational), and require substantial investment (Aaron and McGill, 2012). They are receiving increasing attention as evident in literature where many demonstrator projects are published (e.g., in the FABRICATE series whose focus is on the integration of digital design and manufacturing processes (FABRICATE, 2025); and international exhibitions such as the International Architecture Exhibition, established in 1980 as part of La Biennale di Venezia, that showcases some of the world’s cutting edge architectural solutions to address the most pressing challenges seen in society and the built environment (La Biennale di Venezia, 2024)). Despite their growing application to demonstrate the potential of new technologies, methods and processes, demonstrator projects are often discussed as failures as vehicles to facilitate transfer of innovations from research to industry (Sjöo and Frishammar, 2019), and there is limited literature on the objective, types and designs of demonstrator projects (Bobbe et al., 2023). In addition, their focus is often on technical feasibility but omits the social aspects that are required for the success of a new innovation (Graser, 2023; Preston, Sujun and Habli, 2025).

Despite these challenges, application of demonstrator projects in the development of new technologies including DFAB is increasing. They are an effective method of exploration, their implementation increases acceptance (if not yet adoption) of DFAB in AEC, and they are instrumental in the establishment of a new praxis for DFAB (Graser, 2023). Given this growing attention, this paper aims to provide a comprehensive definition for demonstrator projects in the domain of DFAB in AEC. It does so by evaluating current understanding of demonstrator projects generally through literature, and engages with researchers and practitioners of DFAB in AEC specifically. Providing a useful definition is an important step in enhancing understanding of demonstrator projects’ philosophical role for DFAB in the AEC community. Definitions provide “*distinctions that mirror common language use and real-world phenomena while paying special attention to context and implications*” (Mitcham and Schatzberg, 2009, p. 27). The act of “*sorting out, classifying, and defining [...] remain fundamental to human acting and thinking*” (Mitcham and

Schatzberg, 2009, p. 56). The research question for this paper is therefore: *How do we define demonstrator projects for DFAB in AEC to enhance understanding of their purpose in the transfer of DFAB innovations from research to commercialisation?*

The remainder of this paper is structured as follows: the next section presents the methodology adopted for this paper, then definitions for demonstrator projects are presented. Following analysis, a comprehensive definition for DFAB demonstrator projects in AEC is proposed and its implications discussed. Finally, the paper is concluded.

Methodology

As there is little literature available on the topic of demonstrators and even less on demonstrators in DFAB for the AEC industry, this research adopts an interpretivist epistemology to uncover new theory around the practice of demonstrators. The study adopts a qualitative research enquiry that engages with researchers and practitioners with experience of demonstrators in DFAB. The steps taken to conduct this study are shown in Figure 3.



Figure 3: Methodology

First, a traditional literature review was conducted to identify any existing definitions of demonstrator projects in DFAB and beyond. The criteria for selecting papers included: demonstrator projects as the main subject of the paper, inclusion of a definition of demonstrator projects, and related to the production of something physical (i.e., this study is not concerned with software demonstrations). Then, semi-structured interviews were conducted with participants of the DFAB House demonstrator to understand what they believed their notion of the purpose and effects of a demonstrator to be. The interviews were conducted as part of a wider longitudinal study of DFAB House and to establish a methodology for DFAB demonstrator projects in AEC. However, the scope of this paper is concerned only with defining demonstrators and, therefore, only one question related to this subject is included here: *How do you define a demonstrator project in the context of DFAB in AEC?* DFAB House was chosen as the case study as the most comprehensive representation of the use of DFAB in AEC to date (Graser et al., 2020). DFAB House combines six different DFAB objects as a demonstration of some of the leading advances in DFAB showcasing its feasibility and potential to the global community.

The sample included eight academics and one client (specific roles can be seen in Table 1), selected for their work on DFAB House during its design, development and/or construction, and because some were previously interviewed for a study on DFAB House shortly after its completion as they form part of the longitudinal study. The interviews were recorded and transcribed in Microsoft Teams and the interviewees were asked to approve the transcript post processing. Relevant

