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A concept design stages protocol to support collaborative processes in architecture, engineering and construction projects.

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2021

A concept design stages protocol to support collaborative processes in Architecture, Engineering and Construction projects

Abstract

Purpose/Design: A collaborative approach from the outset is imperative for project success, especially when considering multidisciplinary teams in the Architecture, Engineering and Construction (AEC) industry. However, involving different disciplines hinders communication paths and affects informed decision-making. This paper proposes and tests, through a series of structured multidisciplinary design activities, a 'Concept Design Stages Protocol' (CDS Protocol) to structure project initiation, to attain smoother collaboration and greater consensus among multidisciplinary project teams.

Findings: Based on these findings, the research demonstrates that the CDS Protocol provides a solid foundation to aid in the optimal implementation of collaborative design, and with particular regard to multidisciplinary working.

Originality: The research demonstrates the potential for significant improvement in the optimisation of the conceptual design stages, with positive implications for time, communication and whole-team engagement.

Keywords: collaborative processes, multidisciplinary teams, design stages, design protocol, AEC projects.

1 Introduction

Against the backdrop of current policy and professional drivers encouraging the widespread application of Building Information Modelling (BIM), where design certainty is required at an early stage, it becomes even more critical to ensure a smooth transition from the very start of handling a design brief to building the design team and the team members' interrelations, in order to create an enabling collaborative environment (Eastman *et al.,* 2011; Miettinen and Paavola 2014; Oh *et al.,* 2015; Succar and Kassem 2015). The potential benefits of being able to optimise processes and communication between design team members extend to affect time resources, and the ability of teams to develop, agree and complete designs which meet extensive design requirements, including implications for buildability, whole-life performance and satisfaction of client and building user needs (Papadonikolaki *et al.,* 2019). Furthermore, by being able to support an inclusive and whole-team approach at the conceptual design stages, the central aims of lean construction can be addressed (including minimisation of material waste, optimisation of human resource and expertise), and ensure that the core design drivers underpinning such optimised design can be carried into the detail design, construction and operational stages (Whyte and Hartmann 2017). Therefore, this paper might best be regarded as addressing a topic which is central to current challenges facing the industry, helping to ensure that a change in design team collaborative behaviour can be supported. Success in establishing such an environment requires maximising the information exchanged among the project stakeholders, including consideration of their motives and objectives, the contract strategy, and the identification and allocation of risk, uncertainty and costs (Bryde, Broquetas and Volm 2013; Lu, Won and Cheng 2016).

To this end, cooperation in relation to decision-making, planning and risk allocation can lead to predicting, preventing and overcoming unforeseen problems that arise during a project, thus making collaboration a central theme for the delivery of projects within the Architecture, Construction and Engineering (AEC) industry (following Egan 2008; Latham 1994). Importantly, the project initiation and concept stages are "the phase at which the greatest degree of uncertainty about the future is encountered" (Uher and Toakley, 1999). The early design stages are the most vital for the development of the building and the decisions taken during these steps are significant for the further progress of the project, in relation to project's life cycle including cost, performance, reliability, and sustainability (Hsu and Liu, 2000), and deficiencies identified during the later stages of any project usually require increased and significant costs in order to compensate or to correct for the early design shortcomings (Leon *et al.,* 2014; Shen, Ong and Nee 2010; Wang *et al.,* 2002). Therefore, it is argued that a shift of paradigm with the focus of effort directed towards the early and concept design stages will ultimately lead to fewer problems with project execution and cost, mainly when applied within a multidisciplinary collaborative context. Indeed, this gap in knowledge between theoretical aspects of design collaboration and practice can be regarded as an important area for investigation. This research, then, aimed to explore the use of a design process protocol - that is, a structured approach to early stage design processes - to ensure efficient collaboration during the development of early project phases. Previous studies have suggested that this can result in greater overall project success in terms of design efficiency and lowered risk of cost escalation due to later design changes (Kolltveit and Grønhaug 2004; Jones, McQuitty and Thompson 1992; Morris 1989; Sinclair 2013).

The paper is structured as follows; following an extensive literature review of previous research in relation to existing processes and descriptive models for solution finding, a Concept Design Stages (CDS) Protocol is proposed. This is evaluated through a number of case studies, where the results are compared to that of a control group, thus validating the CDS Protocol with regards to the mapping of pathways to "best practice". The paper concludes by highlighting that the practical application of the CDS Protocol is timely, primarily due to the increasing demands for efficiency and effectiveness in processes, with the BIM mandate and the cost efficiencies placing higher pressure in the construction industry. Practical application of such processes will be critical for achieving increased efficiencies but also for addressing a smoother transition and avoid information loss among the different design stages.

2 Concept Design Stages Protocol development

A systematic framework is proposed to address multidisciplinary problems with a focus on ideation, workflow, education and organisation, thus bridging the gap between the early concept and design stages. Such a framework could help embed the findings of research work in reflective practice and descriptive solution finding, which has developed in a fragmentary fashion to date (Cross 2008; Lawson 2004; Schön 1991; Sommer *et al.,* 2014). It would also promote facilitation and collaborative approaches to management. Bridging the gap between ideas generation during concept design and their representation in later and more advanced design stages is about linking the space of ideation with communicating and realising these ideas. As a result, this smooth transition can integrate the different stakeholders, including the design professionals (i.e. architects, engineers, facilities managers), promote informed decision making and minimise iterations and problems at later and more advanced construction stages. Therefore, such a framework could enhance strategic, holistic and integrated project development, thus promoting lean project management and allowing future research to connect all the pieces and stages of project execution within the AEC industry. We propose a framework, termed a Concept Stages Design Protocol (CDS Protocol) which:

- is based on research related to descriptive models of concept and project initiation processes;
- describes the structure and contribution of the CDS Protocol;
- showcases the application of the CDS Protocol in a series of studies together with the future directions and applications of the research.

2.1 Review of descriptive models for concept and project initiation stages

Processes and models describing concept steps for solution finding have been modelled previously from a variety of different perspectives (Schön, 1991; Valkenburg and Dorst, 2008; Pahl *et al.,* 2007; Lawson, 2005; Rod, 2011). Descriptive models illustrate the steps of a process as sequences of actions (Lauche, 2003). These models tend to identify the importance of the concept stage at the beginning of the process, thus focusing on the solution-based approach of design thinking (Cross 2008). The initial concepts are afterwards subjected to analysis, evaluation, refinement and development or, according to Pahl *et al.* (2007) and Cross (2008), analysis, concept, embodiment, and detail design. If there are problems within this process, feedback loops lead to the generation of new concepts and the process starts again. The described process is heuristic, meaning that it builds on the acquired knowledge, and the design problems are ill-defined by nature; therefore, there is no definite solution at the end of the design process. An overview of the concept stages as described in published process models are illustrated in Table 1, and, although, the list may not be exhaustive, however, it provides an overview of the core published concept stages processes. The list is not focused solely on design processes, with the reason being that they all have applications across a range of disciplines (Costa *et al.,* 2015). The shared aspects among them involve the interpretation of the project requirements; development of project characteristics; a search for design solutions and transformation of the solutions depending on suitability and convergence for improved results.

Schön's theories describe the most fundamental problem-solving process applicable to design thinking on reflective practice (Schön 1991); that includes the four steps of naming, framing, moving and reflecting, with feedback loops among them, and this process can be implemented solely for the concept stages with the output taken forward to more detailed design and construction stages. Similarly, tackling an engineering project, as described by Pahl *et al.,* (2007) follows the same principles that involve sequential relationships between the different stages. These stages include conceptualising the problem, embodying and detailing the possible solutions, evaluating them and deciding on a suitable option. During these cases, the solution finding and design process involve the division into working and decision making steps, thus ensuring the links between objectives, planning, execution and control (Pahl *et al.,* 2007; Krick, 1969; Penny, 1970; French, 1971; March, 1984; Archer, 1984; VDI 2221, 1993).

When it comes to AEC focused design processes, the International Organisation for Standardisation (ISO), the British Standards Institute (BSI) and Industry Professional bodies have been actively promoting effective collaboration through key work stages (Sinclair, 2013; East, 2013; BS 7000-4:2013; ISO 44001, among others). According to these models, the solution space is described as a set of steps or stages, which illustrate the sequences of actions that occur during design, with integrated iterations to support incoming feedback for a solution-based approach of design thinking. The RIBA Plan of Work 2013 aims at organising a project's work stages, from setting the strategic definition of a project before the design brief, up to the post-occupancy evaluation after the project has been completed. Similarly, PAS 1192-2:2013 specifies methods to support information management by computational methods, within a BIM environment (Project Information Management, or, PIM). These standards guide data management and information flow from the design brief up to the project's operation. Predecessors of these guides that provided information on design management and CAD systems implementation include BS 7000-4:1996 on design management systems and BS 1192:2007 respectively, superseded by BS EN ISO 19650 19650-1:2018 / 19650-2:2018.

