Theme:	2.1 Integrated and Smart Models
Title:	**Design & Construction: What are they?**

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Abstract: *How can we communicate design knowledge in construction? Models convey information and are sourced from a greater process of design. Seeing a latent potential for knowledge-implementation in modelling as design process reengineering, a basis is first required for representing the design to construction process as modelling. What is design and construction in this context? How can we 'read' the modelling process in practice before improving it? This paper discusses some research related issues for constructing a description of what we do in practice to answer some of these questions. This approach is the core of a PhD project within CID working with the idea of concept-framed object transformations based on the formalisation of practice-related CAD-methods.*

Keywords: *CAD, model transformation, design knowledge, construction information*

Introduction

This paper addresses a simple big question with complex undertones: 'How can design knowledge be communicated as information in models for construction?' Computing in design and construction is still an active area of research far from a state of general consensus about means and ends [PG 01]. Whilst models serve to define information, and research in to this area is well established (IFC, AECxml data exchange), models do not yet communicate knowledge of a design. Two factors are identified as being fundamental in the future application of knowledge-oriented processes:

1. Design and construction are increasingly information based as a result of transition from analogue to digital media. Methods are reapplied in response to a need to structure our actions in terms of the information that results from them. Tools are developed to assist in this process, challenging the nature of the methods themselves. As a result, structure dictates method.

2. The rationalisation of the global building industry witnesses increasing empowerment of producers in the design and construction process. Outsourcing of information by responsibility implies that construction can be said to figure over and above design. Or put another way, an operational perspective dominates a conceptual one as a result of expert activation.

How can the real issues, the making the possible desirable, be supported in design and construction environments in transition in line with the above? Here a 'gap' can be said to exist between design knowledge, and its representation as models under incremental development [AE 01]. However, before answering the 'big question', a more detailed understanding is first required of what, precisely, we mean when we talk of developing a project from a design project into a construction one (in terms of the use of tools and the building processes they are applied to). This implies a certain degree of 'process reengineering', placing importance on description. But process reengineering of what? The specific aim of this paper is therefore to discuss recent findings for a (CAD) tool related and model-based understanding of design to construction as it is today. Issues relating to the construction of practice are discussed and some definitions given. How we can use this view as a basis for process-based development is outlined, where the term 'construction' is used to represent more than just building. Research into CAD modelling methods has been conducted based on case studies of construction projects and conclusions can be drawn about how models are made and why in terms of the context of building application. Design and construction have been delimited in these terms as an answer to the title's simple question: 'Design and Construction: What are they?'

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Background: From construction to production

Knowledge is understood to be a human, conceptual process. This is defined as knowing something through experience or association, an understanding of technique, a body of truth, information and principle [MW 02]. Knowledge applies to facts or ideas acquired by study, investigation, observation or experience [KF 01:12]. Information is the communication or reception of knowledge or intelligence, knowledge obtained from investigation, study or instruction; the attribute of sequences or arrangements of something producing specific effects; data representative. It is also something justifying a change in a construct. [MW 02]. Whilst design, as a conceptual process can be defined as the solving of ill-defined problems with multiple objectives and sub-optimal solutions [DR 02], Architects still rely on other non-model means, sketching and use of metaphorical association to develop thinking and knowledge of a design solution. Operationally, construction is a complex sequence of actions and responsibilities linked to the explicit communication of information. This process is derived from information resulting from both model and non-model means of knowledge-construction. Knowledge in turn is used to inform which models are made that adequately represents form, behaviour and relations amongst parts [CE 99]. Here a distinction can be made between primary elements and functional parts or systems [AE 01].

A starting point for answering the big question, is viewing the above in simple terms as conceptual and operational perspectives. Taken together, these serve to 'realise an idea' of a building into a definitive solution. This is understood as the changing of existing situations into more desirable ones, of devising artefacts to attain goals [HS 96]. How can we do this if conceptual and operational processes fail to find correspondence? The building industry is now more production industry than artisan practice, and a need can be identified for improvements to both design and construction through their integration. Today, construction is being radically restructured, as elements and parts are digitalised and increasingly sourced from the makers of building parts. Here the big question relates to how building design can (computationally) relate to construction when construction itself is being transformed. How can we seek integration when 'the gap' can be argued to be increasing as a result of this transformation? At best, design knowledge fails to be communicated to the makers, at worst design related processes are effectively removed from the picture of developing construction related information. This ultimately devalues the results, focuses on short term gains and restricts building to a lower level of investment.

