A Conceptual View of the Interface between the Detailed Design Process and the Construction Process.

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Abstract:

With the closer integration of industry participants, contractors are accepting greater responsibility for managing the detailed design process. Successful management of the crucial and complex interface between design and pre-construction activities is becoming increasingly important. The different theoretical backgrounds to the design and construction processes described in current literature are examined, and their effects on the interface between the two processes in practice are discussed. Published work identifies a significant difference between the theoretical understanding of the design process and that of the construction process. What emerges could have implications for the management of the interface between them. In addition, a potentially significant impact on the design process created by the lack of access to specialist knowledge at the optimal time is also identified.

The significance of conceptual frameworks in research is identified, and the conceptual frameworks for the interface between the detailed design and construction processes are developed. These could provide a basis for an improved model for the understanding and management of the interface that reflects the different theoretical foundations, and for an optimized process for the selection, appointment and input of specialist subcontractors.

Keywords: Design planning, construction interface, contractor led, procurement, theoretical backgrounds.

1. Introduction:

The reports prepared by Sir Michael Latham (1994) and Sir John Egan (1998) into the construction industry in the United Kingdom particularly identified the traditional fragmentation of the industry as lying at the root of many of the industry's problems. This fragmentation placed the responsibilities for design, fabrication, assembly and production with separate commercial organisations, each with their own separate responsibilities, objectives and agendas. The industry's response has included contractual and organisational efforts to integrate design work and construction activities, and to place responsibility for both with one body in a range of design-and-build formats. Advances have been made in transferring responsibility for detailed design in particular to main contractors and, with it, the responsibility for managing the detailed design process. Latham and Egan also identified the need for closer programme integration of design and construction, to overlap the design process more with construction activities, and reduce the period of time between design and its realisation on site.

Partly as a result of these initiatives, considerable research has subsequently taken place into the nature of the design process in construction and its management, by Lawson (1997), Austin *et al* (1999a and 1999b), Gray & Al-Bizri (2004), and others. The ensuing techniques for the planning and control of the design process include those described by Austin *et al* (1999b), Coles & Barritt (2000), and Gray & Hughes (2001). Each is increasingly being used with varying levels of frequency within the design-and-build sector of the construction industry. However, as Lawson (1997:119) stated, "the design process rarely has a natural conclusion of its own, but must more often be completed in a defined period of time". Brawne (2003:160) concurs, stating that "There is, as a rule, an attempt to improve the design, to answer some criticism, until a deadline is reached". Thus it is clearly identified that time is a fundamental aspect of design and of design quality. It follows that planning, which deals with the allocation and use of time, should therefore be placed at the centre of the management of the design process.

The detailed design stage of the design process is the most extensive and complex stage, particularly in terms of the volume of information produced by the design team, the degree of detail, and the proximity to its use in construction. It is also the stage most frequently included within the main contractor's responsibilities under design-and-build or design-and-manage forms of contract (Gray & Hughes, 2001:53). The corresponding increase in the certainty of the contractual arrangements at this stage of the project means clients have higher expectations of the detailed design stage with regard to programme predictability and performance than they do of the preceding stages. In this context 'clients' includes both external and internal customers, those requiring a building and also all of those requiring information from the design process in order to carry out their construction responsibilities. Detailed design is also the principal stage of the design process that interfaces with the construction process. The term ‘construction’ is used here to cover the whole range of on-site and off-site activities, and therefore includes project planning and organisation, the procurement of subcontractors and other specialists during the pre-build period, shop drawings, and off-site fabrication and pre-assembly, as well as the on-site building works. ‘Procurement’ here refers to the selection and appointment of specialist subcontractors and suppliers.