In terms of project delivery and procurement methods, the Integrated Design Process (IDP) is promoting the integration of design and construction lifecycle with clients' requirements, especially during the project initiation and the first three stages of RIBA Plan of Works (BRE, 2014). Integrated Project Delivery or Lean Project Delivery "integrates people, systems, business structures, and practices" while focusing on enhanced communication and collaboration (AIA 2007). Target Value Design (TVD) focuses on integrated collaborative design as well, with a key emphasis on responsibilities, planning and lean systems (Ballard, 2011). A generic framework for the AEC industry that goes into further detail was developed by Austin *et al.* (2001). This research acknowledged a lack of shared understanding during the design activities and suggested that design teams could work better when "in possession of a general program of events or activities through which they are likely to pass than when no such structuring concept is help" (Macmillan *et al.,* 2001).

More recent developments in the field of concurrent engineering and agile processes promote the consideration of multiple viewpoints during solution development (Détienne, Martin and Lavigne, 2005). Collaborative design further supports this process since the cooperative solutions' space, especially within Computer Supported Cooperative Work (CSCW), encourages negotiations among professionals, engineers or designers (Bucciarelli, 1988), as long as it encompasses all the relevant information for the project (Cheng, 2003). The cooperative awareness information as defined by Chen *et al.* (2015) aims to assist multidisciplinary collaboration by providing sufficient information on a project within the digital collaborative platforms, while avoiding information overload.

A final and equally important approach to concept stages comes from project management and business background that highlight the necessity for controlled project gates, where appropriate reviews evaluate potential risks and issues that could threaten the successful delivery of a project (Kagioglou *et al.,* 2000; OGC Gateway Review for Programmes and Projects, 2011). Similarl to the previous approaches, agreement from all stakeholders is required to reach the first decision point of finalising the concept design. Therefore, successful collaboration among the project team members is essential.

Table 1: Overview of Concept stages iterative processes

2.2 Principles and insights for the development of the CDS Protocol

Based on the previous review, several insights in relation to the concept design process applied within the AEC industry have been identified:

1) A concept design process is composed of three main parts (initiation, brainstorming and verification/agreement). The **project initiation** pinpoints the clients' needs and objectives, sets up the business case and concretises the design brief and all its necessary information. Afterwards, the actual **brainstorming** process for ideas generation occurs, with a number of design iterations occurring at that point and finally an **agreement** among the involved stakeholders with **design verification**.

2) While the initiation and verification of a design process are quite clear in their essence, the middle part, brainstorming, describes a process that requires greater detail to be applied for design purposes. This particular part is considered a 'black box' for the AEC industry (Lawson, 2004), with no particular process having been identified.

3) Details of these steps can vary according to different types of projects' complexity, project governance and contractual requirements and due to differences in procurement approaches on project delivery methods, as can be deduced from Table 1.

4) Many problems arise where there is a lack of an organised method to support collaboration between participants, resulting in miscommunications and conflicts among professionals, with non-informed decisions inducing additional design iterations and leading to fragmented workflow (Kagioglou, M., *et al.,* 2000; Pahl *et al.,* 2007; Lawson, 2005; Rod, 2011).

5) Importantly, a smooth integration with the current paradigm of the construction industry (i.e. RIBA Plan of Work, COBie Data Drops, BS 7000-4:2013, LPD, IDP) in relation to design and construction development is fundamental to promote the usability of any new and innovative process from the design and construction teams.

The processes applicable to the AEC industry, in particular, are focused on an overall yet loosely defined approach to the initial design stages with no detailed steps or processes being provided for a holistic workflow during concept design. Design and construction professionals often try to achieve a generic approach on the types of decisions that have to be accomplished without focusing on how these decisions can be taken (Lawson, 2004; AIA, 2007; BRE, 2014; PAS 1192-2:2013; ISO 44001; ISO 19650; Sinclair, 2013; East, 2013). What is more, standards tend to consider the initial stages of a project as consecutive and directional steps, while research has tended to show that the actual process of design has a strongly iterative nature with a significant number of stakeholders, including the side design team and the client. Sinclair (2013) notes that one of the longer-term (level 3) benefits of BIM adoption, for example, with be the possibility of using early design sketches and ideas to perform environmental analysis, indicating the value of '*minimising iterative design time*' at a later stage. Therefore, encompassing enhanced understanding, space for iterations and input from all the involved professionals becomes essential for informed decision-making and effective concept design.

Furthermore, not enough attention is given to the participants in these processes, the team members that have to collaborate effectively in order to achieve the ideas' consensus (Kagioglou *et al.,* 2000; BRE, 2014). This research acknowledges that the lack of shared understanding during the project initiation and the early design activities is one of the most significant factors hindering projects' progression and suggests that multidisciplinary design teams can provide the required information for informed decision making.

2.3 The Developed Concept Design Stages Protocol (CDS Protocol)

Based on the analysis of the descriptive models considered in the previous section, the Concept Design Stages Protocol was synthesised, as illustrated in Figure 1. The CDS Protocol includes structured and linked steps that have been developed to support the early concept design stages among multidisciplinary teams of professionals. The steps are divided between working and decision making, to ensure that the links between objectives, planning, execution and control are made. Three parts have been identified, 1) the project initiation, 2) the brainstorming and ideas generation and 3) the agreement and design verification.

Project Initiation: Bringing together the Multidisciplinary Design Team

Application of the CDS Protocol begins with the formation of the design team and the initial introduction to the design brief provided by the client to the AEC professionals, which includes information on the client's needs, the budget and other disparate specifications deriving from the dialogue among the stakeholders. At this stage, design goals are set, and the relevant AEC professionals evaluate the specifications and derive some further attributes from the information provided (e.g. like the size of the building). Afterwards, the designers will refer to that list of attributes related to the building's typology, regarding materials, structure or other buildings examples.

Multidisciplinary brainstorming and ideas generation

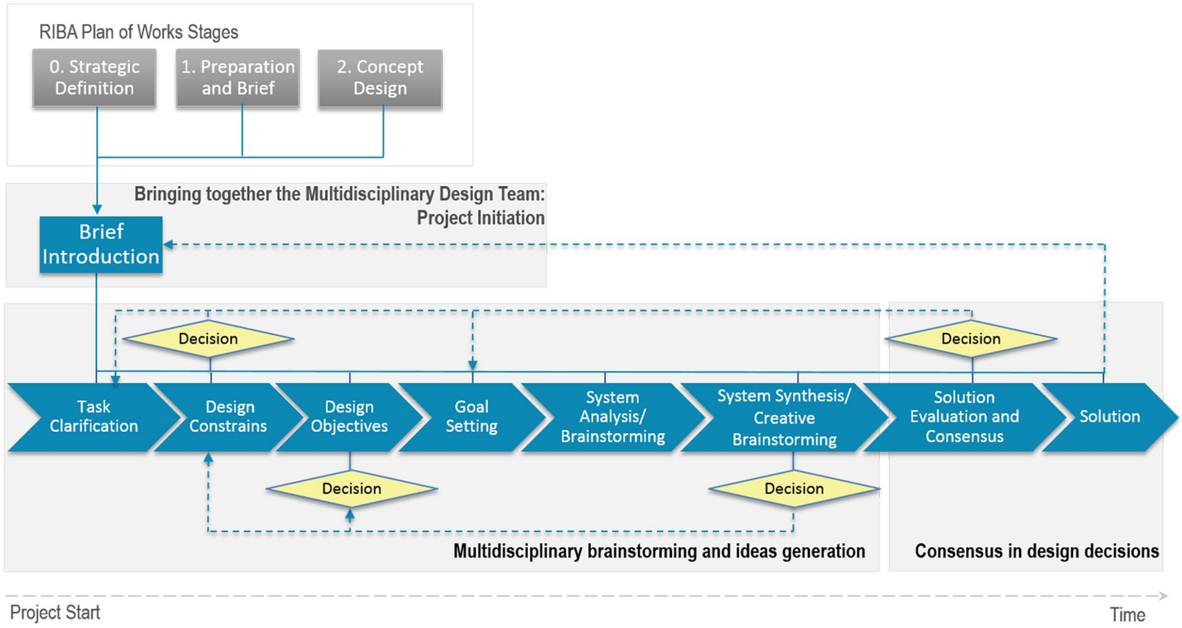
During brainstorming, objectives of the project need to be prioritised, constraints have to be specified, and the first outlines of design proposals are created. Typical constraints applying to most projects will include cost, value creation and value for money of the project, lifecycle of the project, aesthetics, ergonomics, timescale, scope and risk assessment and in many cases, they are project dependent. What is more, design alternatives can be generated by triggering the design with newly imported information. The whole design begins to acquire structure by being decomposed into smaller problems, thus leading to well-structured smaller problems but ill-structured bigger ones.

