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Early-stage Codesign of a Material Passport for Volumetric Timber Building Components

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Abstract. Typically, the architecture and construction sector struggles to adopt digital innovations. Slow, fragmented, and carbon-intensive, the sector often frames digital innovation as efficiency pathways, disregarding broader socio-cultural or environmental factors that enable digital transitions. In that context, this paper reports the development of a material passport (MP) for volumetric timber components for the British market. To facilitate adoption, we present a codesign methodology that ensures industry input from early stages of development and testing. Fieldwork activity included architectural design professionals, timber supply chain stakeholders, manufacturers, and digital developers. Data have been codified into emergent themes influencing the development of MPs. Early-stage analysis indicates a sectorial complexity in design aspects such as trust and data logging, creation, maintenance, or ownership of MPs. Last, we introduce upcoming development stages comprising testing and further refinement of the MP prototype in the context of two building lifecycles in the United Kingdom.

Keywords: Digital fabrication, Material passport, Prefabrication, Codesign, Buildings as material banks.

1 Introduction

The construction industry is encountering significant issues on its transition to net-zero, including high carbon emissions (Zhang et al., 2020), low productivity (Hasan et al., 2018), and shortages of skilled labour (Forde & MacKenzie, 2006) to name a few. The increasing demand for sustainable and efficient construction practices is driving the development of new technological innovations (Fokaides et al., 2020), however the sector struggles to adopt digital technologies (Sawhney & Knight, 2023). Therefore, developers of digital innovations must consider the complexities and adoption barriers in industry for

successful implementation. A possible pathway explored in this project is the co-development of digital innovation with industry partners, including design, development and validation stages. In that context, we are developing a digital material passport (MP) able to “track and trace” timber building elements. This is part of a project developing digital systems to support small- and medium-sized enterprises (SMEs) entering distributed timber manufacturing supply chains.

In detail, a MP is a digital “live record” that documents the material composition of a building, showcasing embedded materials, lifecycles (Honic et al., 2021), spanning from construction to end-of-life through tracking, reuse, and effective recycling (Honic et al., 2019). Literature comprises multiple approaches to MPs data architecture such as scores related to deconstructability, recovery, and the environment (Atta et al., 2021), product context use and location (Göswein et al., 2022), or assembly and disassembly instructions (Byers et al., 2022). In addition to these variations, there is not an agreed systematic approach to database design when it comes to specific MP solutions. Reported MPs are often developed within specific geographic and regulatory contexts, allowing for adaptive data architectures and implementation scenarios in areas such as waste (Lu et al., 2023) or supply chain management (Wilson et al., 2023).

In this paper we introduce a progress report on the codesign of a MP for timber components for the domestic market of the United Kingdom (UK), with a focus on the fieldwork process and its codification into early-stage data architecture requirements. This is part of the project “100 Factories: Unlocking the collective capacity of local timber MMC manufacturers” in partnership with Open Systems Lab and funded by the UK Forestry Commission (Timber in Construction Innovation Fund). The aim of the project is to develop digital systems that allow SMEs to join distributed housing manufacturing networks, including a MP prototype and a quality control plan for volumetric blocks that compose the Wikihouse building system (Open Systems Lab, 2024) – although we expect results to be replicable across a broader range of timber-based components.

The paper is structured as follows: the methodology section details the participants of the study, data collection methods employed, and analysis techniques. The results section presents the coding structure for the qualitative analysis and code frequency of the collected data. The discussion section interprets these findings in the context of existing literature and industry practices. Finally, the conclusion summarises key insights and implications of the study as well as upcoming research steps.

2 Methodology

The research follows a participatory approach that aims to embed industry perspectives directly within the development of an MP. This approach is implemented through two core strategies: codesign activity, and research ‘in

residence' including on-site prototyping (Sanders & Stappers, 2014) and real-world implementation scenarios with two industry partners. Our codesign planning includes scenarios such as production, assembly, or transport/handover of building blocks. Our initial cycle of codesign fieldwork comprised manufacturers, system designers and assembly staff working with volumetric timber elements. Not only they are aware of the challenges and limitations of current ways of working but have offered insightful feedback on socio-cultural industrial issues (such as fragmentation and lack of trust between businesses) which can affect the implementation, handover, and ownership of ICT adoption (Turk, 2023). Following recruitment of participants, codesign activity has been delivered in-residence – that is, within industry partners' facilities and workshops, and framed by the experimental delivery of two small structures used as a testbed for MPs' implementation. By directly engaging with communities of end users and on-site evidence,

"*research in residence facilitates the translation of outputs into impactful interventions, building relationships that facilitate the coproduction of digital solutions which are sensitive to those users and directly respond to their needs and expectations (Gradinger et al., 2019)*".