Looking ahead before looking back, prototypes for improvement to the building design and construction industry can be found in the production industry. Driven by internet-based object technologies, the production industry is already based on an enterprise-wide product lifecycle development process [SF 00]. From 3D-CAD in the 1980's to Computer Aided Engineering in the 1990's, the production industry is implementing concurrent art to product environments whilst the building industry still on the threshold of accepting a *concept* of interoperability. Here 90% of actors fail even to make 'a reaction' [TK 01]. However, self-referential interests are one part of an undeniably complex situation. Delimiting design, constructing models, communicating them, using product information, applying expert knowledge as information in representations all cut across traditional professional boundaries. A need exists driving change, which is also resisted by the protocols and delimitations of these boundaries. From an architectural perspective, the idea of form-to-detail still pervades design thinking when the model and construction basis for design implementation requires otherwise. Emerging 'partnering' paradigms offers a way to share responsibility, but here focus on productivity-related aspects focuses on back-end processes that fails to address the fundamental front-end nature of a building project as a design project. Implicitly, this means a shift from sequential to more parallel, or concurrent, search, research, prototype and production types of processes. For these to be implementation capable, knowledge in the conceptual must, somehow, find correspondence with the operational and vice versa.

Towards a knowledge of design practice

Designing and constructing can be viewed as two aspects of the same process or lifecycle of a 'Practice of Design': this has been described as the process of converting process based information into form based information [GB 90]. Architectural Design, as an aspect of this practice, (AD) has been defined generally as creative problem solving [AE 01] and as the production of design representation [PG 01]. Design is understood to be a greater process to representation. A Practice of Design is first about constructing knowledge. This knowledge informs construction. It is also a process of optimisation, of value building. It can be read from many angles. It implies that the designer has made a conceptual construction of a

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potential. That he reflects on it. This reflection takes the form of bringing unconscious patterns and tacit understandings to conscious understanding through articulation [KF 01:13]. As a definition for relating the thinking dimensions with the models, a Practice of Design is defined as the continuous process of transformation of knowledge into model-based information of which construction is a result.

This implies more than the development of design models. Perhaps, when product models are easily configured online, we will witness design processes where time spent representing is negligible compared to 'intention mapping' into the producer-network. Time spent thinking and coordinating will replace time spent projecting, modelling, detailing and constructing drawing documentation. This represents a desirable scenario but still a very far sighted perspective that for now, at least, remains out of reach.

However, to prepare for tomorrow first requires a construction of today. For the time being, the processes of designing and constructing are restricted to the demarcations of the building industry. Traditional boundaries maintain a distance amongst the professions and industries, at a time when the structures of their delimitation need to be dissolved and replaced by project, or enterprise, related alignment. In terms of the making, the capability to design and build is based on the use of modelling technology within these demarcations. A Practice of Design remains limited to the designers and fails to find correspondence with the use of building information by constructors. It is also straight-jacketed because of the necessity to structure how we do things. Builders are left with a set of instructions, that at times, are often confusing and misunderstood. The issue is not costly building errors, or inadequate instructions for building, but a fundamental limitation of the potential in applying digital technology to the realisation of buildings. Here it is important to understand design and construction as a two way process of information gathering and information constructing. As an enterprise-wide activity, building related information does not have direct access to either the knowledge of a design, or of the components of which knowledge is composed. Design knowledge is effectively removed from the flow of information from process into form. Whilst it is common for designers to explore, informed by the producers, it isn't common for producers to explore on behalf of the design. Not yet.

Improving a use of tools

A first step in rectifying this situation is to examine precisely how we use tools to structure our information. New tools imply new structures to process. At times, tools can alter the very foundations of the processes themselves. Intentions are not realised merely through the application of tools, but our use of tools also conditions our thinking about how to achieve our intentions. The means, the methods and the ends are interrelated. The trick here is to find a way of describing this interrelationship before looking at how it can be developed. However, the use of tools is also a paradox. Whilst 'use of' implies a certain structure and capability in design, it is also self evident that the use of tools has obscured the importance of design rather than making it clearer [KF 01]. We can say that as a result of such new tools, the act of design is being restructured. IT-based tools are not only introduced, but are constantly being updated. Processes, too are also constantly being restructured. The intuition and understanding of the practitioners in the use of these tools are constantly challenged. Practitioners, through tacit understanding, automatically apply a 'knowledge of practice' to these ends. This can be viewed as a process of 'direction setting' for modelling related activity. The use of tools implies not only a knowledge of a design, but of the processes required to apply such tools to the construction of models. Here a distinction can be made between the development of tools based on existing or supposed methods, and the development of methods based on understanding of the actual application of tools.

If it is possible to bring some of this tacit tool-based knowledge to the surface, then a tool-process based foundation for knowledge implementation in construction is theoretically possible. This idea has been described by Hillier at al in other terms as the 'prestructuring of design' through the formalisation of 'informal codes'. Here the failure to escape preconception has been attributed to the proliferation of technology and information and a designers reliance upon them. Innovation is seen to become more restricted, because of the proliferation of information being thrust upon the designer and the requirement to increasingly structure a designs knowledge as structured information [HMS 84:255].