Importantly, the decision points along the process reflect the shared views and agreements among the participants regarding the project. These decisions consist of small milestones within a project collaboration management where the informed consensus between the different disciplines is achieved. Feedback loops support the reconsideration of the achieved consensus in case this ‘informed compromise’ does not comply with the project’s design brief requirements, objectives and goals. Within the context of this research, the type of professionals involved during the application of the CDS Protocol were restricted to the design team members, with the end-users’ and clients’ requirements and viewpoints described within the brief introduction and the presentation of the design problem. In this research, a moderator applied the CDS Protocol within the context of a design team. In order to further adapt this process to the AEC industry, the role of the moderator could be assigned to the design manager or to a “collaboration” manager. Eventually, the solution achieved at the end of this process represents the product to be published and presented to the client(s).

Consensus in Design Decisions

The third part focuses on design verification regarding whether the design proposal satisfies the functional and other specifications. The suggested solutions are evaluated and the design team achieves a consensus or an informed compromise and the final design solution is proposed. The attributes of the proposed solution are examined against the projects constraints and objectives and the client requirements.

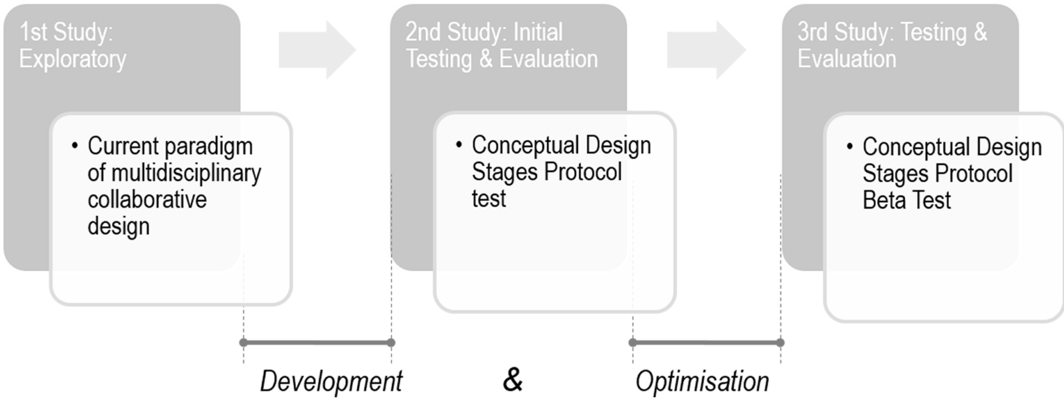
Figure 1. Proposed Concept Design Stages Protocol (CDS Protocol)



3 Methodology

Our framework for studying the manner in which a bespoke Protocol (CDS Protocol) can be used to support design team collaboration during concept stages of a project involved the application of case studies, to develop a well-informed understanding of the phenomenon within a real context (Creswell, 2003), applicable for the AEC industry. Importantly, the reliance on multiple data sources by case study research enhanced data reliability (Baxter and Jack, 2008). The case studies involved an investigation of concept design stages with a control group and two additional case studies afterwards, where the CDS Protocol was implemented, as illustrated in Figure 2. The aim was to evaluate the application of the CDS protocol and to test how it supported multi-party agreement and multidisciplinary 'whole team' early involvement in the design, with the intention of maximising the potential of collaboration and coordination for the entirety of a project.

Figure 2. Case studies



3.1 Case studies structure and participants

Each case study concerned the development of a concept design, as defined by RIBA Plan of Works (Sinclair, 2013), by a multidisciplinary design team, a unique team each time. The case study participants formed a design team comprised of multi-discipline professionals (eight disciplines in all, across the studies), with different participants included in each study to ensure lack of bias, limiting prior knowledge of the processes. All participants had extensive industry experience (five to ten years).

Study one: Architect (two participants), Building Surveyor, Project Manager, Structural Engineer
Study two: Architect (two participants), Building Surveyor, M&E Engineer, Structural Engineer, Quantity Surveyor
Study three: Architectural Technologist, Architect (two participants), Building Surveyor, Quantity Surveyor

A design brief was provided each time concerning the design of a small educational and research facility, located in Scotland. The duration of each of the case studies was 4 hours while all of them were video recorded and monitored by the studies facilitator. The aim for each team was to provide a solution to a given design brief that would satisfy the scope and objectives of the project.

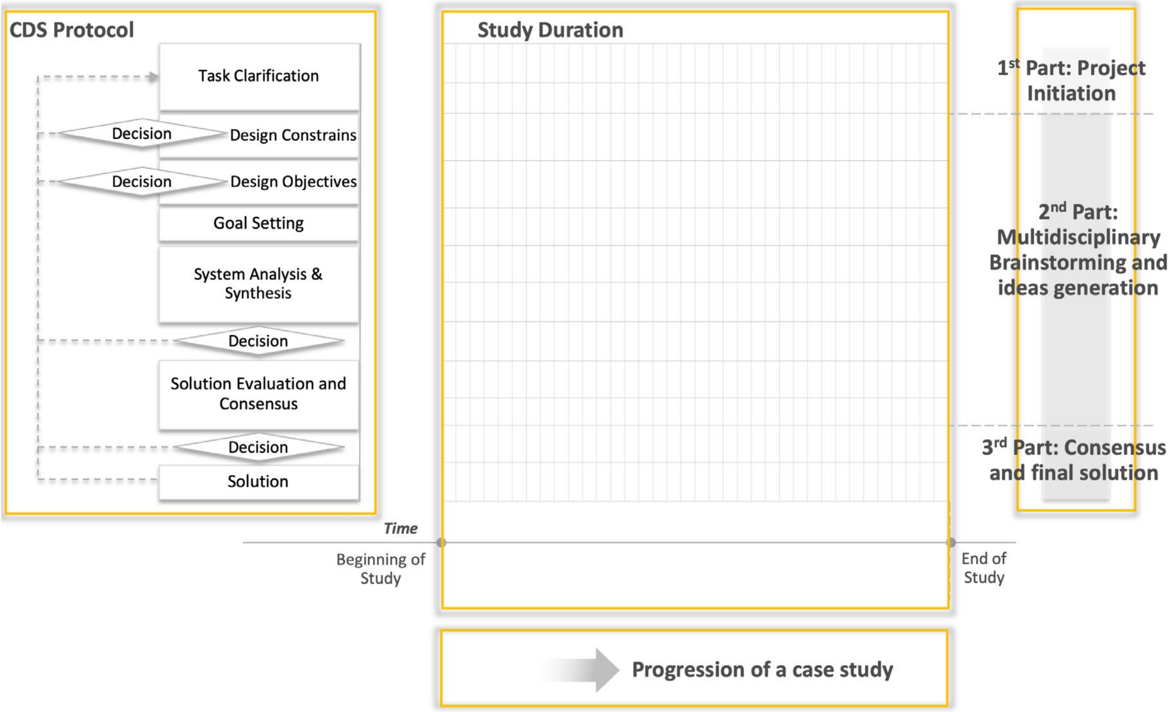
3.2 Data triangulation and the methods applied

For ensuring the validity of the data collected during the case studies, a triangulation approach was followed involving three different data collection methods, for assisting internal validity (Merriam and Tisdell 2016). The three types of data collection methods included activities mapping to evaluate the design team steps in time and against the CDS Protocol, the application of a Design Quality Indicator, and a Likert scale for the self-reported users' perception.