This strategy, additionally, follows an institutional research tradition that has successfully delivered digital innovations to communities of end users in the challenge areas of extended reality for heritage sites (Veliz Reyes et al., 2024), care home design for dementia (Burke & Veliz Reyes, 2021), and hybrid digital craft practices (Holmes & Veliz Reyes, 2024).

2.1 Participants

This paper focuses on a first cycle of codesign activity, comprising two types of participants: local SMEs (including owners and CNC operators), and WikiHouse developers. We acknowledge their differing perspectives on MP adoption, either to facilitate industrial processes (local SMEs), or to facilitate the monitoring and use of their building product (developers). There are, however, variations on ways of working recognised in the study: SME roles in the supply chain vary based on their workflows. Generally, they handle the manufacturing and assembly processes, transforming raw timber material into ready-to-build blocks on-site. Their workflows also include communicating with suppliers and arranging transportation to construction sites. In contrast, developers design the modular timber elements, provide cutting files to the manufacturers, ensure structural integrity, make material-based decisions, and update the blocks. Their inputs are valuable for creating and maintaining the database with pre-defined template information, and data such as carbon footprint calculations. Specifically to WikiHouse, Open Systems Lab also maintains a national network of manufacturers which, so far, have developed more than 10 residential projects throughout the UK.

2.2 Data collection

Data has been captured mainly through a series of on-site workshops, each structured similarly based on the availability of participants (Table 1). Most activities have been conducted on-site in order to better understand the practical complexities of each business (Figure 1), with an additional interview conducted online. In total, five industry professionals engaged in the codesign activities: three are direct manufacturers and assemblers of the volumetric timber block elements, planned to undertake the creation of the MPs (MPs) for each block, and two are developers of the system that provides blocks.

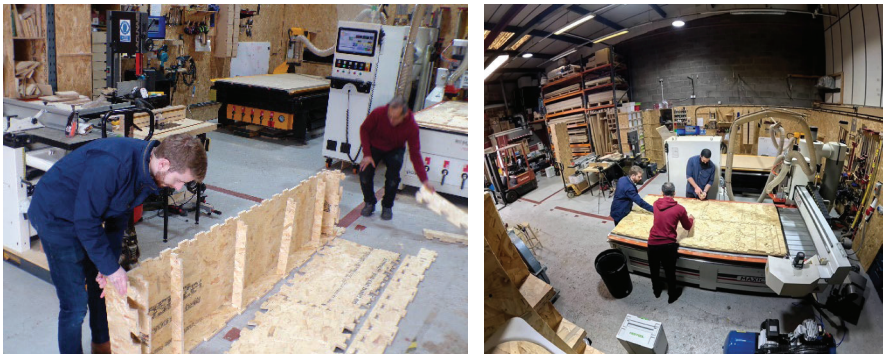

Figure 1. On-site data collection in a SME in Leicester, UK. Source: Olmez, 2024.

Table 1. Summary of collected data. Source: Olmez, 2024.

When	Whom, where	Method	Type of Data	Amount
6.3.2024	Two participants, SME workshop.	Semi-structured interview	Voice and video recording	72 min. recording, 12,000 words transcript.
7.3.2024	One participant, SME workshop.	Semi-structured interview, visual mapping	Voice and video recording, photography	118 min. audio, 79 min. video recordings, 17,400 words transcript, 5 images
8.3.2024	One participant, SME workshop.	Semi-structured interview	Voice and video recording	71 min. audio, 55 min. video recordings, 10,600 words transcript
12.3.2024	Two participants, online.	Online Semi-structured interview	Video recording	93 min. video, 55,000 words transcript

Codesign sessions have been planned based on semi-structured interviews, navigating several topics while participants engaged with manufacturing

activities such as CNC cutting and assembling timber components. This approach allowed them to directly illustrate and discuss the relevance of MPs into their own work, while considering specific “ways of working” influencing the data collection process. Interviews have been designed around 6 core topics. A semi-structured approach allowed participants to provide additional insights not originally considered by the research team. The structure of the data collection sessions, alongside some sample prompts and questions put to participants, are detailed in Table 2.

