Carbon Artifacts

Visualising carbon in design and delivery of non-domestic buildings

Findings Report

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Project Web Page:
https://research.reading.ac.uk/carbon-artifacts/

Executive Summary

The purpose of this report is to provide an initial overview of key findings derived from the ESRC funded project Carbon Artifacts Work Package 3 (WP3). The aim of the project is to understand how design and construction professionals negotiate net-zero in design and delivery of net-zero commercial buildings. The project is made up of a number of deliverables, one of which includes WP3, concerned with understanding the role visual artifacts play in this negotiation process. WP3 involved analysing ways design professionals and sustainability consultants use visuals for negotiations of carbon reduction. This was conducted in three phases and included an initial review of documentary evidence of 217 visuals collated from the project's case studies- three commercial projects. The second phase involved piloting discussing use of visual artifacts with participants online followed by in person workshops across three architecture firms in the UK across four office locations with a total of 28 participants. The workshops were conducted in the period between April and July 2024. Workshop discussions were transcribed and fully anonymised and images collated into an image bank. The third phase was analysing the transcripts thematically in NVivo software, looking to understand the context through which visuals were discussed, what was seen as important to convey and impact visual artifacts may have had on project outcomes.

Overall, three key themes emerged that characterised ways visual artifacts communicated carbon reduction negotiations in design:

- *Clarifying targets*
- *Simplifying what was seen as complex*
- *Learning and enhancing practice*

The first theme portrays discussions within which participants discuss ways visuals represent how a design achieves a target or benchmark. Images were largely decontextualised, with diagrammatic graphics indicating target numerical values and proximity of this being met with by conducting comparisons and benchmarking. These discussions revolved around visuals representing solutions that conveyed 'potential targets'; or the effect of achieving a target (possible targets). The second theme, 'Simplifying what was seen as complex,' was characterised by discussions that explained visuals as simplified information, showing one solution, indicating key impact on project factors or features. Complexity here referred to mostly multiplicity of information, most participants discussed how often complex information needed to be simplified for clients. The third theme, 'Learning and enhancing', included discussions that explained the learning value of visuals, enhancing and asserting the architect's role and revealing what still needed clarity or working through.

The implication of these insights is threefold. First, visuals that convey carbon reduction play an important role in mediating perceptions of key or only solutions; Second, editing out of what is discussed as complex information may obscure different kinds of assumptions that may shape critical design decisions; Third , the learning potential of visuals should not be underestimated – future work could better understand the types of learning different kinds of visuals may enhance or diminish. Whilst the insights are significant for understanding how net zero design is negotiated through visual artifacts, there are some limitations in the research. These limitations included: 1) **Participant Backgrounds**: All participants came

from architecture and design fields, which limits the diversity of perspectives and may not fully represent other industries or areas of expertise; 2) **Data Confidentiality**: Restrictions on the projects' data confidentiality influenced the participants' ability to share certain images, potentially impacting the depth or breadth of the visual data included in the report; 3) **Methodological limitations:** this study was initially involved conducting an ethnographic study[1] to observe how professionals engaged with visuals during design communications. However, applying this method was restricted due to research time limitations and data confidentiality.

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[1] a research method where researchers observe people in their natural settings to understand how they interact and behave. This method is used to understand social and cultural dimensions related to the studied phenomena.

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1.0 Project overview

This report presents key insights drawn from work package 3 within the research project 'Carbon Artifacts: a socio-material approach to low and net zero carbon building design from concept to handover'. The project is led by Prof Libby Schweber (University of Reading), Dr Martin Green (University of Reading), and Prof. Sonja Oliveira (University of Strathclyde) and funded by ESRC. The aim of the project is to develop new knowledge on ways design and construction professionals engage with and negotiate net-zero in design and delivery of commercial building projects.

1.1 Introduction

The Carbon Artifacts research project examines the organisational challenges that accompany the introduction of new technical standards and guidance for low-carbon building (RIBA, 2019; LETI, 2020; RICS, 2017; NFB, 2019). There is currently a fair amount of research into the technical challenges, with a number of professional bodies producing frameworks and guides. These are clearly invaluable, but the delivery of net zero carbon buildings also depends on project teams adapting standard ways of working to support new techniques. The research assumes that building design is an ongoing process shaped by the successive formulation of problems, development of design solutions and communication of those solutions across multiple teams, working on different aspects of a design/building at different scales.

Miscommunication and misalignment of incentives within and across building teams and phases often lead to modifications in the design which undermine initial ambitious carbon targets. To address these challenges, the project examines the initial development and ongoing modification of carbon reduction strategies in commercial buildings in the UK. The project is made up of 6 work packages and is due to complete in February 2025 (Figure 1). Within this project plan, WP3, spanning from October 2023 to February 2025, examines the role of the visual artifacts in the negotiation of net-zero design.
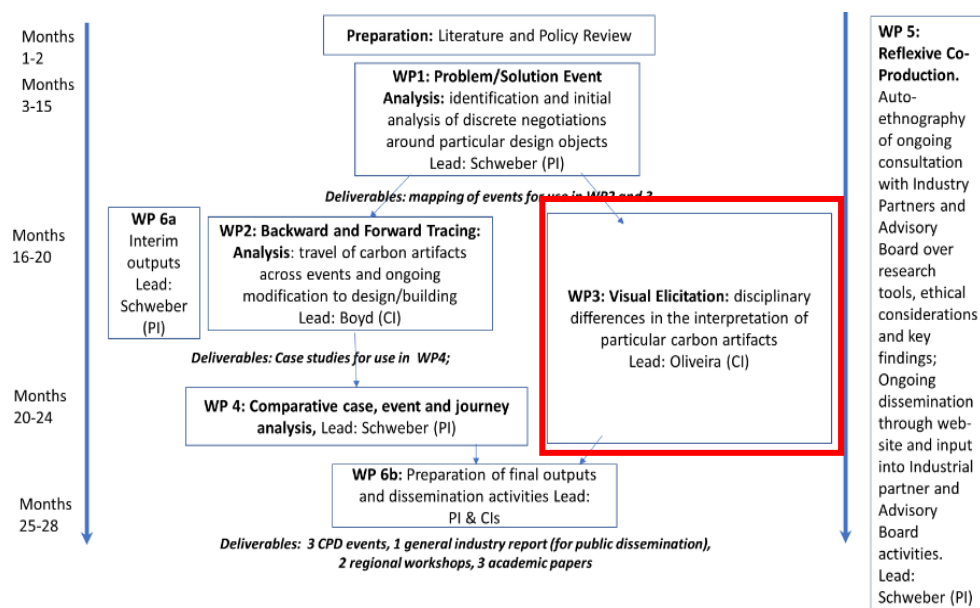

Figure 1 Showing the Carbon Artifacts research plan.