Table 1: Definitions of demonstrator projects in literature

#	Reference, domain	Definitions
R1	Aaron and McGill (2012), defence/public services	“short term projects (or project activities) that help demonstrate the level of maturity of technologies in support of capability management decisions” (UK Ministry of Defence cited in Aaron and McGill, 2012, p. 2).
R2	Bobbe et al. (2023), Internet of Things (IoT) and robotics	“(a) an embodiment or representation, (b) of a hypothesis about the future and (c) that is communicated to a specific audience” (p. 4); “an artefact which is created during the scientific process to support science itself, but also the dissemination and communication of it” (Moultrie, 2015, cited in Bobbe <i>et al.</i> , 2023, p. 2).
R3	Graser (2023), AEC	“tools of digital fabrication research and development: Demonstrator projects implemented on the construction scale span the boundaries of research and implementation practice, usually focusing in-depth on a single building system or fabrication technology” (p. 7).
R4	Husain, Wehrmeyer and Reeby (2023), demonstrator projects	“the process by which new thinking is tried and tested at scale and proactively communicated to target audiences, in order to improve processes, products, and services” (p. 32).
R5	Karlström and Sandén (2004), fuel cells and hydrogen supply systems for public transport vehicles	“a finite initiative to test hypotheses about a technology” (p. 287); “a finite initiative to test a technology according to the project objectives. [...] The project starts with a conceptual design and by deciding project objectives. It ends when the technology is implemented and the results are evaluated and communicated” (p. 287).
R6	Moultrie (2015), design	“technological prototypes which are close to market” (p. 2).
R7	NASA (2023), space exploration	TRL 6: “System/sub-system model or prototype demonstration in an operational environment”; TRL 7: “System prototype demonstration in an operational environment”.
R8	Sjöö and Frishammar (2019), sustainability transitions	“‘technological infrastructures’ often intended for multiple uses by a number of actors (rather than being geared towards one firm)” (p. 331); “they ‘bridge’ basic and small-scale knowledge generation in laboratories with large-scale industrial application and commercialization” (p. 331).
R9	Stelvaga and Fortin (2022), aerospace	“a project devoted to the development of a functional piece of technology with the goal of showing its capabilities” (p. 275).
R10	Sviridova and Verlinden (2023), product development and industrial design	“at least a partially physical one-off design object that facilitates the interests of designer, client, user, and technology, and communicate them to the audience in an interactive way” (p. 950).

responses to the question asked above were extracted and put into a table to allow for coding and content analysis to be performed along with analysis of the definitions found in literature. This consisted of finding recurring terms and phrases across both sets of definitions as well as identifying any terms and phrases that are applicable. The terms and phrases were then examined to establish whether they were indeed relevant for the domain of DFAB in AEC and the results were formulated into a comprehensive definition.

Defining demonstrator projects for DFAB in AEC

Finding a unified definition for DFAB demonstrator projects is challenging, in part because many projects have the intention of ‘demonstrating’, e.g., a new method or process (Husain, Wehrmeyer and Reeby, 2023), but they are not necessarily a demonstrator project per se. For example, a prototype project can be used to demonstrate something but the scale of development cannot yet be considered a demonstrator project. In current literature, terms are often interchangeable, such as in Wang, Hunhevicz and Hall (2025) who refer to both demonstrator and prototype, without clearly defining

either; the Rijksdienst voor Ondernemend Nederland (the Netherlands Enterprise Agency) (RVO, 2025) indicates use of the Technology Readiness Levels (TRLs) system and refers to demonstration of a prototype (TRL 7), which mixes terms; and often demonstrators are not defined by papers that write about them, which could mean a) authors assume the concept is understood by the reader, or b) the authors are unsure themselves of how to define them.

The literature review conducted for this study found only one paper with a definition in the context of AEC. To supplement this, definitions were found in papers from other domains bringing the total to 10. The definitions along with the domain to which they belong can be seen in Table 1.

To ensure the study’s ability to position demonstrators specifically in DFAB in AEC, interviews were conducted with people who had been involved in the DFAB House project. The participants responses are shown in Table 2.

Analysis and discussion

Across these two sets of definitions, there are several recurring themes that appear to be relevant to formulating a comprehensive definition for DFAB demonstrator projects in the AEC domain. Relevance was determined

Table 2: Direct quotes from interview participants on the definition of demonstrator projects for DFAB in AEC