Most of the recent research, including that by Lawson, Austin *et al*, and Gray and Al-Bizri identified above, and many of the resulting techniques for planning the detailed design process, including the Analytical Design Planning Technique (ADePT) (Austin *et al*) and those described by Coles & Barritt and Gray & Hughes (noted previously), can be used to successfully achieve improvements in the internal flow through the design process and the consequent delivery of design information. However, they do so by focussing on the processes within the professional design team (Gray & Al-Bizri, 2007), effectively dealing with the design process in isolation. In reality the detailed design process does not proceed in isolation; it has interfaces with the initial stages of the construction process, primarily those that occur in the period prior to works on site, and including in particular the introduction of more comprehensive and accurate design information by enlarging the project team through the selection and appointment of specialists and subcontractors. It is proposed here that the information requirements of these early construction activities place pressures on the detailed design process that distort it from the natural shape and flow that would prevail if it did indeed take place in isolation. Furthermore, these pressures and the consequential distortion may be increased by the initiatives of Latham and Egan previously identified to increase the programme integration of design and construction and to increase the programme overlap between the two processes. In effect, creating a sub-optimal sequence through the design by constraining the process to conform to the construction sequence is the only means of ensuring the optimal overall project process.

The objective of this study is to achieve greater understanding of the interface between detailed design and construction in order to improve the management of it. It builds on the dependence between detailed design and the input from specialist subcontractors identified by Mitchell *et al*, (2004), considers the theoretical understandings of the design process and the construction process, and is concerned with producing a conceptual view of what occurs at that interface between the two processes both theoretically and empirically. Current theories of the design and construction processes suggest significantly different progressions (Koskela, 2000 and Brawne, 2003), with design perceived as being iterative and cyclical, and construction as being linear in nature. Potentially there may be a significant theoretical dichotomy between the two processes, which could influence the flow of information across their interface and thus affect the management of said interface. A key stage in the investigation of this dichotomy and its possible effects in practice is to develop conceptual frameworks for the design and construction processes and the interfaces between them. To develop these frameworks data has been drawn from published literature and initial investigations and is currently being drawn from case studies in the construction industry and beyond. In due course it will be used to develop an empirical understanding of how this theoretical dichotomy, and the manner in which it is currently managed, affects performance at the interface between the design and construction processes, and how the integrated process can be optimised.

2. Context:

Since time is a fundamental parameter of design, successful management of the design process should include the allocation and use of time; this represents the main contribution of planning to the overall management process. Traditional planning techniques, generally founded on critical path method (Burke, 1993), have evolved over time and are now used successfully for planning site activities and in the planning and control of the works of subcontractors and suppliers. Their use has been extended to include some pre-construction processes, most notably procurement. However, all of these processes are generally sequential in nature (Mitchell *et al*, 2004), and contractors have found that planning based on critical path method has been significantly less successful in planning the design process (Austin *et al*, 1999b). One reason is that the design process is frequently ill defined, generally iterative, and usually contains design cycles (Coles & Barritt, 2000), which cannot be effectively modelled using sequential planning techniques. It has not therefore been possible to extend the use of the contractors' traditional planning techniques into the design process, and contractors have been denied the opportunity to use their tried and tested procedures in the management of their design responsibilities.

However, development of the ADePT planning technique and supporting software (ADePT Management Ltd. 2008) based on Dependency Structure Matrices (Newton, 1995, and Austin *et al*, 1999a), has advanced significantly since the early 1990s, and it now enables iterations to be identified, planned and managed more successfully. Generic models of design processes for a range of building types have been developed and tested, and the resulting design process has then been managed with conventional project management and planning tools (such as 'Asta Powerproject' version 10 from Asta Development plc.).

Current theories suggest that design is generally iterative and cyclical in nature (Austin *et al*, 1999a and Brawne, 2003:33), and construction is generally linear and sequential, (Koskela, 2000:257). This view of construction is based on transformation theory, which concerns the process by which inputs are changed into outputs, and is the theoretical model that underlies the current understanding of the production process and thus of the construction process (Koskela, 2000:38). These contrasting cyclical and linear characteristics make the important interface between the design process and the construction process complex to manage. They also make it difficult to find one tool that will cope with planning both.