The studies were focused on monitoring the evolution of the design progression and examined if a design consensus and solution was achieved. Therefore, the focus shifted from the produced designs to the process. As a result, activities mapping was the most suitable approach to understand not only the steps that a design team is undertaking but, most importantly, how the process is moving forward and mapped against the CDS Protocol. This approach drew on previous studies concerning design thinking and design team interactions at the concept design stages (Austin *et al.*, 2001; Kim and Maher, 2008; Salman *et al.,* 2014). Through the use of three related design process studies, we drew the activities mapping methodology devised by Austin *et al.* (2001) to identify, map and visualise the phases and stages undertaken by a design team during the conceptual design stage of an architectural project. The data utilised consisted of video recordings of the whole duration of the case studies, which present team members conversations, interactions and gestures, and any type of additional information required to promote design thinking (Stempfle and Badke-Schaub, 2002; Suwa and Tversky, 1997), like sketches drawn from the participants, excel spreadsheets with their calculations and information found on the Internet. From that approach, three separate activities maps were created, as presented in Figures 4, 7 and 11.

The focus of this analysis was the duration and the steps' interdependencies according to the CDS Protocol; this analysis led to the creation of larger design stages' clusters and allowed further conclusions on the iterative nature of the design process applied for the built environment. Therefore, the maps show the evolution of the design process of the studies within time, based on the steps of the given CDS Protocol, and as a result they illustrate how closely the teams of participants followed the CDS Protocol, as illustrated in Figure 3. The vertical lists describe the activities according to the CDS Protocol and the horizontal axis presents the evolution during time and within the different parts of each study. The rectangles characterise a unit of time and the filled squares showcase the occurring activity at a particular time unit. Shadowing of these units is either intense, which is the main activity, or lighter, which showcases parallel and secondary activities. Importantly, even though the CDS Protocol was applied in studies 2 and 3, it was critical to monitor the process of the first study according to the same tool for methodological accuracy. This approach enables observations on the effectiveness of the intended use of the CDS Protocol, while the impact on concept design is mapped and monitored.

Figure 3. Tool for mapping the design activity



A Design Quality Indicator was also implemented for the participants to self-evaluate the design solution individually and rate their conceptual design. The participants' opinions were measured numerically by implementing an answering scale, ranging from one to five. The Construction Industry Council developed the rating tool for measuring and evaluating design quality among the project's stakeholders (Gann *et al.,* 2003; Prasad 2004; CABE 2011), and it was based on Vitruvius design qualities that describe design qualities based on 'commodity, firmness and delight'. Design quality is a totality and not the sum of parts according to Prasad (2004) and the three quality fields in the rating tool included functionality (use, access and space), built quality (performance, engineering systems and construction) and impact (form and materials, internal environment, urban and social integration, character and innovation), in a synergistically approach.

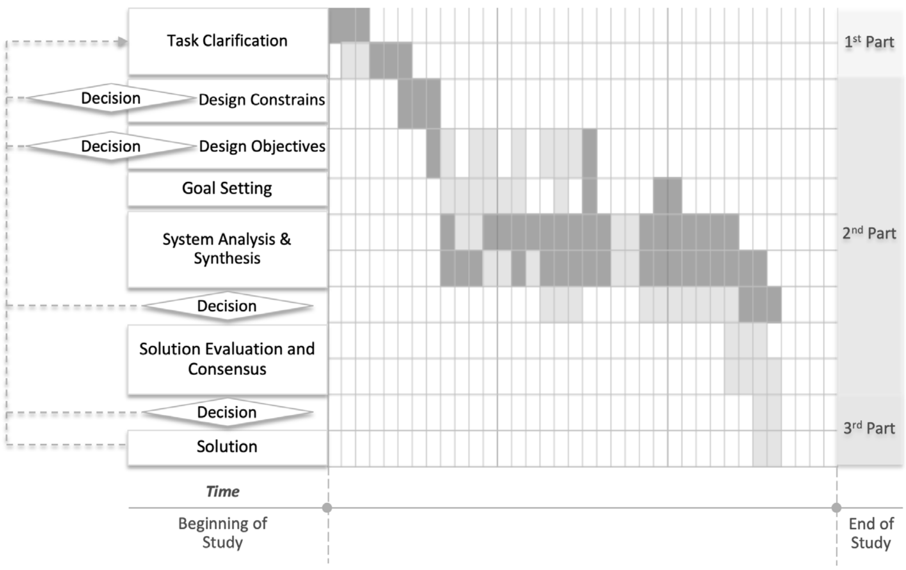
The third data collection method involved a Likert scale for the study feedback since it was the most suitable tool to provide the self-reported users' perception (Tullis, 2013). The particular system was able to capture the experience of the participants and their personal opinion. A classic type of scale was utilised with a five-point scale of agreement, with statements that did not evoke potentially different attitudes than what expected. All case studies included questionnaires regarding the overall and group feedback, while studies two and three included an additional questionnaire evaluating the effectiveness of intended use of the CDS Protocol.

4 Evaluation and validation of the CDS Protocol

4.1 Control group - first study results

The first study was focused on the current paradigm of concept design processes, monitoring the steps of a multidisciplinary design team to develop a concept design based on a design brief. The participants did not receive any guidance on what process to follow, and they had no walkthrough or framework to support tackling the design task. The team displayed interdependency at the beginning of the study, followed by more intense activities focusing on system synthesis and analysis for the most considerable part of the study. The actual design activities were fragmentary, since the team leaped the introduction to the actual brainstorming without deciding on critical aspects of the project. As a result, that led to a large number of feedback loops between setting goals, deciding on aspects and moving back to brainstorming.

Figure 4. Design activity during the first study (dark areas highlight the main activities while the lighter ones parallel and secondary activities)



Professional disciplinary silos were also quite prominent, with the less design-led professionals less active in the collaboration. The overall process moved slowly, there was a slow production of designs, and no decisions were taken for the overall project goals. The lack of particular direction appeared to lead to a series of open-ended discussions on the building's typology, space organisation and energy performance. A variety of different solutions were examined, and the design concepts were generally undeveloped, while no final design was decided. The clusters of intense activity during introduction and design were monitored and indicated in Figure 4.

Following the completion of the design process, the participants were asked to evaluate their design and filled the Design Quality Indicator, with the findings illustrated in Figure5 and the self-evaluation of the whole process, as illustrated in Figure 6. Overall, even if they were not pleased with their end product, the first team commented that they considered the process productive, and they felt that the interdisciplinary approach widened their vision. On the other hand, the designers in this team feared that their creativity was restricted due to the input of the other disciplines, while at the beginning of the first study the project manager had commented on the suitability of the professional silos for each design stage.