Interviewee	Definitions
P1: project manager	“the use of a digital or digital fabrication technology, or method, on the full scale, meaning the scale of buildings, and I think it needs to be in an environment that resembles the process of construction”; “in the technical sense, a demonstrator is usually something you do once the technology is already at a certain [TRL] level and the demonstrator is basically your final proof”.
P2: researcher	“the demonstrator is one way to prove the feasibility of a certain approach, maybe a technological methodology or a complicated workflow”; “first and foremost, geometric scalability”.
P3: researcher	“an attempt to show that this is not just an academic exercise, and that there is the possibility to do something with a meaningful scaling”; “it has to leave the lab, but it can be produced in the lab”.
P4: client	“takes technology, systems, materials, concepts from a laboratory level to a near market level”.
P5: PI	“a real world installation involving the outcomes so that the finished research is demonstrated”; “something that goes beyond the function of a demonstrator; it is actually something that demonstrates by using the research outcomes”; “it would ideally be something that is then also in use”; “the confrontation of research with the real world scenario”; “a demonstrator should be out of the lab”.
P6: PI	“an attempt to benefit from the challenges of transferring research to application very early on in research by actually making the full scale application of digital fabrication”.
P7: PI	“it needs to be enough to leave the lab”; “there is an expectation to the outcome that is beyond only demonstrating literally a new technology, so that you add the challenge of giving it a function, either a more infrastructural and architectural and engineering kind of function perhaps”; “the threshold of a demonstrator project: did you have to face the real conditions? So even though the client is set up, even the budget might be not typical, but at least all the other aspects like building codes and stuff like that”; “demonstration is challenging your concept to a real scale”.
P8: member of NCCR DFAB (role hidden to maintain anonymity)	“It's a demonstration of the innovation that you've created, but it's also a demonstration that you or the surrounding team around you know how to make that thing and make it ready for the real world”; “a demonstrator is a proof-of-concept, whereas a prototype is a development of an idea. A prototype is a working document, and a demonstrator is the document itself, it's the finalised version of the document”; “in DFAB, a demonstrator has industry partners working on it. That's a major difference between a prototype and a demonstrator, that you engage people who are going to learn from this demonstration already in the making of the demonstrator”.
P9: member of NCCR DFAB (role hidden to maintain anonymity)	“a demonstrator project is whether it's with or without industry, but usually it's with industry, is that you upscale from the lab scale to the real scale, to the one-to-one construction site scale. And demonstrator project means actually to demonstrate that all the processes work out at the larger scale”; “to demonstrate that all the processes can work in reality given the building codes and other constraints”.

by frequency of occurrence (set as a minimum of two) as well as recognition of importance from the authors based on their knowledge and experience of the topic. The results of the coding process are shown in Table 3 ordered in terms of frequency.

While many of the definitions from literature are specific to the subject of the individual publication, the material aspects of them can be applicable to other fields, i.e., AEC. The interviewees' definitions are more specific to the AEC context, but could equally be applicable outside of that if reference to, for example, buildings and the construction site are removed. The themes are described below in order of frequency as they appear in Table 3, not necessarily in order of importance.

Scale: many of the definitions explicitly refer to the scale of the demonstrator project mentioning full- or one-to-one scale. This scaling is what provides the technology, method or process the experiential learning of transitioning outside of the laboratory context, such as the

requirements to move from research to production at scale for mainstream adoption and commercialisation.

Environmental context: demonstrators take place in an environment that exposes the potential innovation to real-world risks and challenges that cannot be experienced in a laboratory including but not limited to permitting, regulations, and site conditions.

Maturity and readiness: demonstrators provide an opportunity to demonstrate readiness of a technology, method or process, as well as an opportunity for learning during the project. The project forces the concept to be implemented in a real-world context that it has not yet seen in the laboratory. Thus, a concept may increase its maturity and readiness through the demonstrator process.

Inter- or trans-disciplinarity: as a boundary object, demonstrators bring different disciplinary actors together to co-create. At some point in the project, all parties contribute to the production of an artefact and through doing so contribute to the knowledge created and learning

Table 4: Coding of literature and interview definitions of demonstrators

Code	Occurrence	Frequency
Scale	R3 R4 R8 P1 P2 P3 P5 P6 P7 P9	10
Environmental context	R3 R7 R8 P1 P3 P5 P6 P7 P9	9
Maturity and readiness	R1 R6 P1 P2 P4 P8	6
Inter- or transdisciplinary	R3 R8 R10 P8 P9	5
Communication and dissemination	R2 R4 R5 R9 R10	5
Functionality	R8 R9 P5 P7	4
Novelty	R4 R10 P7	3
Social feasibility	R4 P7 P9	3
Temporality	R1 R5	2
(Hypothesis) testing	R2 R5	2

experienced. The level of disciplinarity often occurs at the higher end of the disciplinarity scale i.e., interdisciplinary or even transdisciplinary projects. This inevitable collision of social groups often occurs at the boundary between research and industry.

Communication and dissemination: demonstrators have the purpose of communicating and disseminating knowledge, learning and level of maturity of the technology, method or process beyond the project team to interested industry practitioners and potential future investors.

Functionality: demonstrators should produce something that has some level of functionality or use beyond the end of the demonstrator project (i.e., the construction phase of the demonstrator) that proves its utility in the real world over a (defined) period of time.

Novelty: a common theme across the definitions is novelty, that what is being demonstrated is offering something new to complement or replace existing praxis, or establish new praxis.

Social feasibility: the focus of demonstrators tends to be on the technical feasibility and often omits the social feasibility. However, as a boundary object, demonstrators force project participants to communicate outside of their day-to-day environment by considering the organisational context, business model(s) and process(es) of implementing a new technology, method or process along with any changes required to current operations.