In addition, the response of many contractors to the new responsibility for managing the design process and securing the detailed design has been to subcontract it, either internally to design departments or externally to design practices. Some of these subcontracting arrangements necessarily involve specialists, for example for complex trades such as specialist glazing and building services (Austin *et* al, 2001). This introduces further stages to the design process, notably the selection and appointment of specialist subcontractors and the subsequent integration of their specialist design contribution into the design process. The facilities and relationships to circumvent this stage and this aspect of the interface already exist in a mature supply chain. In their work on Integrated Collaborative Design (ICD), Austin *et al*, (2001) discuss the development of project supply chains from an existing business supply chain. They identify the benefits of the 'design chain' inherent in a mature project supply chain, wherein problems can be passed down the supply chain to appropriate specialists, and solutions and innovations can be passed back up to the design team. However, in the area of this research, and in a significant section of the industry generally, supply chains are not yet mature enough for the relationships to facilitate the management of the interface between design and construction, nor to provide robust design chains and the associated access to solutions and innovations (Mitchell *et al*, 2004).

Furthermore, with the pressures to increasingly integrate the design programme with the construction programme, the opportunity to wait for information issue until the design process reaches a suitable state of development is reduced. Information may be drawn from the design process before appropriate maturity is achieved in order to initiate and drive the procurement process and other early construction activities. Design iterations may, and possibly should, then continue after that information has been taken and used, and the design would subsequently evolve beyond the state of maturity it had reached when the procurement activities commenced. Where the design is dependent on input from specialists who will be selected and appointed through the procurement process there is the potential for the design to evolve in an inappropriate direction until that specialist input is secured. Gray and Al-Bizri (2007) confirm that "much iteration occurs because the designer is unaware of [what information is required] or has yet to receive input information to the process". When the specialist input is finally secured significant rework may be required and inappropriate contractual relationships may have been entered into. Gray & Hughes (2001:46) refer to the detailed design stage and the ensuing development of production information and specialists' shop drawings as "the engineering design stage". It is not possible for the engineering design stage to be a simple linear sequence, free of rework, if the design team is yet to receive input information that only specialist subcontractors can provide. However, by better understanding of the interface the management of it may be optimised, specialist information can be secured at the most appropriate time, and consequently rework should be minimised.

It is proposed that both of these problems, namely the difficulty of integrating the planning of design and construction and identifying one approach that will plan both, together with the failure to secure timely input from specialists to the design process, may have their roots in the theoretical dichotomy between the two processes.

3. A Theoretical View:

A review of current literature to understand current developments in design planning, and to review the current theories of the design process and the construction process revealed that neither process is rich in underlying theories. Indeed, Koskela expressed the view that the lack of an explicit theory of construction and sound scientific or theoretical foundations has caused many of the industry's problems (Koskela, 2000:5), particularly because of the hindrance imposed on the industry's ability to innovate and to draw from other industries and other industrial processes (Koskela & Vrijhoef, 2001). Brawne (2003:7) links the paucity of theoretical foundations for the architectural process to design's non-verbal nature and its visual and graphical thinking process. Gray & Hughes state "drawing is inextricably integrated with the design process" (2001:31). The architectural design process does not therefore lend itself to the scientific verbalisation of theoretical foundations. Construction might also be perceived as essentially graphical and visual in nature rather than verbal, and as having a similar and corresponding lack of theoretical understanding.