Figure 5. Case Study one Design Quality Indicator

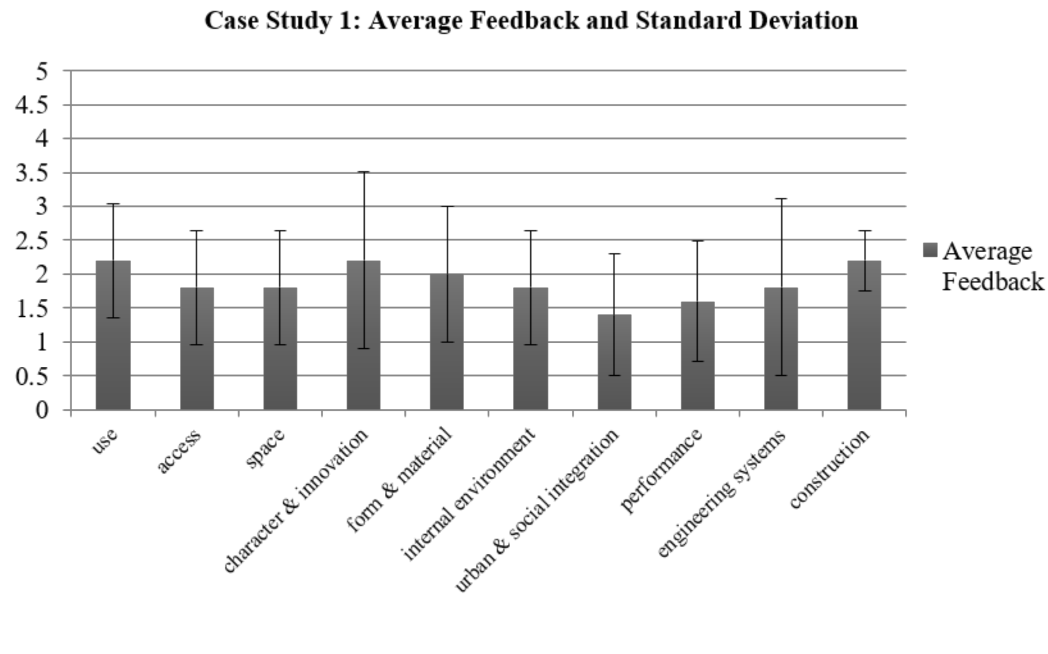
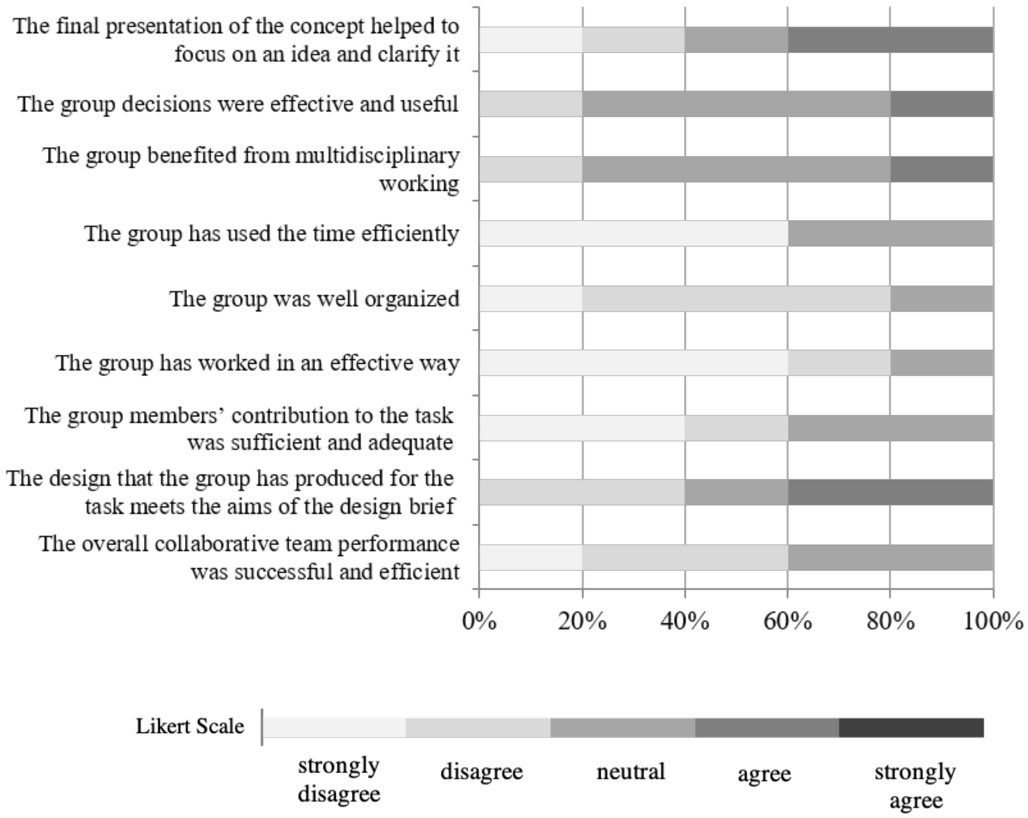


Figure 6. Study one Likert Scale evaluating the overall process the participants followed

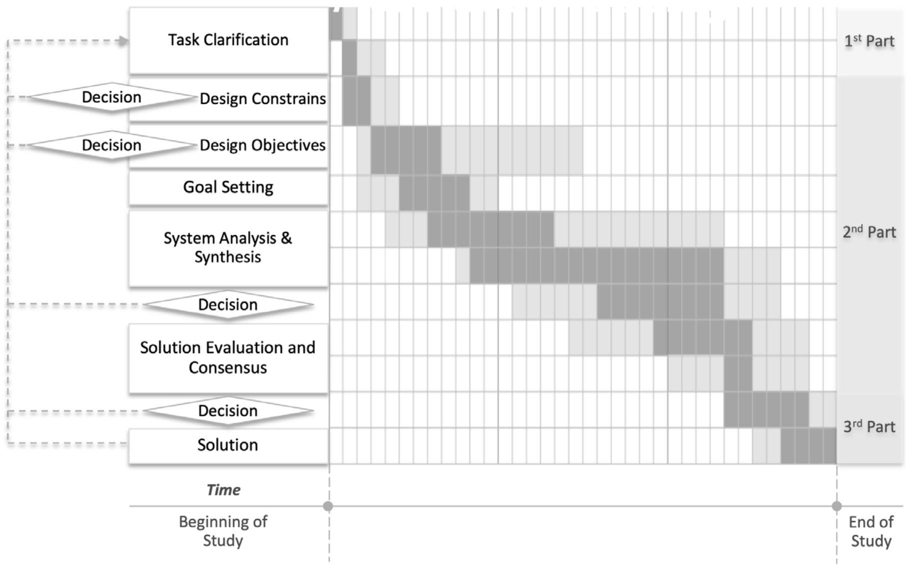


4.2 Second Study results

During the introductory section (presentation of the brief), the design team participants had already started considering the different aspects of the building while they had already started discussing the restrictions that could potentially occur, issues with the budget and the position of the building. As a result, the team was discussing the objectives and constraints immediately and from the beginning of the design process, thus following the theorised CDS Protocol. Deciding on the objectives and constraints was quite fundamental during this study and the team thoroughly examined alternatives until achieving consensus on the project aim and objectives. The iterations occurred between deciding objectives, goal setting, system analysis and creative brainstorming/designing. Following this, the synthesis and brainstorming activities were smoother than in the first study, while decision and project finalisation (3rd part of the study) was straightforward.

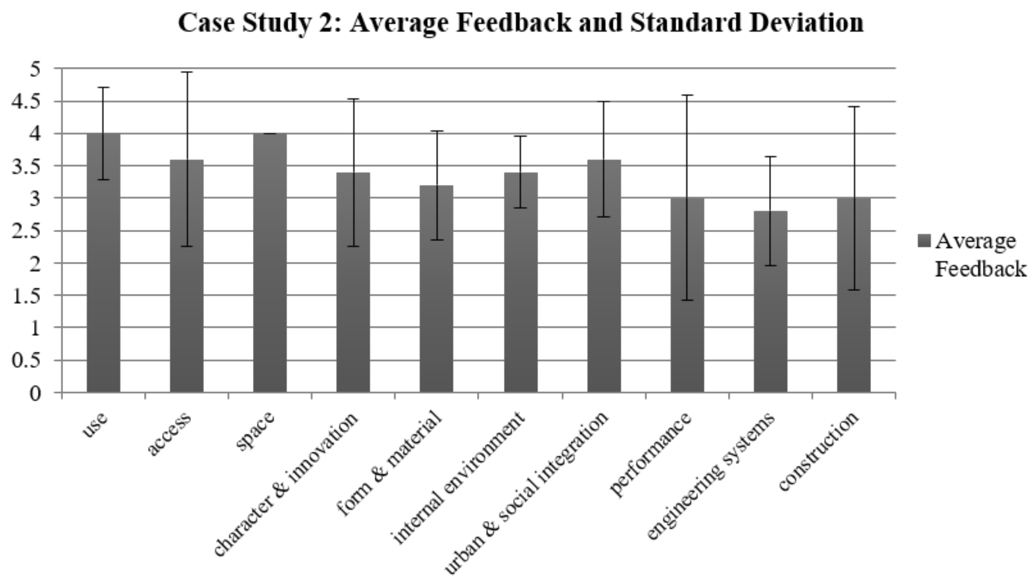
The multidisciplinary team followed a linear process, as represented in Figure7; there was a gradual design evolution with several activities co-occurring and small iterative steps happening during the whole duration of the study as parallel activities. This can be explained based on the fact that the design team was considering multiple options simultaneously during the design; as a result, the main activities were complemented by secondary and parallel lines of discussion and creativity. Such an example includes the relation between system analysis, system synthesis and decision steps, where the highest number of iterations took place between these steps. The system synthesis during the first stage of the study was a speculative process since the intensity of the activity was still focused on deciding on objectives, constraints and goals for the design task. Afterwards, an intensive system synthesis and analysis occurred, which lasted for half the duration of the study. At the same time, the team evaluated design decisions and updated them according to constraints and objectives they had set in the beginning.

Figure 7. Design activity during the second study (dark areas highlight the main activities while the lighter ones parallel and secondary activities)



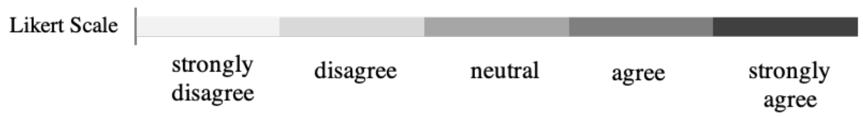
The team was overall pleased with the conceptual design and the details of the feasibility stage that they produced during the study, as it is illustrated in Figure 8. The participants were in agreement when rating some of the characteristics of their solution, with smaller deviation observed in internal environment, forms and materials, while a much higher deviation was monitored when evaluating aspects like character and innovation of the project, access and performance. The reasons for that can be identified on their perceptions of the process; they believed that not enough time was spent on topics of their professional focus.