Table 2. Themes and sample prompts covered in the data collection sessions. Source: Olmez, 2024.

Themes	Sample prompts and questions put to participants
Processing materials	Can you describe your manufacturing process for Wikihouse blocks? What specific information do you seek regarding the materials you use?
Information needs	What information is essential for you to accommodate within material passports, and for what purposes? When you are about to produce a certain piece with CNC, what information is essential to you?
Interactions with customers and suppliers	How do you engage with suppliers regarding timber materials? What are the most common topics or concerns discussed during these interactions?
Experience with Wikihouse blocks	What has been your experience working with WikiHouse blocks? Do you have any concerns or preferences regarding data privacy and security within the system?
Preferences and support	What support or resources would aid in your utilization of the material passport system? Do you have preferences regarding the format or presentation of data within the system?
Enhancements and integrations	Are there additional data sources or integrations you would like to see incorporated into the system? What methodologies or tools do you currently use to assess the carbon footprint of Wikihouse blocks?

Fieldwork activities have been recorded using a Homder Professional Dictaphone Recorder and a GoPro Hero12 to cross-check transcripts. Prior to analysis, interviews have been transcribed using the TurboScribe web-based transcription service and manually reviewed for accuracy.

2.3 Data analysis and prototyping

The qualitative analysis software NVivo 14 has been used for thematic coding. Initial codes have been developed by examining transcriptions and visual materials; these have captured broad themes related to MP definitions, user experiences, and system functionalities. Subsequent coding iterations have allowed for a more detailed analysis. In parallel, a prototype has been developed to translate findings into an early-stage MP data architecture and user interface prototype (Figure 2).

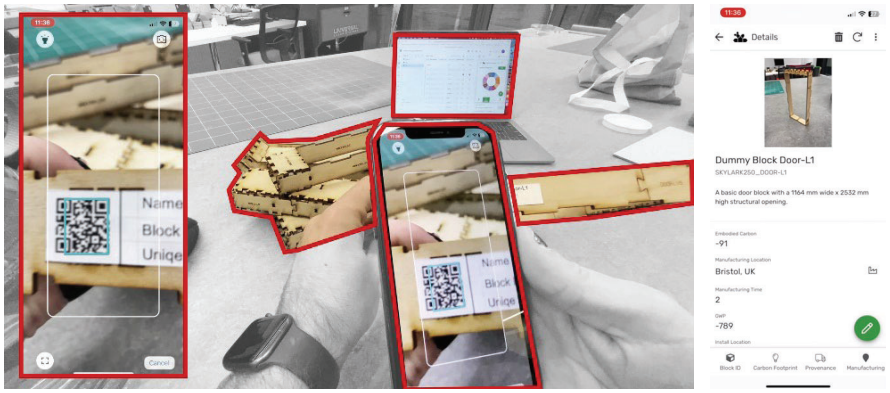

Figure 2. Interface of an early-stage material passport application, showing a QR code tagging prototype (left) and an experimental phone-based interface (right). Source: Grout, 2024.

3 Results

We identified key emerging themes that underline the socio-cultural and professional dynamics involved in the development and adoption of MPs. These include the need establish clear definitions of fundamental concepts and terminologies linked to MPs, highlighting confusion in practical settings and the need for clear boundaries and responsibilities between stakeholders. Data clustered around the user experience design, from awareness to routine use, examining integration requirements and material navigation stages. A category of data specifically focuses on user interfaces, to be designed to streamline construction processes and enhance sustainability by tracking volumetric timber elements.

The above categories, arguably, focus on aspects of technological design and development. Other themes identified in the data, as expected, relate to socio-cultural factors associated to MP development and adoption. A category dedicated to prior experience of SMEs delves into participants' practical knowledge, addressing professional challenges in creating and adopting a MP

system. These include codes and data associated to issues of credibility, privacy and data security, usefulness and access to data, functionalities compliant with regulatory frameworks, or the need to establish clear labelling conventions in relation to the underpinning database design. These general themes have been detailed with subcategories to capture more finely detailed data codes.