Design has frequently been identified and described as an iterative process (Austin *et al*, 1999a, Coles & Barritt, 2000, and Gray & Al-Bizri, 2004). Based on Markus (1969) and Maver (1970), Lawson (1997:35) described an initial understanding of the design process as consisting of an iterative series of decision sequences, each of which progresses the design to another level of detail. Each decision sequence consists of analysis, synthesis, appraisal, and decision, which reflects the cyclical nature identified above. In addition, Lawson noted the possibility of 'sub-cycles' of synthesis and appraisal within each decision sequence. In this model of the design process each cycle commences with analysis, examination of the available information and objectives for patterns and priorities. This is followed by synthesis, which Lawson describes as being "characterised by an attempt to move forward and create a response to the problem – the generation of solutions". Darke (1979) recalls Lawson's subsequent identification of the architectural style of operation as being 'solution-focused', whereby understanding of the problem is achieved by proposing solutions and observing where they fail. Darke describes the proposal of Hillier *et al* (1972) that replaced the ‘analysis-synthesis’ model with one of ‘conjecture-analysis’, thus starting the design cycle with a conjectured solution. Darke further adds to this conceptualisation with the proposal of a central idea or ideas, the “primary generators”, as the features that drive the generation of the conjectured solution. The primary generators are described as providing “a way into the problem” and the proposed model of the process thus become ‘generator-conjecture-analysis’. Lawson notes how little some of these central ‘generator’ ideas are genuinely understood until later in the design process when the design reaches a significant level of maturity. Lawson describes the emphasis being placed by designers on the development of the solution concurrently with understanding the problems; synthesis and analysis in parallel (1997:47). Similarly, Gray and Hughes (2001:28) point out that this process is “aimed at increasing understanding through attempts to change or to reframe the problem” as well as at developing solutions.

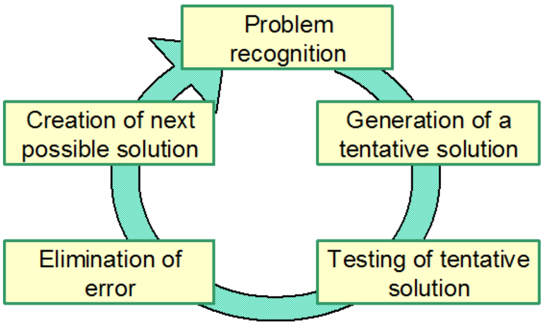
Gray and Hughes (2001:28) from Hickling (1982) also describe the alternative proposal comprising stages of interpretation, generation, comparison and choice. However, they question the linear nature of this model, and revert to the complex cyclical model described as the ‘continuous whirling process’ model of design in Gray, Hughes and Bennett (1994:6) again from Hickling (1982). This represents designers thinking “freely across and around the boundaries of a problem” and shows that, not only is the overall process one of iteration and evaluation, but each stage consists of cycles of iteration and evaluation. This closely reflects the decision sequences described by Lawson. These views are summarised in Table 1.

Table 1: Summary of development of design process models

Model:	**Description:**	**Source**
Analysis-synthesis	Decision sequences of analysis, synthesis, appraisal & decision	Lawson (1997) after Markus (1969) and Maver (1970)
Conjecture-analysis	Conjectured solution used to start the design cycle	Darke (1979) after Hillier *et al* (1972)
Generator-conjecture-analysis	Generator drives the creation of a conjectured solution	Darke (1979)
Interpretation- generation-comparison-choice and ‘continuous whirling process’	Linear decision sequence	Gray, Hughes & Bennett (1994) after Hickling (1982) and Gray & Hughes (2001)
	Free thought across and around the boundaries of the problem	

In his account of the history of theories of the architectural design process, Brawne (2003:33), after Popper (1972), describes the design process as an iterative cycle of problem recognition, generation of a tentative solution, testing that tentative solution and elimination of error from it, and creation thereby of the next possible solution, albeit one still containing problems to be addressed in the next iteration. This cycle is shown below in Figure 1.

Figure 1: The design process as an iterative cycle (based on Brawne (2003.33)



Generally, solutions are perceived to emerge through a process of proposal, testing and error elimination. Notably, no distinction is drawn by these sources between the stages of the design process at which their models apply. Lawson's early model shows the decision sequences and the cyclical design process applying to outline proposals, scheme design, and to detailed design, and Austin *et al* (1999b) have shown that design iterations in at least one form continue into the detailed design stage.