Figure 8. Case Study two Design Quality Indicator



This team reported that they would have preferred to work for a longer duration and apply the CDS protocol for a longer period of time (Figure 9 & 10). They also acknowledged the importance of multidisciplinary work and they recognised that for the available time they managed to produce an excellent result that achieved team consensus. On the other hand, though, the professional silos were quite divisive in this case as well and it required hard work on the collaboration and ideas' exchange aspects.

Figure 9. Study two Likert Scale evaluating the overall process the participants followed



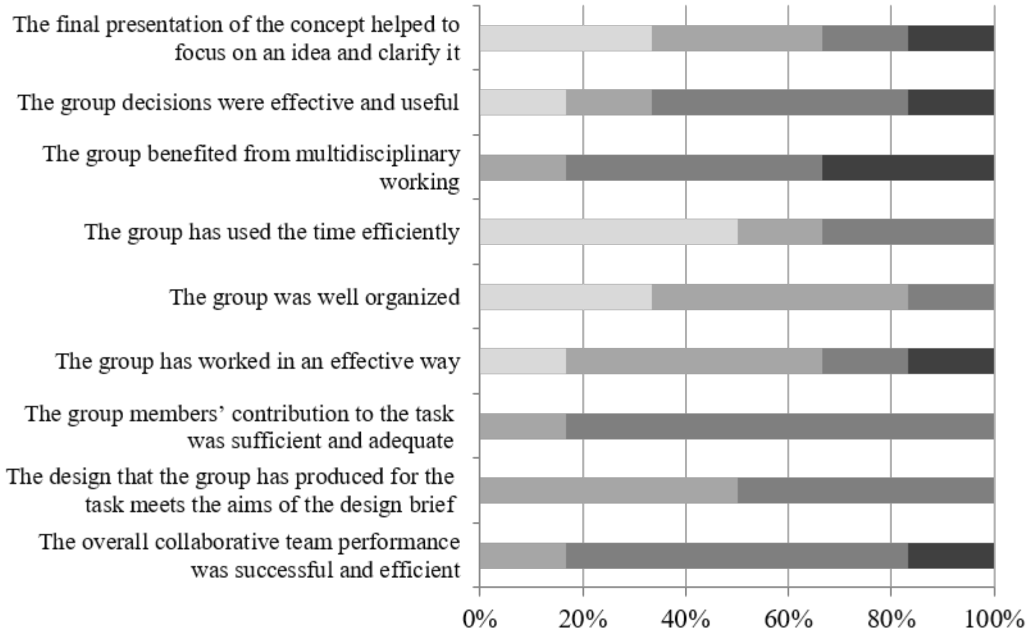
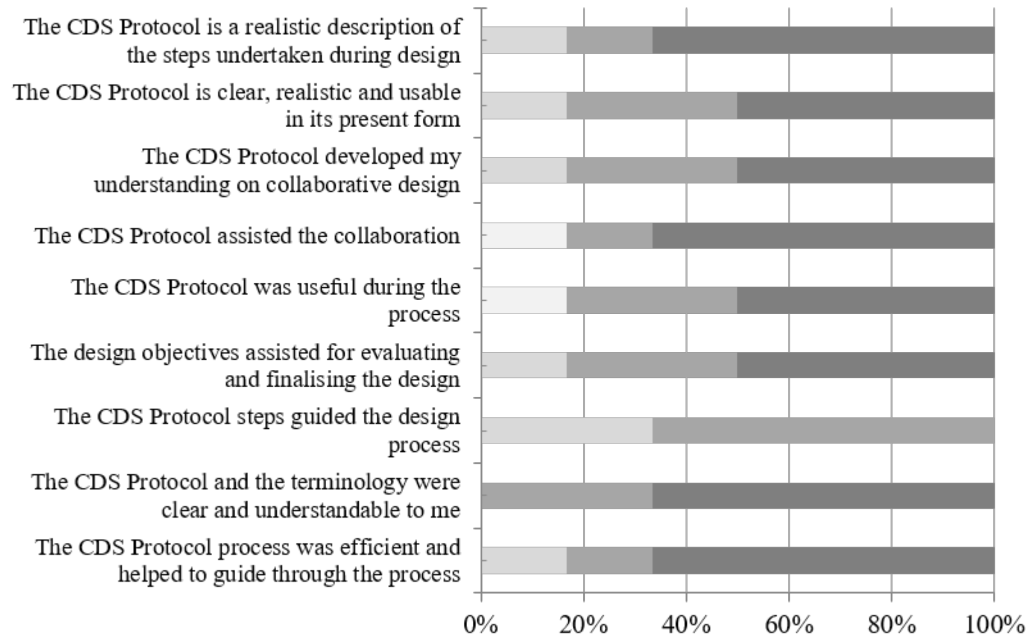
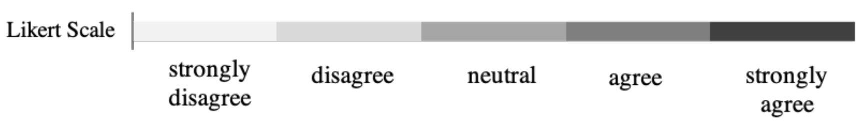


Figure 10. Study two Likert Scale evaluating application of the CDS Protocol





4.3 Third Study results (beta test, following optimisation)

The team commenced the study with a holistic approach to their concept design process by following the CDS Protocol while considering multiple steps at the same time, including discussing possible solutions, and use of various digital and analogue design mediums (Figure 11). Communication among the participants was promoted, with all the different disciplines participating in topics like the budget, the building's potential shapes and building regulations. The specific team chose to investigate their ideas by transferring them to Autodesk Revit, and negotiations took place among the multidisciplinary participants for finalising the design, deciding on constructability and cost, with all of them pleased with the end result (Figure 12). Any problems that emerged were acknowledged as part of the detailed design and soon after the study came to a halt since the concept design was completed.

The design process was linear, but it did not only start by deciding on objectives and constraints as such, rather they instantly started brainstorming on potential design solutions. The design objectives and constraints as specified from the design brief and the project execution plan were guiding their decisions from the beginning of the study. Soon after, the team members were adapting that information according to their professional viewpoints and were adjusting the design objectives to their project. Multiple steps were being undertaken simultaneously, including brainstorming and evaluation of their ideas; at the same time, the CDS Protocol provided the flexibility for the team to move between deciding on design aspects and synthesising information. This process lasted for the whole of the second part of the study (brainstorming) and the final design consensus among the team members was achieved during the middle of the third part of the study, as illustrated in Figure 11. This team gave the most positive feedback on the multidisciplinary work (Figure 13) and the CDS Protocol (Figure 14), they were enthused with the ideas' exchange and realised that it was of great assistance during the process, even though they would have preferred to work for a longer duration.

Figure 11. Design activity during the third study (dark areas highlight the main activities while the lighter ones parallel and secondary activities)

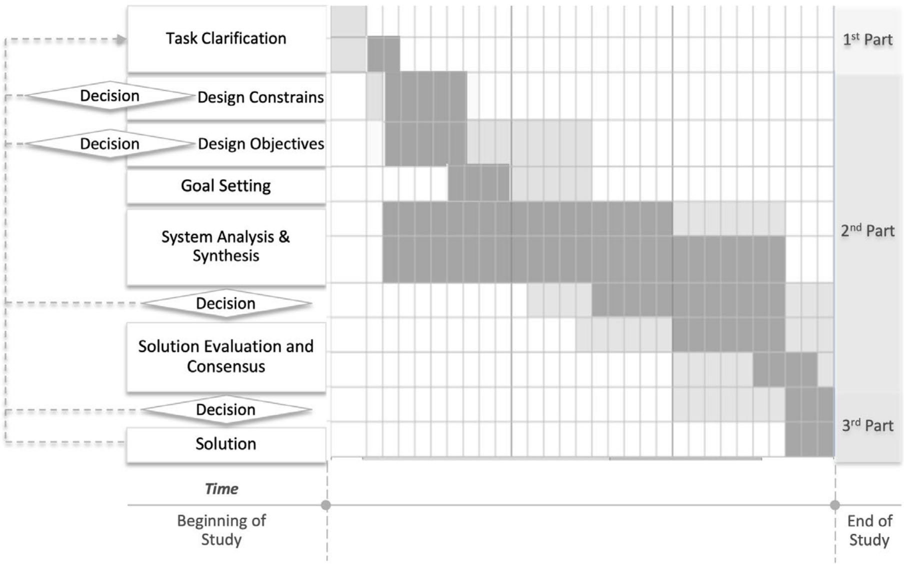


Figure 12. Case Study three Design Quality Indicator.