1.2 WP3 Background and problem definition

WP3 is part of the project aimed at understanding the role of visual artefacts in the negotiation of net zero targets in building design. The research design draws on insights from Science and Technology Studies (STS) which focus on understanding the social construction of technology, in this instance the use of visual artifacts is seen as a means of socially constructing interpretations of net-zero.

1.3 Research problem:

WP3 is concerned with understanding the role visual artefacts used to communicate carbon reduction, play in both representing as well as mediating interpretations of net-zero. WP3 focuses on the following objectives:

1) To identify ways visual artifacts used to communicate carbon reduction.
2) To identify the roles of these visual artifacts in mediating net zero negotiation.

1.4 Methodological Approach:

WP3 research is conducted in 4 stages, with each stage exploring different aspects of visual artifact use (See Figure 2). The methodological approach followed in WP3 was primarily inspired by the use of visual research methods and photo-elicitation (Oliveira et al., 2023). While stage 3 forms the focus of this report, this section explains how multiple visual methods were used in this research, and how each was designed to reveal different aspects of the research problem.
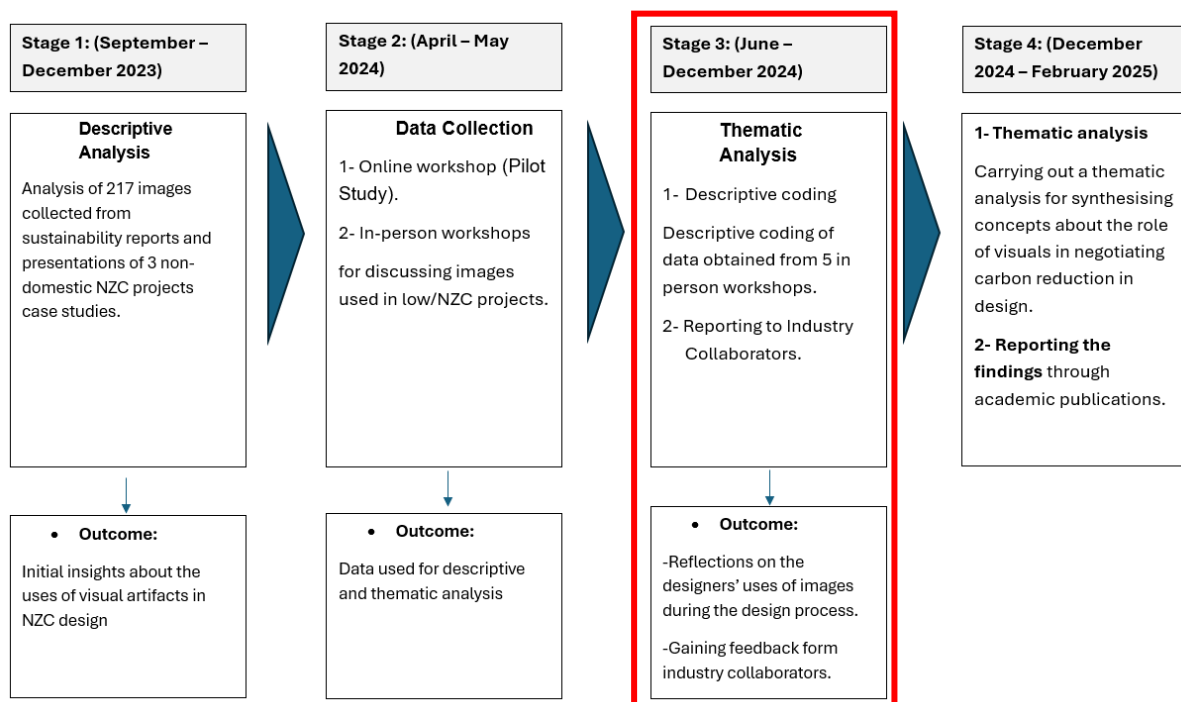

Figure 2 Showing WP3 research stages.

An initial exploration of visual artifacts used to communicate net-zero or low carbon design was carried out in stage 1. This stage involved analysing 217 images obtained from sustainability and design reports and presentations provided by project members from the three cases involved in the broader Carbon Artifacts project. Insights from Stage 1 informed the design of a pilot study in Stage 2. This involved an online workshop with 7 invited participants —including architects, M&E engineers and sustainability consultants —to further explore use of visual artifacts to communicate net-zero in design. Building on insights from the pilot study, Stage 3 data collection was carried out by conducting in-person workshops. Three architectural firms across four office locations took part in this research stage, with 28 participants involved in design and delivery of net-zero or low carbon mixed use and commercial buildings in the UK. Recorded transcripts were analysed thematically using NVivo software in Stage 3 and the findings described in the sections below.

2.0 Stage 3 Key findings

**2.1 Stage 3 Findings overview:**

Stage 1 analysis found that carbon reduction was mostly represented through bar charts, graphs, diagrams. The analysis of these images informed how engineers and sustainability experts used these visuals for communicating carbon reduction-related information when making comparisons and benchmarking. In such light, conversations with the participants in Stage 3 were analysed with a focus on how architects used the images for negotiating carbon reduction design solutions. For doing so, we looked at the context of using the images, why they were important, how the audiences engaged with them and how the images influenced the design decisions*. According to the thematic analysis procedure outlined in Section 1.4, the following key themes emerged, portraying three dimensions of the uses of visuals in low and net-zero design:*

- Clarifying targets (confirming a shared understanding of targets, clarifying potential targets, clarifying possible targets).
- Simplifying what is seen as complex (editing information out, simplification for opening up options, simplification for narrowing down solutions).
- Learning and enhancing (enhancing the architect's role, asserting the architects' role).