In his discussion of the broader concept of design, Schön (1991:77) refers to the proposition that "all occupations engaged in converting actual to preferred situations are concerned with design". This emphasises the concepts of change and conversion, of transformation and improvement, and of progress towards a "preferred situation" in the overall understanding of design.

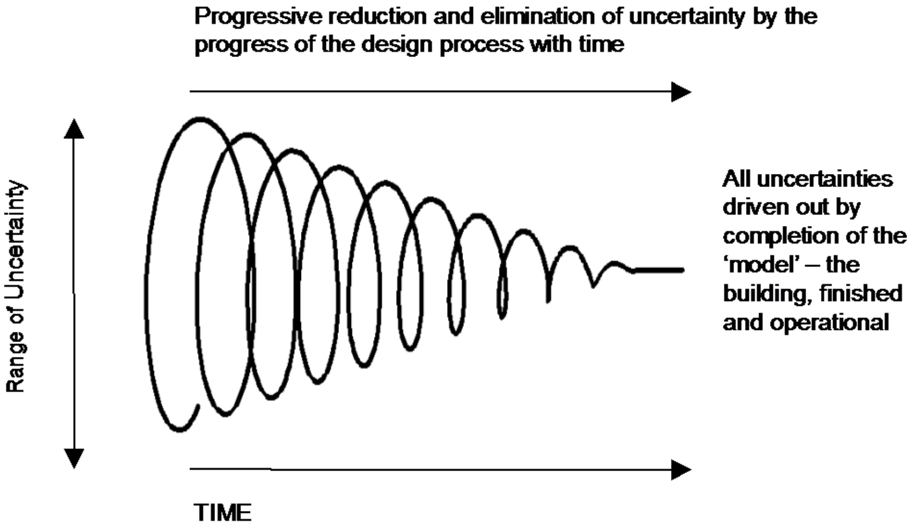
The concept of transformation is also central to Koskela's description of theories of the production and construction processes (2000:38). His work to address the lack of an explicit theory of the construction process is based on a general understanding of production and manufacturing and their underlying theories. Three views are explained and applied to the construction process - as a transformation, as a flow, and of adding value. Koskella argues that each of these concepts captures an intrinsic phenomenon of production, and proceeds to integrate them in a transformation – flow - value (TFV) theory of the construction process.

Koskela also discusses the relevance of these three views to the design process (2000:109). As discussed above, Schön describes design as a process of transformation and improvement, and Koskela identifies how this view was applied to the design process concurrently with the re-engineering of production processes after the Second World War. As design increased in complexity and more specialists became involved, the view of the design process as a flow of information between specialisms became more relevant. Equally, as design progresses towards the preferred outcome identified by Schön, its purpose is also to add value. However, it is difficult to represent iterations in the design process using the transformation view, as it cannot accommodate a circular sequence of activities. It is thus possible to apply the TFV theory to the construction process, but only to a limited extent to the design process.

Koskela, partially based on Giard & Midler (1993), identifies two intrinsic differences between design and production (2000:110). Firstly, as discussed previously, whereas design is frequently described as iterative, production and construction are perceived as more sequential and linear in nature, based on being seen as processes of transformation. Secondly, there is much more uncertainty in design than in production. Thus, while the design process is one of refining solutions to a set of problems and reducing uncertainties, construction is the creation of a product and must therefore close out all uncertainties, including those that devolved to it from the design process. This introduces the possibility of perceiving the design process as one of progressively eliminating uncertainties by making the decisions identified by Lawson (1997:35). The progressive reduction of uncertainty could then be perceived as the emerging maturity of the design, from the initial conceptual stage to project completion. The passage of time and the reduction of uncertainty through decision-making are accompanied by the increasing maturity of the design. Again, from Lawson (1997:119) and Brawne (2003:160), theoretically the design is only complete when a deadline is imposed. This closure may be by the withdrawal of resources to develop the design further, or by the design's physical realisation in the constructed building. The corollary in this perception of the design process is that the design still has a reduced but residual amount of uncertainty in it when information is drawn out to initiate the procurement process. Furthermore, specialist input secured through the procurement process may be the key to driving out some of the remaining uncertainty.