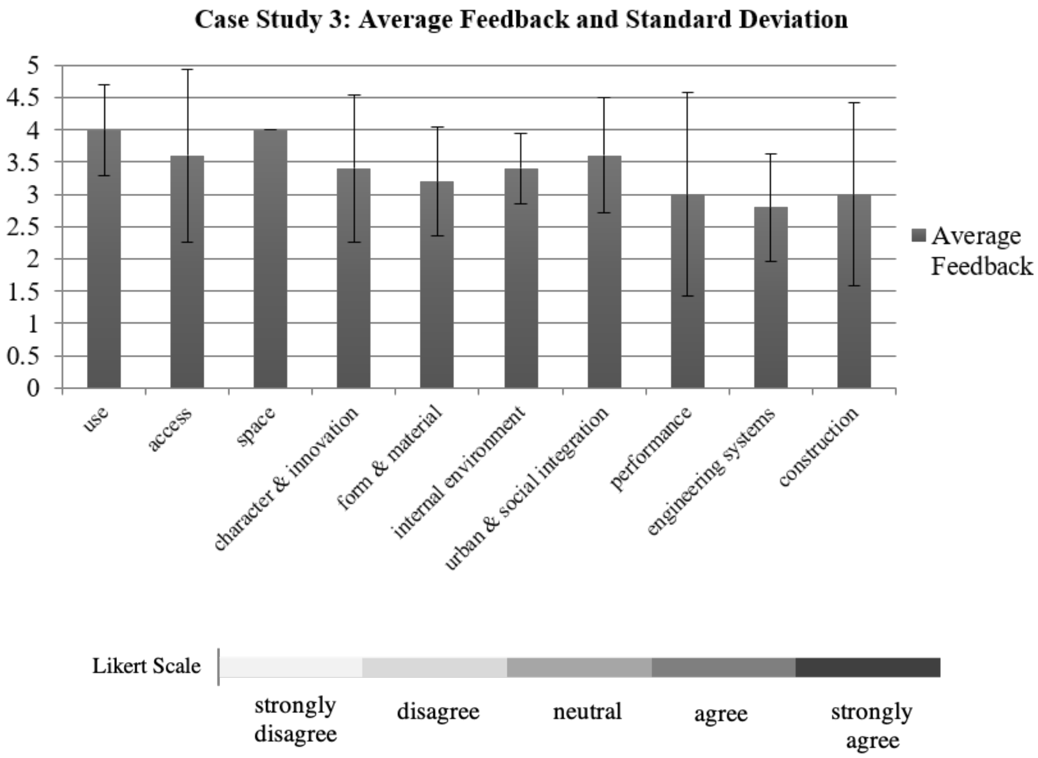


Figure 13. Study three Likert Scale evaluating the overall process the participants followed.

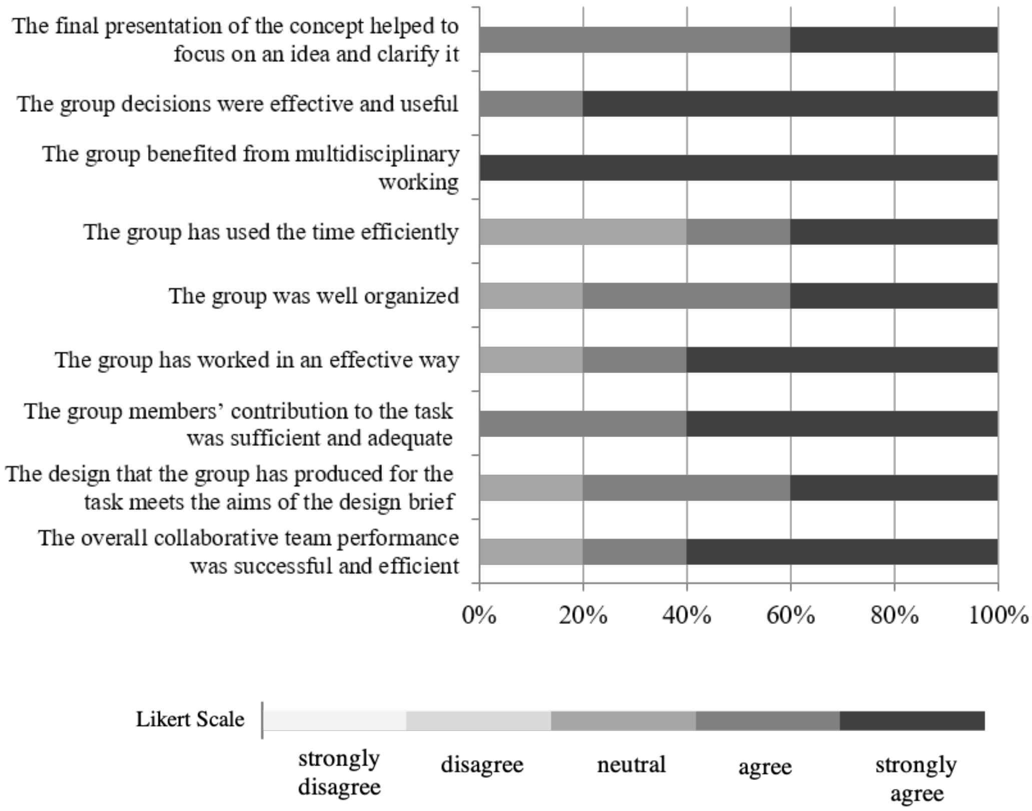
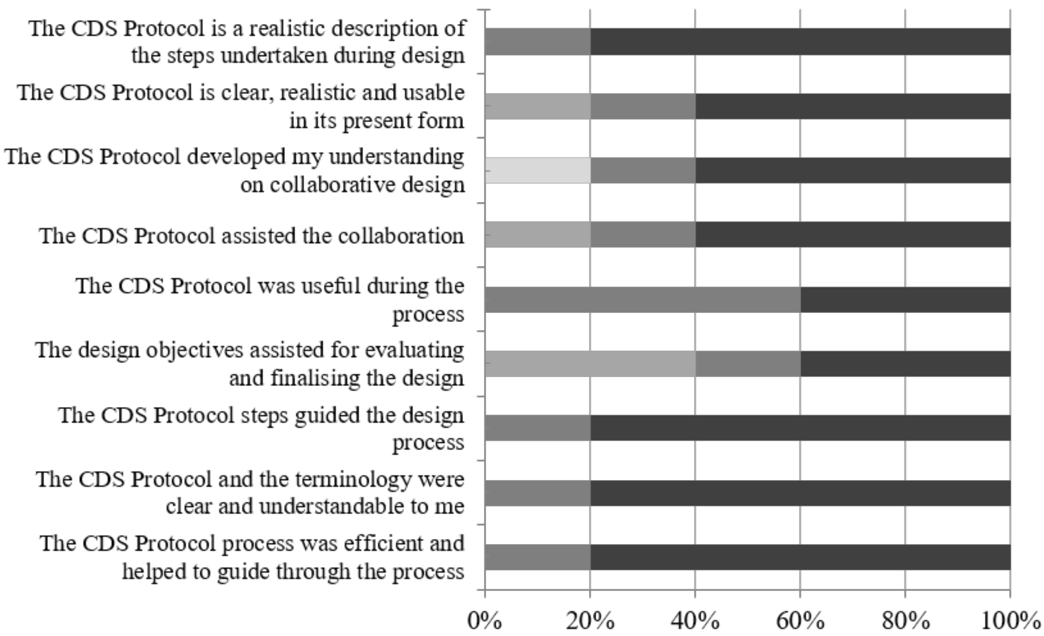


Figure 14. Study three Likert Scale evaluating the application of the CDS Protocol



5 Discussion of Findings and Conclusions

Discussion: contribution to knowledge

The conceptual model of CDS Protocol as derived from the specific study contributes both to theory and knowledge. Not only it confirms previous research that highlights collaboration as a procedural approach (Gray, 1985), most importantly, it builds on previous research on descriptive solution finding processes (Schön, 1991; Lauche, 2003; Cross 2008) by bridging the gap between the early concept and design stages; thus, CDS Protocol advances the related body of knowledge. At the same time, and according to several researchers (Cross 2008; Lawson 2004; Schön 1991; Sommer *et al.,* 2014), reflective practice and descriptive solution finding developed in a fragmentary fashion to date and this study addresses these issues by embedding the findings of research work in reflective practice and descriptive solution finding.