Theme 1:

Clarifying targets

Influential dimensions

Guiding targets → Project specific targets

Design Features   Resources

Knowledge and skills
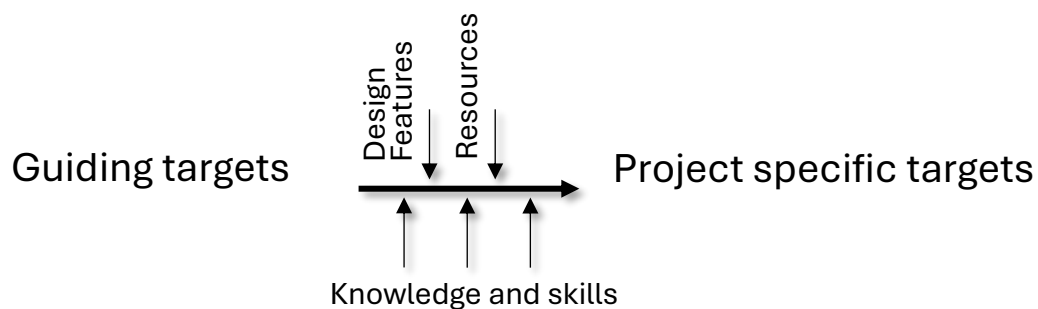
Theme overview

Clarifying the targets that will be achieved by the proposed design was a prominent purpose of using the visuals at the early stages of the projects for participants in all firms. Relying on different forms of visuals, the participants aimed to establish a common understanding of what could be achieved. This step in design negotiations was seen essential for facilitating internal communication with the project team and external communication with the clients and their expert consultants.

When defining the shared targets, none of the participants referred directly to the guiding targets set by the leading organisations in the field. Instead, setting carbon reduction targets was part of the design negotiations that participants viewed as essential for reaching realistic agreements with clients. This section outlines the way visuals were used to convey to the client's the feasibility of the proposed project-specific targets in relation to the design features and project resources.

2.2.1 Confirming a shared understanding of targets

Participants from all firms emphasised the importance of representing agreed on targets during external and internal discussions. According to a participant from one of the firms, using visuals representing the breakdown of targets about the building elements was seen useful in clarifying the objectives for each team member and assigning tasks effectively. When communicating with the clients, participants from all the firms found it essential to use the visuals to set clear boundaries about 'what we were trying to achieve' (P3TLA) and how it deviates from the guiding targets (Figure 3). Visuals were used to help detail these boundaries, illustrating variations in expected outcomes, such as carbon reduction across building elements, and the level of intervention needed to achieve these outcomes.

> 'So, we largely use it at the end when we presented everything, we had a few meetings. We probably used that this or something precursor to it. Trying to show... So this was like a lighter retrofit, a deeper retrofit and a sort of end 'fittish' retrofit. And so we tried to… keep everything in those like options so there weren't too many different proliferation options…' (P3BLWA).
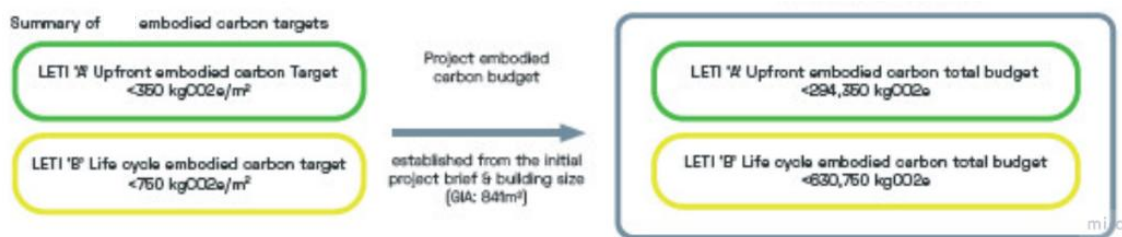

Figure 3 Showing an example of the images used to set shared understanding of the targets.

Explanations of the targets implied clarification of potential areas of carbon reduction and what will be possible to achieve according to the project circumstances and the available resources as demonstrated in the following subsections.

2.2.2 Clarifying of potential targets

The participants' reflections informed how they used the visuals to clarify potentially achievable carbon reduction goals. Identifying potential targets implied the consideration of targets required in the project brief in relation to the features of proposed design or an existing building. To do so, participants relied on a range of visuals to achieve this purpose, such as using infographic comparisons, conceptual illustrations, and technical detailing drawings, to provide a clear connection between the targets and specific design elements and details (Figure 4). In client communications, participants from all firms explained how these visuals were used to clarify the possible areas of improving the carbon footprint of the building in relation to the design features. In this context, the visuals were used to illustrate areas where the building's carbon footprint can be improved in relation to its design features, such as the design of the façade, size and orientation of the building, showing how specific design features informed opportunities for carbon reduction targets. Using the visuals this way was also seen

to help breaking down the targets into actionable steps, such as 'changing windows for example, or making sure that the thermal bridges are minimised or mitigated where existing' (P3DCA).