In terms of coding density, participants showed varied interests in discussions related to the scope of the codes. A prevalent theme with partners is the database architecture of the MP system (Figure 3). Participants also discussed the specific characteristics of timber processing from supply chain to decommissioning, with a strong focus on manufacturing (n=109), assembly (n=76), and installation (n=38) processes. They discussed the labelling interventions in their current systems, particularly the labelling of volumetric timber elements. The discussions significantly focused on labelling individual blocks (n=94) rather than each sheet component. On the other hand, it was possible to codify differences in the way stakeholders would deal with the adoption of MPs. For instance, differing opinions about cluster labelling emerged during the discussions. Other topics covered during the codesign activities included MP functionality, mainly focusing on quality control plans (n=82), policy needs, and user journeys to be considered in the development of MPs.

Differences in the data can also be associated to participants' different roles in the timber construction supply chain. System developers primarily concentrate on technical and functional aspects of the MP system. A coding category focused on database design comprises the highest frequency among system developers, detailing their significant interest in how data should be logged, stored, and maintained. Additionally, they discussed MPs' functionalities extensively, reflecting their concern with the capabilities and features of the MP system, especially in terms of certification and regulatory controls. On the other hand, manufacturers focused more on practical and operational aspects, which are evident in the higher frequency of data codes related to the process of MPs utilisation, and its labelling features. Manufacturers are deeply concerned with how the MP system integrates into their existing (and often financially-sensitive workflows), from production to assembly and installation. Moreover, manufacturers showed significant interest in the MP database design, providing substantial insight on the practicalities involved in the manufacturing process, data needed (by the right person at the right time) within their day-to-day operations. This contrast underscores the different priorities between developers and manufacturers, with developers focusing on certification, control plan, and data management, while manufacturers emphasise issues of practical implementation, such as labelling conventions and usability.

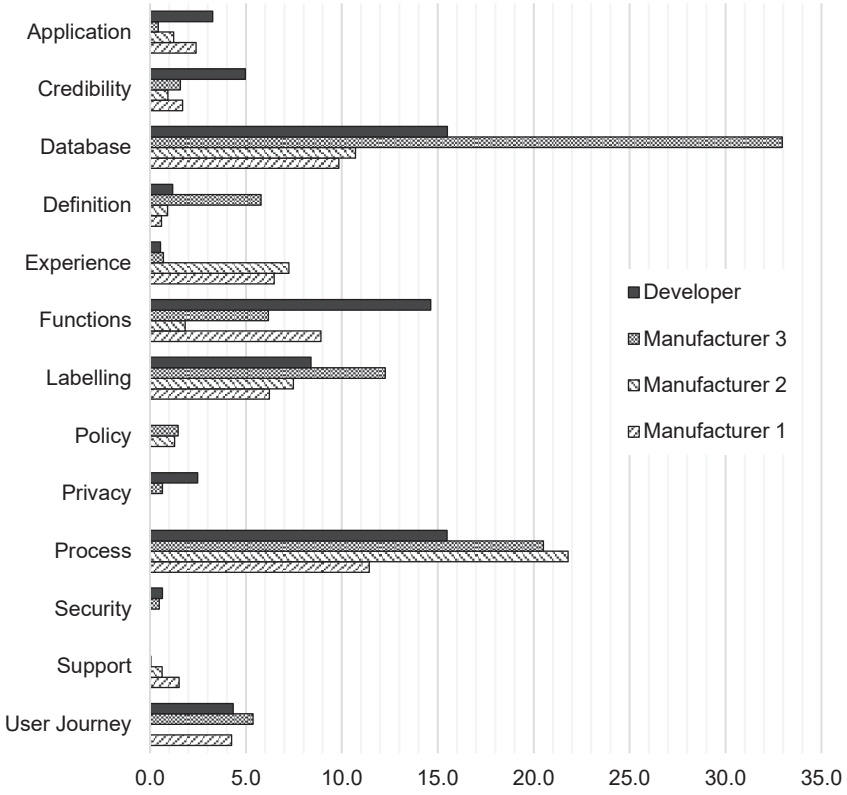

Figure 3. Codes coverage in each participant's dataset. Source: Olmez, 2024.