Working in professional silos and having separate discipline-limited solutions continues to be a common practice within the AEC industry, hence causing problems for collaborative practice and miscommunications among design teams (Matthews *et al.,* 2018; Sommer *et al.,* 2014; Sinclair 2013; Egan 2008). Consequently, not only collaboration is of paramount importance (Oraee *et al.,* 2019), most importantly, the information exchanged during team meetings could benefit from the application of the CDS Protocol. As shown here, this would also offer a smooth integration of design decisions and informed decision-making, within the context and the requirements of any given project.

Discussion: Impact to practice

The knowledge areas within descriptive solution finding processes target an overall investigation of the potential solutions space, thus, involving projects requirements interpretation, development of projects characteristics, and a search for design solutions, which are transformed based on suitability and convergence (Schön, 1991; Valkenburg and Dorst, 2008; Pahl *et al.,* 2007; Lawson, 2005; Rod, 2011). Solutions finding processes are not restricted to specific sectors; instead, they have applications across different disciplines, from engineering and construction to design and manufacturing, among others (Costa *et al.,* 2015).

Practitioners and project managers often apply stages and gates during projects (PMI, 2017); however, there are limited mitigation measures to avoid information loss between early concept and more advanced stages. The CDS Protocol provides a practical framework, according to which several recommendations can be outlined. The CDS Protocol can systematically, strategically and efficiently bridge different professional viewpoints and promote an effective and analytical ideation process. This conceptual model also outlines a practical approach according to which a recommended process is defined, which can be considered as gated stages for managing collaborations.

Furthermore, and similarly to Harty (2012) and Bosch-Sijtsema and Henriksson (2014), who suggest different types of professionals undertaking managerial roles, this research suggests an additional role for any project team, the CDS Protocol moderator or else the role of "collaboration manager", a role intended to monitor and ensure that the teams are following the structured collaborative frameworks. For the purpose of adapting the process to the AEC industry, it is essential to consider the potential professionals who could embrace this role. The CDS Protocol is not dependable on any specific profession; as a result, it could be applied from different types of professionals related to project management, design management or professionals that have a deep understanding of the multidisciplinary collaborative teams. Current agendas focused on BIM require effective collaborative work; therefore, the CDS Protocol provides a collaborative process through which this can happen.

Comparing activities mapping within the 3 studies

Following the critical comparison of the case studies, the essential conclusions included the evolution of the design process and the faster progression of the feasibility stage when using the CDS Protocol. The first study (control group or the current paradigm of multidisciplinary teamwork) was irregular, inconsistent and stagnated due to lack of a particular focus for the participants and due to their unwillingness to collaborate. It did not result in a concept design solution, and neither team consensus was achieved. However, during the second and third studies, the participants reached a concept design solution, and the application of the CDS Protocol assisted the design process since it kept the participants focused on the design task steps. Furthermore, the Protocol allowed the multidisciplinary collaboration since the design brief specifications and consequent decisions on it were requiring the understanding and consensus of all disciplines.

Most importantly, it guided the participants regarding their own progress, and they were able to self-manage the development of their ideas. The two teams that applied the CDS Protocol were able to work efficiently and develop their concept designs that reflected all the topics and design briefs they discussed. They also achieved multidisciplinary agreement on the concepts produced, by following a demonstrably dynamic collaborative design process, with extensive interactions among the participants following concurrent processes and multiple viewpoints.

The CDS Protocol is demonstrated to be a highly adaptable and represents a collaborative design process that could be applied at any point within the different stages of design. Additionally, the teams' structure and the professions of participants could further adapt according to the type of procurement model utilised for a project. The duration of this process and its milestones are not restricted, but it could be modified according to the requirements of a project. Regarding the application of the process, it could be facilitated by design, collaboration or project managers, and it could easily be integrated within an ongoing or a new project.

6 Limitations and future research

It is acknowledged that this research has yet to exhaust the field of collaborative working within AEC industry. These limitations might be in the considered theories within the literature review section and most importantly, in the application of the CDS Protocol and its methodological protocol analysis; the case studies were simulating professional practice and they involved laboratory-based observations over time-limited design sessions. Protocol studies methodological approach are characterised by time demanding data collection and analysis (Salman, 2014). Importantly, protocol studies' methodology acceptable teams' size in most published protocol studies require a sample size of one to three or four to six participants (Jiang and Yen, 2009).

This research showcased that the CDS Protocol aids project initiation by facilitating enhanced communication and informed cooperation across multidisciplinary professionals involved in concept stages. This is achieved with guided facilitation of the CDS Protocol. The data analysis of three case studies proved that the application of this CDS Protocol not only promoted understanding among the different disciplines but also created the environment for informed decision making and actual multidisciplinary design work. CDS Protocol integration with the current industry processes allowed design teams for a straightforward application. Further research would necessitate a systematic longitudinal study where the CDS Protocol is tested in real-life situations within the concept design stages of projects, to provide greater insight on teams' interactions, improve the CDS Protocol as such and integrate it in a smoother way within the teams' meetings. As a result, the information exchanged during design and construction team meetings would align with the CDS Protocol, thus enabling an automated computational approach to demystifying the exchanged information and decision making.

The application of the CDS Protocol could lead to a smooth integration of design decisions and informed decision-making within the context and the requirements of a project. The CDS Protocol aims to systematically, strategically and efficiently bridge different professional viewpoints and to promote an effective and analytical ideation process while this research provides a solid foundation for a more comprehensive implementation of the CDS Protocol within different design and construction stages to work as an aid for informed collaborative practices.

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From problem definition to conceptual design

RIBA Plan of Work 2013	1. Preparation: Project Objectives, Business Case, Feasibility Studies, Assemble Project Team.	2. Concept Design: Outline Design Proposals (Structur Services, Landscape), Preliminary Cost Planning, Agreement on Project Brief					
Integrated Design Process (IDP)	Design Basis & Site Analysis	Refine Brief and Targets	Multiple Concepts Design	On track monitoring & delivery			
PAS 1192-2:2013	Brief	Concept	Definition	Design			
COBie Data Drops 2012	Data Drop 1: Requirements and Constraints	Data Drop 2: Outline Solution	Data Drop 3: Construction				
Cross	Clarify Objectives	Establish Functions	Set Requirements	Determine Characteristics	Generate Alternatives	Evaluate Alternati	
Macmillan, Steele, et al.	Interpret: Specify Business Need, Assess Functional Requirements, Identify Problems	Develop and set Functional Requirements, Determine Project Characteristics	Search for Solutions Transform and Combine Solutions, Select Combinations	Converge: Evaluate and Choose Alternatives, Improve Details			
CIC Scope of Services	Preparation (Stage 1)	Concept (Stage 2)	Design Development (Stage 3)	Production Information (Stage 4)			
BS 7000: Part 4: 1996, Design Management Systems	Design Brief: Interpretation of the Project Brief, Assigning Responsibilities, Brief Development	Concept Design: Outline of the Design Process					
Schön	Identification of the Design Problem	Decision	Reflection	Result			
Pahl e al.	Design Problem	Task & Goal Setting	System Analysis & Synthesis	Decision	Evaluate System	Decision	Embodiment Design
VDI 2221 (Verein Deutscher Ingenieure)	Clarification and Task definition	Specifica tion	Determine functions and their structures	Research on solution principles	Principal solution	Divide into modules, Develop modules layout, complete overall layout, prepare production	
Archer	Training, Brief	Data collection	Analysis	Synthesis	Development	Communication Solution	
March	Induction: Design characteristics	Induction: Evaluate	Induction: Supposition	Production: Data Models, Describe, Design	Deduction: Design Theories, Predict, performance		
French	Need	Problem Analysis	Statement of the Problem	Concept Design	Selected Schemes		
Salford Process Protocol (SPP)	Demonstrate the need	Conception of need	Outline Feasibility	Substantive feasibility and outline financial authority	Outline Concept Design	Full Concept Design	

Office of Government Commerce- OGC Gateway Process 2011	Gate 0: Strategic Assessment (Establish Business Need)	Gate 1: Business Justification (Develop Business	Gate 2: Procurement Strategy (Develop procurement Strategy)	Gate 3: Investment Decision	Decision Point 1: Outline