> 'The client did understand at the time that they could see how the orientation then affected the performance. So, they kept having that kind of plan that shows, you know, north south, that master plan, the different buildings. They could then correlate between the two and understand what was get been affected. And obviously the original brief for this scheme was fully Passivhaus, but they understood there's potentially ones that wouldn't achieve it due to the difficulties.' (P3GAA)
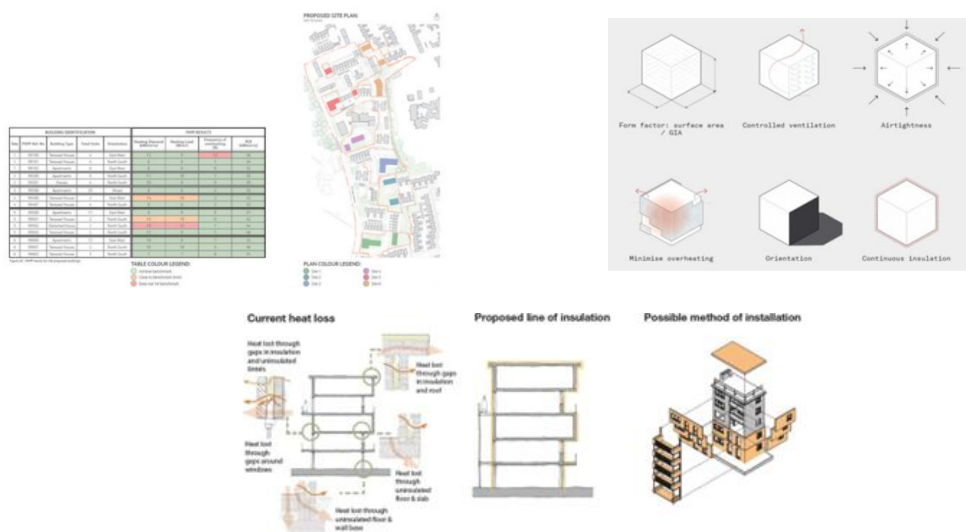

Figure 4 Showing the different types of visuals used to convey the targets in relation to the design features.

2.2.3 Clarifying possible targets

When clarifying the targets, participants used visuals for further outlining what is possible to achieve within potential areas for carbon reduction. For this purpose, the visuals included infographics and tables were used in this context to make comparisons to link potential opportunities to carbon assessments related to specific design features and constraints (Figure 5). Participants from all firms found that using visuals in this way allowed them to suggest what could realistically be achieved and prioritised given the available project resources— which participants from all firms mentioned as cost. Additionally, most participants explained how comparisons and benchmarking were also carried out to identify which areas were showing 'biggest impacts' and 'flagging up risks' in an existing building.

> 'It's a diagram that I put together to show the client how like the steps in construction from existing to achieve net zero and there was another construction timeline showing like if you like the best way to achieve net zero here, which is this one is like the first big amendments that you need to change the extract units, change the windows all together and then make the building act isolated with the EWI etcetera and move on. Whereas a lot of clients sometimes they prefer to do

it in a longer term. Where they have to, for example, put triple [glazing] on the windows and then a few years later they'll have to come in, put the put, MVHR, unit heat and extract units, and you'll kind of bounce it back again, like the heat in the mount just goes up and down constantly.' (P3FRA).
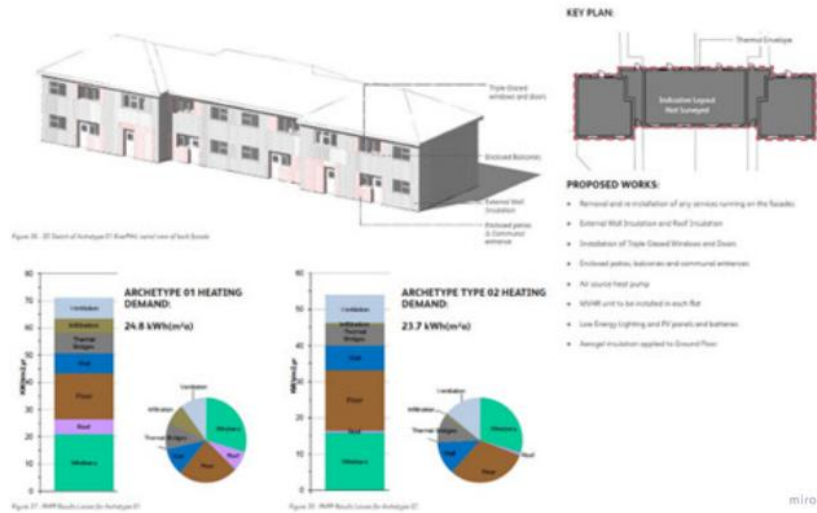

Figure 5 Showing an example of visuals used to set targeted priorities.

Summarising points

This theme portrayed the participants' descriptions of how they relied on visuals to clarify the targets that could be achieved by the proposed designs as follows:

Using the visuals for setting a common understanding of targets:

- For internal communications, using the visuals to confirm common targets was seen essential to support each team member to work towards the assigned objectives effectively.

- For communication with the clients, the use of the visuals to confirm common targets allowed clarifying what could be realistically achieved and how it deviated from guiding targets.

Using the visuals to convey to clients where the effort should go Identifying opportunities:

- Using the visuals to identify opportunities relied on the skills and knowledge of different experts engaged in the design process to relate the guiding targets to project-specific ones.

- Breaking down the design features and elements offered a precise understanding of opportunities and how they could be applied in relation to the design features.

- Identifying possibilities for carbon reduction was an iterative process that responds to design changes across the project stages.

Identifying possibilities:

- Using the visuals for identifying the feasibility of the available options required relating the identified possibilities to the available resources, most commonly acknowledged was cost.

- Identifying possibilities included the prioritisation of tasks according to the effectiveness of each target in achieving carbon reduction.

Theme 2:

Simplifying what is seen as Complex
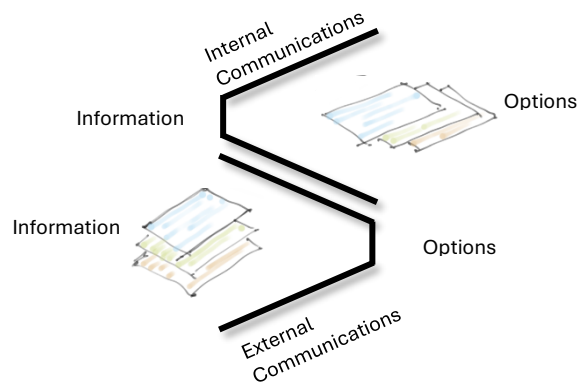
Theme overview

It was not uncommon to hear from the participants that simplification was a key use of the visuals representing the information shared with the clients and among members of the team. The participants' perceptions of what simplicity of the visualised information meant was linked to facilitating 'clarity' of information and 'easy' engagement.