Brawne's description of the design process as a cycle does not encompass the concepts of either the passage of time or the evolution of an improving design from which uncertainty is being driven out (2003:33). However, Darke (1979) describes the process as "spiral or iterative", and the image of a spiral has been adopted here to represent the design process. The iterative loops are shown as coils, which can be laid diagrammatically against a time axis, and which can be shown by the decreasing radius of the coils to be evolving towards a finite model from which all uncertainty has been removed – the finished building. This is introduced in Figure 2.

Figure 2: The design process as the progressive elimination of uncertainty



4. Research Methodology:

The subject area of this paper forms part of the deductive phase of a larger research project, and touches on establishing the context, the conceptualisation, the proposition and the methodology of the larger investigation.

An early aspect of the research methodology for the broader research study was to consider the value and importance of constructing suitable conceptual frameworks to guide its development. A conceptual framework in the sense being used here can be thought of as a diagram or map of a researcher's current view of the territory being investigated (Miles and Huberman, 1984:33). It is useful for setting the boundaries and limitations for the research and can form the basis for the research design strategy and suggest the direction for the fieldwork. These frameworks of research are intended to help link the theoretical and practical aspects of the project in such a way as to add logic and meaning to its development. In their examination of the conceptual frameworks, Trafford and Leshem (2007) stress the importance and role of conceptualisation and the conceptual framework in a doctoral thesis. When discussing doctoral candidates they suggest that it is an essential device "to raise their level of conceptual thinking about research". They argue that the conceptual framework has "an integrating function between theories that offer explanations of the issues under investigation". Thus, the conceptual framework can not only act as an early guide to the formation and direction of the research, but can aid in making sense of the data and in drawing higher level conceptual conclusions from the findings. For this paper however, conceptual frameworks are used to help in the formation of the investigation, and to identify the key variables and the links between them.

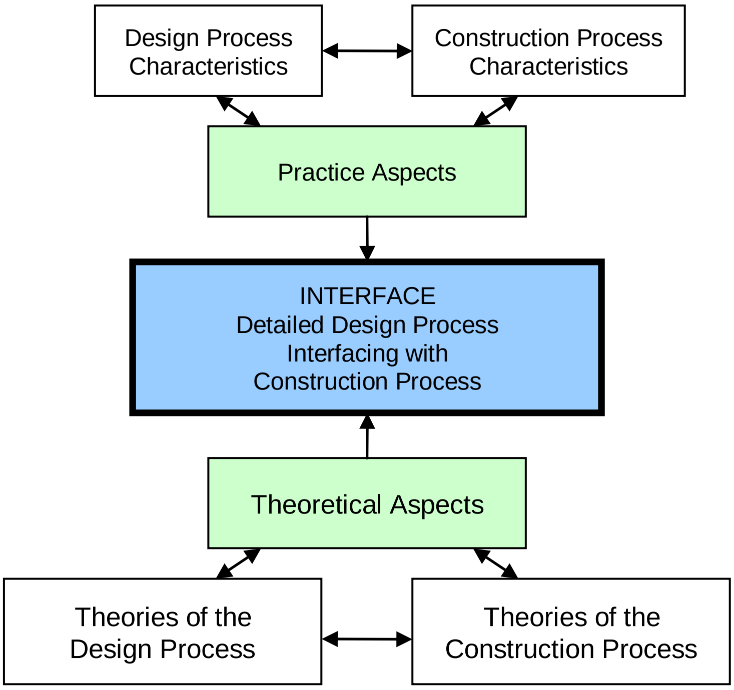
The construction industry is generally project-based, and the unit of analysis identified for the broader study, after Yin (2003:22), is the project. Construction projects have a very high number of different skills and specialisations (Gray & Hughes, 2001), each of which forms an independent and un-controllable variable within the project. For example, Mitchell *et al* (2004) found the number of contractual and other interested parties to their North London case study project exceeded 50, each with their own responsibilities, objectives, teams of personnel and agendas.