4 Discussion

Our preliminary findings confirm related literature in showing the critical role of the MP data architecture, encompassing detailed information such as material composition and lifecycle data (Atta et al., 2021). This structure is crucial for ensuring that building components can be effectively tracked, reused, and recycled. Göswein et al. (2022) propose a robust methodology for creating MPs while stressing the need for comprehensive data on product context, use, and location. Their approach stresses the importance of diverse data points from different stakeholders to enable better decision-making and MP design.
Despite the advancements in the creation of MPs globally, there is no standardised approach MP data structure, leading to fragmented implementations that vary widely in their scope and detail (Honic et al., 2019). Our study addresses this gap by providing a detailed analysis of industry stakeholders' perspectives on MP systems following a codesign approach,

offering valuable contributions into the practical requirements for successful implementation which respond to the specific needs of the UK market and SMEs “ways of working” influencing data collection and analysis. For example, participants highlighted the necessity for including detailed environmental impact assessment and carbon footprint calculations, aligning with the findings of Almusaed et al. (2021), who investigated the integration of environmental profiles within MP systems.

Furthermore, our preliminary findings suggest the importance of labelling conventions within MP systems. Manufacturers particularly stressed the need for clear, standardised labelling to ensure the efficient tracking and management of timber components. This aligns with the literature, where effective labelling is seen as crucial for maintaining the integrity and usability of MPs (Byers et al., 2022). Our findings expand on this by detailing industry-specific labelling needs, such as differentiating between individual building elements and larger clusters of these elements for managerial ease, thus providing a more nuanced understanding of labelling requirements in the context of volumetric timber construction. In the UK context, this aligns with the framework by Rute Costa and Hoolahan (2024) which indicates a scalable approach to passport material elements, components, systems and buildings.

In addition to technical aspects, our study highlights the socio-cultural dynamics involved in the adoption of MP systems. Participants pointed out challenges related to trust, data ownership, and the integration of MP systems into existing workflows. These issues are echoed in the literature, where the fragmented nature of construction industry is often cited as a barrier to innovation (Ozorhon et al., 2014; Turk, 2023). By considering these socio-cultural factors, our research contributes to a more comprehensive understanding of MP system adoption through functions like individual certification.

In terms of levels of detail, data requirements and availability in the AEC sector vary significantly, from the built environment scale to the individual product level. Çetin (2023) discusses this challenge and stresses the need for comprehensive data templates to create effective MPs. When our results are compared with Çetin’s findings on product properties, participants in this study concur on the necessity of including details such as dimensions, weight, material composition, and physical properties of building elements. However, participants raise additional data requirements such as visuals of building elements and their geographic location aggregated in a “live” document to be updated throughout the lifecycle of each uniquely identified building element.

Last, we recognise other development areas, although not addressed in depth by our participants, are influenced by a growing body of literature in this field, such as QR tagging models (Byers et al., 2022) or the alignment of MPs architecture to broader sectorial and national policies, such as the upcoming UK Industrial Decarbonisation Strategy which is expected to implement product labelling and data transparency requirements (UK Government, 2021).

5 Conclusion

This interim report outlines preliminary findings on a research project aiming to codesign and develop a MP specific to volumetric timber components. Although our starting point for this research is the WikiHouse building system, we expect our final prototype to be usable in the long-term by different prefabricated building systems. By considering the insights from industry partners in early development stages, we expect this innovation to respond to implementation and adoption requirements throughout SME distributed manufacturing supply chains. Our codification analysis will shape core elements of the MP system's database, guiding the next phases of development. As we continue to refine and test MP prototypes, these early-stage observations provide a critical framework for addressing both the technical and practical aspects of MP implementation. This iterative process ensures that the final MP system will be validated by stakeholders, usable by their current workflows, and aligned with the needs of the construction industry, ultimately contributing to more sustainable building practices. In terms of further work, our research involves:

- The development, testing and implementation of a manufacturing control plan, to ensure quality standards are maintained throughout a distributed supply chains of SME manufacturers.
- A second codesign cycle, focused on different types of housing procurement stakeholders such as community housing associations and land trusts. We expect this sample of participants to help us determine the ownership and community-based impacts of MPs, including insights into community data ownership, as well as the implementation of MPs in neighbourhoods and cities to enable the mining of building elements through dynamic marketplaces (Kovacic & Honic, 2021).
- Last, this research project considers the testing of MPs in an actual building procurement scenario, to be developed with our industry partners before March 2025.

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