The participants' reflection on the tension between 'having a bigger picture in mind as well, it's quite important' (P3BNTA) and the perception that 'it's never just one thing that tells everything' (P3BCYA) provoked questions about what was seen complex and what aspects of complexity the participants needed to simplify using the visuals. Findings in this section frame how the participants perceived simplification of visuals, what they described as simplified visuals, and how they were used for opening up and narrowing down solutions in internal and external communications.

2.3.1 Editing information out

Participants from all firms used, what they referred to, as simplified visuals to support different communication purposes and design practice. Simplification from this perspective was perceived by participants as selecting the information to be represented through visuals. This interpretation was further confirmed through participants' explanations of the multiplicity of carbon reduction details in design to be a source of vagueness or lack of specificity, which they expressed as 'everything' and a 'crowd' of details in low and net-zero design. Accordingly, they selected what to share 'depending on what part of the process [they were in, and] depending on their experience' (P3BCYA). What was seen as simplified visuals varied to include colour coded tables, graphs, and conceptual illustrations. Editing the visuals in this way, facilitated two forms of design communication, as portrayed in the following subsections.

2.3.2 Simplification for opening up options

During collaborative design discussions, the participants from most firms used simplified visuals for opening up discussions about the design solutions. Participants from one of the firms reflected how eliminating other aspects of the design from the visuals helped avoid alternative interpretations that might result from the varied expertise of team members. This approach ensured that multiple dimensions of carbon in design were considered during decision-making. Facilitating engagement in discussions was another reason for using the simplified visuals, which one of the participants described as 'a resource to prompt a wider conversation' (P1IKA). According to participants from two firms, using the visuals to clarify the area of focus in the discussion was seen necessary to encourage the engagement of experts from different disciplines.

> 'People talk [at] cross purposes, they've different interpretations of the same thing. So, these simple diagrams I find really quite helpful. These are the things that we think we're talking about. Somebody else might come in and say, well, what about the type of material that you use and you could say, well that's another one… [ ] It just helps frame the conversation.' (P1IWA).

When asked about the difference between editing the images for external communication with clients and for internal communication with the design team, one participant clarified how relying on professional skills and knowledge, indirectly, led to a reduction of details that could be known by the professionals. Simple diagrams in this case did not represent all the spatial dimensions that could accompany the decision on each (Figure 6). Instead, the participants implicitly relied on their understanding of various spatial dimensions that were not illustrated in the image used for evaluating of each option.
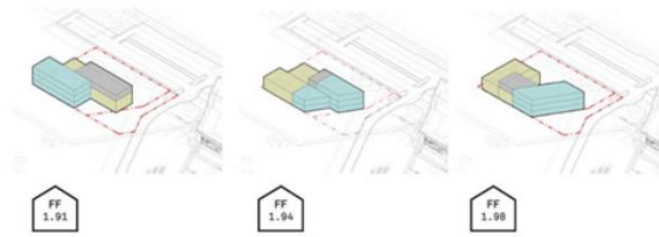
Figure 6 Showing an example of visuals used during collaborative discussions with experts.

2.3.3 Simplification for narrowing down options:

In external communication with clients, simplified visuals were presented to convince clients that the proposed solution or design approach was the most effective for carbon reduction. According to participants, simplification here involved using measurable criteria to help clients understand why the proposed solution was better than other alternatives. Visualised comparisons were used to clearly justify why a given proposal was the best option (Figure 7). In this case, reflections of participants from one of the firms revealed that alternatives included in these comparisons were not intended to present an array of possible solutions. Instead, the alternatives were used to support the case that the proposed design offered the best carbon reductions.

Figure 7 Showing different types of visuals used to highlight carbon reduction gains from the proposed solutions and approaches through comparisons.

Despite the attention given to using visuals for simplifying information, participants from most firms reported that clients' limited knowledge of the topic hindered their ability to critically evaluate and question the proposed solutions. To engage non-experts with the reported carbon reduction solutions, the participants translated carbon reduction measures into aspects that directly related to the clients' targets. Cost, identified as the most influential factor behind the clients' decisions, was seen by participants from all the firms as a powerful mediator of the gains associated with carbon reduction[2]. Another effective way for communicating proposed solutions using visuals was relating these solutions to everyday related needs and experiences, as mentioned by participants from most firms. Participants from two firms further explained how 3D modelling representing the experiential dimensions of the design was seen as another effective way for relating proposed solutions with the social and emotional needs of the end users (Figure 8).

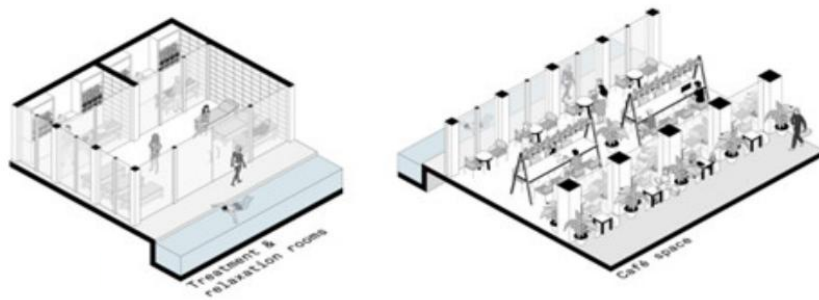**ENABLING ARCHITECTS TO DISCUSS CARBON IN COMPLEX SPACES**

Figure 8 Showing 3D used to communicate experiential dimensions related to proposed carbon reduction solutions.

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[2] Despite the agreement among participants on the importance of including cost-related information, it was excluded from the shared visuals. This might be due to restrictions related to information confidentiality.

Summarising points

What is complexity?

- Complexity was seen as the multiplicity of elements and systems encompassed in low and net-zero design. This way of perceiving complexity was associated with concerns about lack of clarity of information during design negotiations.

- Simplification, achieved by editing and selecting information, was an approach followed for offering clear and focused information during internal and external communication.

- The selection of visualised information or design elements is a common practice in design communication. However, participants' reflections informed purposes of simplification of visuals in low and net-zero design negotiations as explained in the following:

Purposes of simplification:

- Opening up possible options was achieved when using simplified visuals with professionals. Professional knowledge and skills allowed for the expansion of details during design discussions.