In addition, every project takes place in a unique set of circumstances and is what Holloway (1997:7) described as being “context-bound”. These circumstances of time and location shape the execution of the project and the interactions within it. In this conceptualisation, some aspects of this context relate to the prevailing background, the *industrial environment*, and others relate to the project itself and the way in which it has been organised and form part of the *project environment*. Both these sets of circumstances contribute to the complexity of the project and the data available. Furthermore, the research area is generally social in nature, involving people, their interactions and their decisions. In particular, the researcher is involved with the research area, and is part of the interactions within the projects. This further adds to the complexity of the research. It also suggests that action research, described by Greenwood & Levin (1998) as “social research carried out by a team encompassing a professional action researcher and members of an organisation or community seeking to improve their situation”, may possibly be a suitable approach for further research.

5. Findings and Discussion of Results:

This enquiry is into the theoretical understandings of the design and construction processes as discussed above, and the effect that they have on the interface between them. The literature described identifies the areas associated with the research that needed to be considered in the conceptualisation, principally the detailed design process, the construction process, the theoretical perspective, and the underlying industrial and project environments. In addition the design and construction processes have practical aspects that have a bearing on the interface between them. These include the uses to which issued information will be put, the specific contractual restraints, the prevailing custom and practice, the technology adopted for information transfer, and the complexity of the project relative to the skills and knowledge of the designers and the constructors. The relationships between the theoretical aspects, the practical aspects, and the interface is conceptualised in Figure 3.

Figure 3: Conceptualisation of the practical and theoretical aspects at the interface between design and construction