A possible solution to this dilemma could be made by rendering the implicit processes explicit as a meta-knowledge model for the definition and placement of information models. To this end, it is hoped that research into CAD-based method, as a 'principal of process' coupled to building, offers an alternative to conventional descriptions of designing as form to detail.

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Where lies the fundamental scientific basis for these problems? Adopting an anti-reductionist view, the simple question posed at the beginning of this paper can be decomposed into a number of interrelated aspects: How is a basis to be found for reconciling the act of designing with knowledge-sourcing? How is this basis to relate to the act of constructing and building as application of human and material resources? How can this basis define, control and coordinate information models? How can these models be sourced from the use of tools originating in an idea of a more desirable design condition? Answering these questions requires the construction of practice. A practice dimension as the focus for design research is therefore made as an interpretation of practice. To do this, we have to theoretically construct design and construction and see if it suits our observations. With the aim of making a detailed description of modelling that relates CAD information to the greater (all encompassing) process of designing, how is modelling informed by design? How does it end in the construction of construction information?

Research method

We can only generalise from observation of the specific. Trying to define how we do something when we design, in terms of a use of tools, the structure such tools have on out actions, is dependent on some form of observation. A method of research has been developed that explores CAD as modelling activity. Models serve to register changes made, making it possible to compare one copy with another copy of the same model at another moment in time. The difference between represents the changes made to the model, registering implicitly the design activity undertaken over the intervening period of time. The model can then be said to undergo a change of state as a result of the activities undertaken. Design and construction, as a transformation process based on model state, can be said to navigate these changes. A model also informs the design actions that are required to alter the state of a model to this end. The term incremental modelling has been used to describe this process aspect in terms of models [AE 01]. How can such models be 'read'?

To read the data, a method has been used with reference to Imre Lakatos. Lakatos draws attention to the shift from theory to the 'research program' built around a particular problem situation. This offers a more rigorous test of a problem situation, locating much of the success and rationality of science. According to Lakatos, the use of a 'Hard Core' is made as a postulate that is methodologically inviolable, being a matter of agreement and convention. Negative hypotheses are thus not entertained because they do 'fit' into the logic of the hard core. This hard core is surrounded by a 'protective belt' of auxiliary hypotheses, which bear the brunt of the test, and are altered to maintain coherence of data to hard core [SA 84]. A hard core has been introduced, that first, explains what the models are and how they are made. This method reads CAD model data from a construction project by first, making a theoretical construction. The construct 'Composition – Decomposition' is used as the hard core. This concept represents *both* the thinking, design related compositionary processes and their decomposition into related themes and ideas, as well as a design composition being made in terms of a number of different models. The models can be said to be a decomposition of a design composition. This explains the relationship with activities made in structuring models to building elements and parts. Satellite hypotheses are then made that explain composition decomposition in terms of the models to which the hard thinking core is related. This is used to develop both the hypotheses and an understanding of the hard core itself. The method adopted is therefore one of the conceptualisation (or theoretical abstraction) of practice that identifies a link between types of design thinking and the modelling activities undertaken.

Application of Method

An initial conception C1 is made to read 'design to construction' as a modelling practice P. In real terms, P as a process is finished; it is dead. Instead it is represented by a vast complexity of data as multiple model files on a hard disc. The process of making these models needs, somehow, to be reconstructed. A description of practice P_D can only be made once the practice is complete through observation of its results P_O. It is not thought possible that practice and be simultaneously read as it is happening, a distance being required between design actions and the CAD models resulting. Distance is required from the phenomena in order to make a constructed view of its behaviour. In this case, Design processes *had been* used to define and develop a complexity of cross-referenced model files *as is*, from which construction information *had been* sourced and developed. This represents the data that must be read to derive a description P_D. But now the process is over and only the models and their relationships remain.
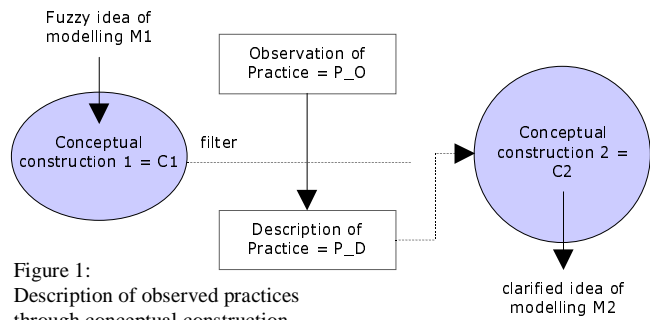
These models and relationships are then used to explore the nature of the process from which they originated, by first constructing a view of what it is that happens when these models are being made. Some insight is also required here. In this instance this author is the

Figure 1:
Description of observed practices through conceptual construction

maker of a significant proportion of the files on construction projects as a practitioner and the reader of the files as a researcher.