- Narrowing down options was achieved by using the simplified visuals to demonstrate why a proposed solution was the best option. This approach relied on selecting information for comparison and benchmarking. This approach to simplification also aligned with the clients' and consultants' judgement criteria.

Challenges:

- Knowledge background was perceived as an influential factor influencing how carbon reduction solutions were conveyed in design. For non-experts, mediators, such as cost or experiential dimensions of the design, were seen effective ways for conveying the gains from the proposed carbon reduction solutions.

- The perception of complexity as a multiplicity of elements posed a challenge when representing the holistic image of a design as overlays of multiple details.

Theme 3:

Learning and Enhancing
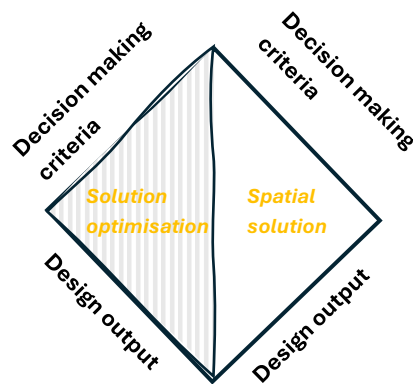
Proposing low and net-zero design

Theme overview

This final theme of the findings highlights how the visuals were used to enhance the role taken by the participants in low and net-zero design. This role relied on integrating their architectural knowledge and skills into the design process and evaluation criteria, which did not align with those followed by the clients.

This misalignment was accompanied by using the visuals to demonstrate the ability to apply criteria for design evaluation like those followed by the clients. The implementation of architectural knowledge and skills in the domain of low and net-zero design was also accompanied by the need for a perceived gap in knowledge about the effective use of visuals, which motivated the participants to expand their knowledge and skills in using the visuals in this design field.

2.4.1 Integrating the architect's role

> 'That's like the classic quote, but I use it quite a lot. The lowest carbon pool is the one that nobody uses, so we've gotta get there.' (P1IWA)

The participants' reflections on their images revealed an underlying perception of the role of the architect in low or net-zero design. Understanding this role further clarified two purposes of using the visuals and ways of the participants' engagement with them, as explained in the following.

During the design process, participants from three of the firms explained how they used the visuals to make comparisons aimed at balancing between environmental efficiency with design features, such as recesses in the façade, visibility between spaces and material choices, that influence the end users' experience. Additionally, participants from one of the firms related their design decisions to the ways of building management that may affect the materials lifecycle in reality (Figure 9).

Connections between human experience and the implemented carbon reduction measures were evident when participants discussed carbon reduction decisions in relation to 'how people feel comfortable', 'feel kind of semi-sheltered and secure', 'how that looked on the street', and 'amazing views of London from this building'. To achieve and communicate this balance between design qualities and carbon reduction gains, the participants combined visuals representing the design features with graphs and tables demonstrating carbon reduction measures (Figure 9).

Figure 9 Showing visuals used to evaluate the design concepts.

Participants took on the architects' role outlined above while aware that design qualities do not form a primary concern for the final decision makers, such as clients, planners and competition judges Instead, these stakeholders focused on guiding targets like LETI, Passivhaus standards, or financial budgets. Participants from most firms identified a communication challenge arising from the gap between their approach to carbon reduction and the criteria used by clients and sustainability experts to evaluate the proposed solutions.

This challenge was expressed through the participants' perception of the clients' disengagement with visuals related to design qualities, such as not 'really show[ing] that much interest [in] what the building really looked like', being 'a bit afraid of saying that they don't understand', or claiming that using computer-aided imagery (CGI) to represent the experiential dimensions of the low-carbon design can be 'excluding' and that it 'doesn't allow people to have a lot of sort of a discussion about it [the design features]'.

In response, participants found that using visuals to report the quantified gains of carbon reduction solutions was more effective for client communication. Another strategy for addressing the divergence in design priorities involved bridging the gap between the participants' and clients' perspectives (Figure 9). As mentioned in Sections 2.2.3 & 2.3.3, this approach often relied on mediators, such as linking design solutions to cost benefits.

> 'From Carbon point of view, carbon tracks money, and as you were saying, if it is easier to make that argument because you not only making necessarily carbon argument, you also making a financial argument both on true.', P1IKA.

Another reported use of visuals, as shared by participants from two firms, was influencing the practice of low and net-zero design through the application of their architectural knowledge and expertise. In public debates with experts in the field, visuals representing concepts about design and carbon reduction were used to transfer architectural knowledge to broader knowledge frameworks guiding low and net-zero design. These concepts included negotiating the feasibility of retrofitting solutions or the installation of solar cells (Figure 10). This commitment towards influencing low and net-zero design practice was further observed when participants from one firm explained how they relied on visuals to promote environmental responsibility among their team members.
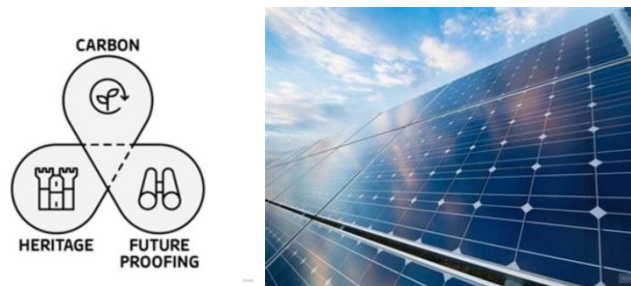
Figure 10 Showing the visuals used to convey carbon reduction concepts wider discussions about carbon reduction approaches informed by design.

2.4.2 Asserting the architect's role

Overview

Asserting the architect's role was one of the dimensions interpreted from the conversations with the participants and the way they used images. Assertion was seen as the need to demonstrate carbon reduction design capabilities and enhance their firm by learning from

previous projects and improving their skills. The following findings explain the participants' motivations and ways of using visuals to assert the architect's role in low or net-zero projects by *proofing their ability* and *enhancing their practice*.