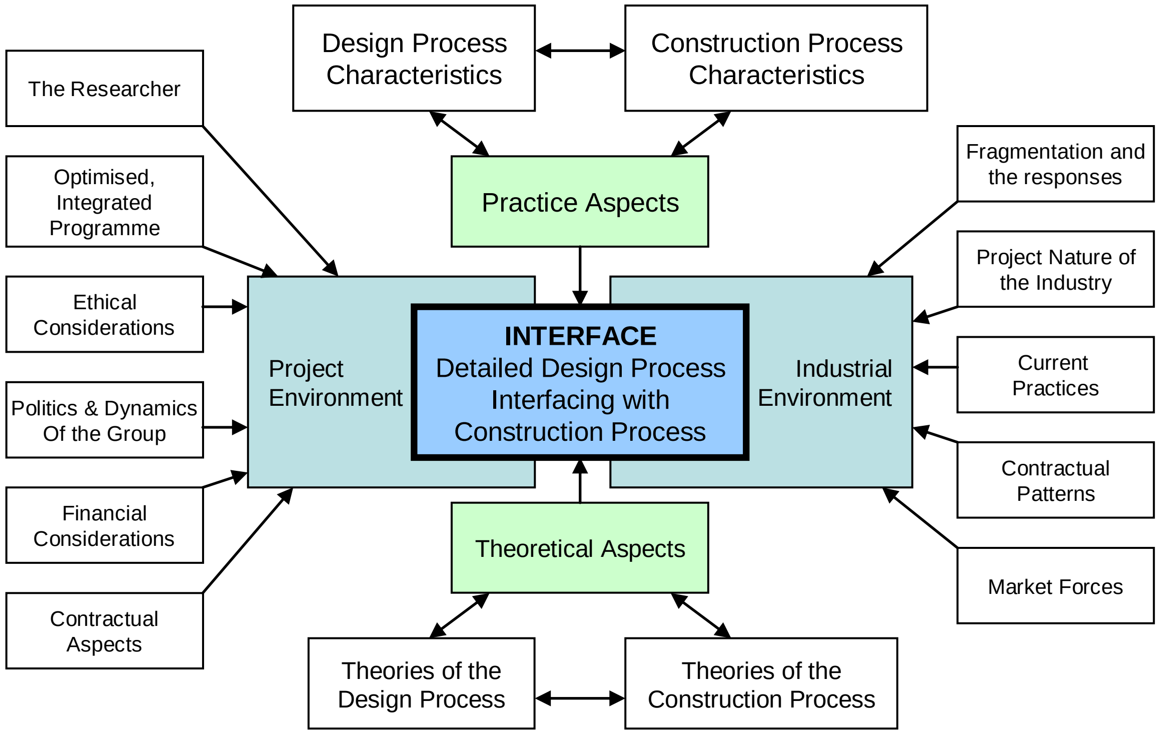


Furthermore, every project takes place in a unique set of circumstances of time and location that shape it. Armstrong (2008:12) states that "all design begins with a clearly defined need" and in discussing the formulation of that need refers to "the cultural societal and physical ethos in which the project is to be carried out". In the context of this research this is the industrial environment and it includes the project nature of the construction industry, the prevailing economic climate, current and potential market forces such as the cost and availability of labour and other resources, the volume of work potentially available in the market place and expectations regarding workload and profit margins, measures to address the fragmentation in the industry described previously including the development of supply chains and design chains (Austin *et al*, 2001), current industry practices, and the prevailing contractual patterns most frequently used such as the decline in the use of nomination to secure specialist input.

The circumstances that contribute to the project environment include the size, location, value, and complexity of the project itself, the financial considerations specific to the project, the specific contractual arrangements, and the project programme, the composition of the project team and its politics and dynamics, the backgrounds of the practitioners carrying it out and their experience both together and separately, any project-specific ethical considerations, and the specific way that responsibilities for design production and design management have been placed within the team, including the supply chain and design chain arrangements distinct to the project. The involvement of the researcher also forms part of this key aspect.

The incorporation of these underlying environmental factors into the conceptualisation is shown in Figure 4, and completes the integration of all the key aspects of the interface into one consolidated conceptual framework.

Figure 4: Overall Conceptual Framework of the interface between design and construction



6. Conclusion:

Through the investigation described above an understanding has been developed into the different theories underlying the design process and the construction process, and the iterative nature of the design process has been compared with the generally sequential nature of construction processes. Conceptual views have been developed of the design process, the construction process, and the interface between them to provide an initial understanding of the relationship between the two processes. These conceptualisations reflect the theoretical dichotomy that has been identified, which arises from the cyclical nature of the design process and the linear nature of the construction process. This dichotomy appears to impact on the flow of work and information between the processes, and may lie at the root of some of the problems that occur in practice and beset the construction industry in U.K. There are implications for the flow of information into the design process, some of which is provided by contractors, specialists and others who are traditionally not involved until later in the overall process, and whose involvement at that later point has depended on a level of design information being developed without benefit of their input.

The view of the design process as an iterative spiral has been developed. It has been used to investigate the interface between the design process and the construction process, to identify the abstraction and use of design information drawn from the design spiral prior to total maturity of the design, and to describe the impact of the selection and appointment of specialist subcontractors and the timing of their input to the core design process. The conceptualisation of the design process as the progressive reduction and eventual elimination of uncertainty has been proposed, allied to increasing design maturity. The completion and operation of the finished building has then been identified as the corresponding point at which all uncertainty would be removed.

All theories and models of the design process identify that decisions are made throughout the design process, based on the information available at the time. The view of the design spiral as reducing and eventually eliminating uncertainty in the design implies that the more information that is available during the design process the tighter the spirals will become, the more efficiently the design will approach maturity, and the greater will be the success in reducing rework. This in turn has implications for the quality of the information drawn from the design spiral and used in the procurement of specialists and in early construction activities.

These conceptualisations have created a theoretical framework for understanding the research area, a guide to the relevant data to be collected in further investigation, and have also indicated possible research approaches. In particular they have identified the significance of the researcher in investigating social situations. They provide a basis for further development and modelling, and for continuing investigation into the interface between the design and construction processes with the aim of optimising the management of the design-construction interface and the involvement of specialists into the design process.

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