Temporality: demonstrator projects are short term and finite endeavours.

(Hypothesis) testing: testing is central to demonstrator projects to test hypotheses about research and its ability to meet the project's objectives across many of the themes discussed above, such as scale, readiness, context and feasibility.

Based on the analysis here and the recurring themes identified across the definitions from literature and the

interviews, the following definition for demonstrator projects in DFAB in the AEC domain is proposed:

Digital fabrication (DFAB) demonstrator projects in Architecture, Engineering and Construction (AEC) are finite endeavours of co-creation to materialise the maturity and readiness of a novel technology, method or process. This is done through production and testing of a functional artefact at full scale in a realistic, non-laboratory-based, construction-specific environment.

A demonstrator project spans the boundaries of research and industry to generate knowledge of technical and social feasibility for active communication and dissemination to parties beyond the project team. The goals are to inform industry of the potentials of DFAB, and attract investment for future development to achieve transfer to commercialisation.

To answer the research question: *How do we define demonstrator projects for DFAB in AEC to enhance understanding of their purpose in the transfer of DFAB innovations from research to commercialisation?*, this paper has collected definitions from literature across different sectors (due to a lack of definitions from within the AEC domain) and from AEC-specific researchers and practitioners to establish what the key aspects of DFAB demonstrator projects in the AEC industry are. This has ensured the definition proposed here encompasses the most important aspects of demonstrator projects to provide a comprehensive and useful definition to enhance understanding within research and outward to industry practitioners. In line with Mitcham and Schatzberg (2009), such a definition is important in the discourse on demonstrator projects for DFAB in AEC because definitions offer a distinction to a phenomenon that reflects its real-world context, that can then effect how humans think and act on it. While acceptance of a unified definition remains the longer-term goal for DFAB demonstrator projects in AEC, we propose here a definition designed to be immediately useful across disciplinary contexts and argue that such practical utility is a necessary condition for any definition to eventually achieve wider adoption.

The definition can solidify the purpose of conducting demonstrators for researchers and practitioners by understanding how they fit into the wider process of technology development. What comes before and after a demonstrator project is as important as the demonstration itself to ensure its success. This definition both enhances understanding of DFAB demonstrator projects and encourages a more holistic approach to the development of DFAB in AEC. This is particularly important if we approach it from a *needs* perspective. In a "push" scenario where academia is developing a new DFAB technology, it can support them in their efforts to seek industry buy-in. In an industry-led "pull" scenario where industry is proposing a technology to solve an industry issue, the definition can support them in seeking validation in collaboration with research.

Finally, highlighting that a demonstrator project is a process of co-creation encourages researchers and industry to focus collaboratively on this transitional phase of technology transfer and the mechanisms required for it to be successful.

Conclusions

DFAB is a growing systemic innovation that could contribute to solving some of the AECs most pressing issues such as needing to build more sustainably and increase productivity and digitalisation. However, DFAB requires new systemic thinking to address some of its barriers to adoption, compounded by lack of a unified understanding of DFAB. One phase in the trajectory of technology development is demonstration to support the transfer of DFAB innovations from research to commercialisation. Demonstrator projects are still relatively new in the diffusion of innovations and as a result there is little academic discourse on the subject. This paper is part of a wider study to look at how demonstrators take place, how they create learning, how they play an important part of the research process in DFAB, and how they can be used to increase the transfer of innovations from research into industry and commercialisation. The aim of this paper was to define the role of demonstrators for DFAB in the AEC industry that will form the basis for the wider study, that is to develop a methodology for DFAB demonstrator projects in AEC.

The paper identified several definitions of demonstrator projects in literature, only one of which came from the AEC domain. These were supplemented by interviews with researchers and a client for the DFAB House project. These definitions were analysed and a comprehensive definition for DFAB demonstrator projects in AEC was proposed. This definition can provide a distinction to the phenomenon of DFAB demonstrators that can effect how humans think about and act on it. It is hoped that this definition will provide some consistency for DFAB in the AEC industry to support its understanding as a viable stage in technology development across research and industry and form the basis for a unified definition in the future.

Limitation and future research

While the wider study is a work-in-progress, this paper is limited by the small sample size and skew of interview participants toward the side of research, as opposed to providing a balanced view with the inclusion of more industry practitioners. This will be addressed in the next steps of the study by conducting further interviews with academics and industry practitioners with demonstrator experience, to evaluate the success of demonstrator projects using DFAB House as a case study, and to formulate a methodology for conducting DFAB demonstrator projects in AEC that can a) support students and researchers in their endeavours to innovate in DFAB, and b) support practitioners with the transfer of those innovations to industry and commercialisation.

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