Proving ability

When explaining the challenge faced by architects in providing evidence about non-spatial design dimensions, such as cost, one of the participants stated that 'architects always get blamed…'. This challenge was further interpreted from reflections of participants from all firms about the need to demonstrate the ability to carry out carbon reduction calculations using modelling tools (Figure 11). Acknowledging that the clients used quantified criteria, communications with them purposefully relied on simulation modelling tools for showing that similar quantified measures were applied during the design process.

> '… [the image] was used to show a particular client that we had the capability to do this exercise, cause, they were interested in it.' (P2TFA)

Figure 11 Showing visuals used to show how the proposed solutions built on reduction modelling.

Enhancing their own practice

The participants' acknowledgement of their need to apply new ways of using visuals in low and net-zero design was accompanied by a motivation to develop their knowledge and skills. This momentum was reflected through expressions such as 'improve' and 'learning' in relation to how certain ways of using the visuals had been applied in previous projects. In some cases, the participants described learning in relation to how they used or will use visuals in other projects after the first time it has been used.

> 'So, it was kind of this was like an intro page. With quite a lot of schedules and diagrams in this report, it's quite data-driven. Obviously trying… I think the next step for us is to get very involved and try and improve the graphics but again…', (P2DPA).

The efficient way of using the images was perceived as integrating the fixed/quantified measures of carbon reduction into the open-ended/iterative design process. This interpretation was reached by the research team from two firms who reflected how they used the visuals to communicate and maintain consistency in the steps followed for making carbon reduction calculations (Figure 12).

The connection between consistency in design and the use of visuals was explained by the participants in two ways. Participants from all the firms described consistency as the unification of visual representations of carbon-related details. This approach was intended to enhance the design process through the 'reusability' of the images, increase 'fluency' when evaluating multiple options, and reduce the time needed to make design decisions. Visuals for this purpose included icons or simple diagrams representing carbon-related information, which were either integrated into the architectural drawings or CAD software.

Using visuals to support an iterative design process that integrated carbon reduction measures was another way participants explained how visuals contribute to consistency. Participants emphasised that maintaining a visual record of decision-making steps at various project stages allowed them to monitor progress and refine decisions. Most participants highlighted this "positive" impact as a key benefit of this way of using visuals.
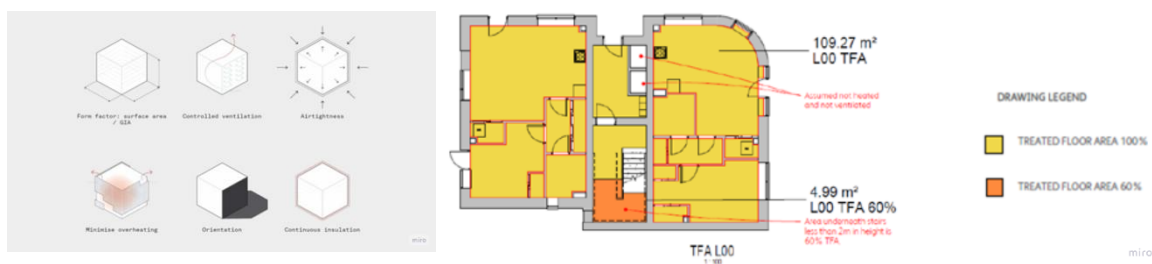

Figure 12 Showing examples of visuals representing concepts transferred across the different projects.

3.0 Conclusion

The project found that visual artifacts do play a potentially significant role in both communicating, representing and mediating net zero or low carbon. The three found themes suggest that the visual interpretation of carbon reduction involves fixing solutions early on in the design process, by focusing on meeting targets. The images used to communicate information mostly through benchmarking or comparing the building solution for achieving three purposes of communication:

- *Clarifying targets*
- *Simplifying what was seen as complex*
- *Learning and enhancing practice*

Limiting the use of the visuals to showing the alignment of the solutions with predefined targets had implication on the purpose of communication and how the communication happened to achieve this purpose. This approach was associated with difficulty in representing a holistic vision of the project and limited engagement of non-experts in conversations about the proposed solutions. Getting around these challenges requires reconsideration of what constitutes the holistic picture of the design and what is needed for facilitating co-creating low and net-zero design.

Using visuals like orthographic drawings or infographics focuses on precise, predefined targets, emphasising predictability and technical accuracy while oversimplifying the complexity of real-world factors. In reality, carbon reduction solutions, as part of architectural design, interact with social, temporal, and building managerial processes which remained unrepresented through the visuals used to explain the carbon reduction solutions, as examined in this research. Subjectivities deriving the design solutions form another unrepresented dimension in the used visuals. While subjective visions and personal concepts and values form an important driver of creative problem solving in design, the focus on showing how the solutions aligned with measured outcomes became the central concern of the visuals. Integrating these central design dimensions into carbon reduction communication will extend the novelty of the proposed carbon reduction solutions and expand the understanding of what is possible to be achieved. This approach to communication implies using visualisation methods that allow reflexivity and openness in exposing subjective views leading the design approach and dynamic dimensions affecting the building performance.

The differences between the findings from stages 1&3 draw attention to the way using photo elicitation as a research methodology allowed revealing invisible dimensions of the use of visuals such as motives and challenges directing the communication. These understandings were restricted by issues related to the confidentiality of information affecting the type of images shared with the project team. The findings in this report were also affected by the sense of some of the participants of unclarity of what information and visuals needed to be shared in the workshops. However, the broadness of the reflections shared with the research in some instances of the fieldwork allowed capturing the participants' views on approaches for practices and broad concepts guiding low and net-zero design. For practice, the research offers evidence of how professionals from architectural and design backgrounds integrate visuals which do not originate from design-related disciplines into the design. Identifying the

way of using these visuals is the first step towards enhancing low and net-zero design by exploring the artifacts used in this process, their role, and how the different professionals engage with them.

4.0 *Appendix:* WP3 stages 1&2

Stage 1

Stage 1 data collection

Stage 1 focused on understanding how the images were used in reporting net-zero or low carbon design by exploring documentary data obtained from the three cases investigated in WP2 (Table 1).

Table 1 Showing details of Stage 1 case studies.

Project Details	Case O2	Case K2	Case R1
Building Type	Offices / Workplace	Offices / Workplace	School
Project Type	Regeneration	Retrofit	New build
Location	Salford	Bristol	London

217 Images representing carbon reduction examined at this stage were obtained from sustainability reports and workshop presentations delivered by sustainability consultants and MEP engineers during stages 1-4 in the studied cases. The visuals were used in workshops and email correspondence to report carbon efficiency and design decisions to clients and members of the project team (Table 2). Representations of carbon reduction in these documents include illustrative imagery, quantified information displayed through various infographics and 3D carbon reduction modelling used to illustrate building performance against targeted measures.

Table 2 Showing the type of documents where the anaysed images were used and professionals engaged in their production.

Case	Type of documents	Professionals engaged in documents production
Case 1	Design for performance report (Stage 2), Design for performance report (Stage 3), Sustainability report (Stage 2), Embodied carbon report (Stage 2), Whole life cycle executive summary (Stage 3).	Sustainability consultant
Case 2	Sustainability report (Stage 1), Sustainability workshop (Stage 1), MEP and sustainability report (Stage 1), MEP and sustainability report (Stage 2), Whole life cycle workshop (Stage 2), Operational energy (Stage 3), Passivhaus workshop (Stage 2).	Sustainability consultant
Case 3	Operational energy report, Embodied carbon report, NZC feasibility report, Sustainability report (Stage 2), Sustainability report (Stage 3), Passivhaus workshop (Stage 2).	Sustainability engineers and consultants

Guided by Meyer et al.'s (2016)[3] archaeological approach in visual research, an analysis was conducted on of the visuals extracted from the reports to explore multiple dimensions related to visualising carbon-related information integrated into architectural design. For this analysis procedure, 217 visuals were analysed using Miro app.

Stage 1 findings

Stage 1 began with describing how the visuals were used in the net-zero design process. At this stage of the research, the data analysis focused on how sustainability consultants and MEP engineers used visuals to report decisions related to carbon reduction. Two key themes emerged describing how the visuals were used in the participants' reports and presentations. The first theme, '*Positioning*', highlighted the use of visuals to represent recognised standards and frameworks established by leading organisations in carbon reduction for the built environment, such as LETI and UKGBC. These visuals were employed to explain the approaches and concepts underlying decision-making processes, ensuring that reported decisions were grounded in credible references.

The second theme, '*Comparing*', informed how visuals served as persuasive tools for presenting and justifying proposed design solutions. In this context, infographics, tables, and other visuals quantified building performance and aligned it with standard guidelines. These comparisons clarified areas requiring intervention, outlined prioritisation strategies, and evaluated alternatives. Benchmarking against established targets was central to validating the efficiency and relevance of the proposed solutions. Alongside benchmarking, visuals illustrated comparisons between building performance at various project stages and predicted performance across the building's lifecycle.

Stage 2

Stage 2 data collection

This stage of the research examined ways architects discussed use of visual artifacts in designing commercial and mixed-use buildings in the UK. This stage relied on the photo elicitation method in which images were used to facilitate conversations about the researched inquiry (Oliveira et al., 2023). The conversations were carried out during a series of workshops that included professionals, primarily from architectural backgrounds, to gain a broad understanding of the dimensions related to the use of each image.

A pilot study was conducted prior to data collection to test the suitability and clarity of the research questions. This pilot was carried out through an online workshop that included six participants with architectural background and one sustainability consultant. During the workshop, professionals from different firms were grouped into 3 breakout rooms, each included 3–4 participants, a staff member, and a doctoral student, both from the University of

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[3] Meyer, R. Hollere, M. Jancsary, D. and Leeuwen, T. (2013) 'The Visual Dimension in Organizing, Organization, and Organization Research Core Ideas, Current Developments, and Promising Avenues', *The Academy of Management Annals,* 7(1), pp. 487-553.

Strathclyde to facilitate the conversation. The participants were asked to share 2–3 images and reflect on them while answering questions about the following:

1) Why did they choose the image?

2) What was the context of its use?

3) How did the use of the image affect design decisions in the project?

Observations from the pilot included limited reflective engagement among the participants in each breakout room. Accordingly, Stage 2 data collection relied on in-person workshops where photo elicitation was carried out with members of each firm. Arrangements for the in-person workshop followed a procedure similar to that followed in the pilot study. The conversations in the workshops evolved around answering the following questions:

1) What was the context where the image was used?

2) What was important about the image?

3) How did the users engage with the image?

4) How did the use of the image affect / related to the design?

5) What did the image inform about carbon in the design?

Stage 2 sampling strategy and recruitment

Criteria for selecting the potential participating firms aligned with the scope of the project inquiry, focusing on architectural and construction engineering firms that had delivered net-zero non-domestic projects in the past three years in the UK. To capture a broad range of dimensions that could emerge from their design communications, the selection criteria were further refined to focus on large and medium-sized firms, defined by the number of members, diversity of in-house expertise, and project size. However, the number of firms recorded by the search conducted by the project team identified fewer firms than required for carrying out the research activities. A revision of the selection criteria included small-sized firms and firms that set a strategy to integrate net-zero targets into their projects.

A total of 39 potential participating firms were contacted via an email with a direct invitation for the online workshop (the pilot study) sent to the design directors, sustainability leads, in-house Passivhaus designers, and members of the firms who engaged in net-zero projects and the firms' admin staff. The invitation introduced the project participation details and requested the potential participants to send 2-3 images prior to participation. Seven firms, including architectural firms and a sustainability consultancy firm accepted the invitation for the online workshop, 4 of which continued engagement with the project through the in-person workshops. To maintain the anonymity of the participating firms in this report, we refer to them as P1, P2, P3, and P3B. Despite the small number of participating firms, compared to the number of the firms that were initially contacted, their engagement was driven by personal interest in the topic and improving the communication of carbon-related details in their work.

Enthusiasm in participation was demonstrated when two of the firms expressed their interest in further collaboration with the project and endorsing the project's activities to other branches of their firm.