Having a clear, but as yet undefined understanding of this process, a first conceptualisation C1 is made that takes the construct 'composition decomposition' as a 'filter' to first, order the reading of the data, before then, attempting an understanding of the data as something resulting from a process. The conceptual construction C1 is placed between observation and description of P_O and P_D as this filter. The filtered description alters the concept itself to a condition more capable of interpreting observation. This is made by development of the hard-core concept through hypotheses about how the concept can be improved. This is represented by C2, or conceptual construction 2. This simple method to structure and order complex data can be represented diagrammatically, as in figure 1.

Conceptual construction 1: LF - HF

Development of figure 1 is now be made in terms of the theoretical abstraction of CAD practices through filter C1. Composition is first related to the definition of a conceptual solution as a sub-optimal basis for a first, general level of design representation. This occurs before development of a design project into a construction project. Typically, this can be understood as defining the overall, semi-abstract extents that are used to develop models to a higher level of representation as design knowledge is constructed parallel with the construction of models. Composition refers to 'Low Fidelity' modelling or LF. Decomposition then relates to the development of sub-optimal models to a higher level of authenticity of the to-be-built artefact, represented as a high level of design representation referred to as 'High Fidelity' modelling or HF. By decomposition, LF models are subdivided into more detailed models representing certain kinds of information. So LF models are composed by design knowledge and then decomposed into more detailed models as HF models as design knowledge is itself constructed and decomposed. Think of a plan at a scale of 1:200 and the zooming in to an area represented on a drawing at 1:50. The 1:50 drawing is a part of the 1:200 drawing, yet shows a higher level of resolution. It can thus be said to be a decomposition of the overall plan that is made to compose a specific planning configuration. The overall plan had to be made before the detailed plan, as a part, could be developed. Information for construction can be regarded as being embedded in the HF model description, as the detailed representation and specification of elements, parts and their relationships.

To develop this understanding, the CAD case data is next observed through the conceptual construction of a LF-HF filter C1 as a hypothetical interpretation of the 'hard core' composition decomposition. The hypothetical constructs LF HF are used to first order the data. They are then used to see if the concept matches the practices as a more specific understanding of composition - decomposition. This is made to find a means of describing how model files progress from a LF model phase of 'design' to a HF model phase of 'construction'. For example, a description 1 is made that describes composition – decomposition in terms of the logic of LF-HF incrementalisation or concretisation. This mirrors a tendency to work hierarchically following an observed logic:

1. Global geometries; principals of structure and construction (composition).

2. Specification of element properties.

3. The detailed configuration of parts.

4. Deployment of parts in a suitably arranged architectural relationship of neighbouring elements.

C1 as LF-HF can be identified as one 'generic' method of modelling based on the conceptual construction composition decomposition. However, in examining the data, it was observed that there were other models which did not fit this description. This required the construction of another concept, C2. Another method could then be made that explained both models falling within the logic of C1 and the others that

did not as an improved description C2. C1 could be predicted, but was not suitable, whilst C2 was suitable and could not be predicted. C1 serves to provide recognition of the necessary design intentions in terms of composition, from which the individual components (windows, steel frames, cladding specification and detailing) are then modelled. This is made according to a frame, and then developed according to their relationships within the frame. In C2, primary components are already defined and serve as generators to structure other components, versions of the component itself, and their combination, requiring another interpretation of the models.

Conceptual construction 2: prescriptive descriptive

C2 accounts for a process of modelling through the use of predefined building components used to inform conceptual development. In this example, a rough estimation of the 'global extents' of a design is used to make a selection of a detailed local element: for example, a geometrical description, specification and mounting detail for a glass façade component. The detailed, preconfigured component informs then the development of the 'global extents' as assemblies around openings and grouping of assemblies to make a complete elevation. In a more detailed appraisal of the elevation, the component is then redefined, or subdivided into complementary geometrical configuration in accord with the development of the elevation solution as a knowledge of the design. A conceptual reconstruction can now be made, building on filtered observation. Another logic then results that does not replace the first logic, but supplements it. This is described as:

1. Temporary estimation of global extents as global model
2. Detailed definition of part/component falling composing global model
3. Construction of whole from application of part database
4. Assessment suitability part to whole. Assessment of suitability part-based assemblies to whole
5. Reconfiguration of part (automatic reconfiguration of whole through referencing).

Both C1 and C2 are derived from a concept of Composition Decomposition, from which the models themselves can be ordered and understood. They represent two basic types of modelling activity can be identified as a result of applying conceptual construction. In the conceptual reconstruction, a logic of design object transformation can be developed in other, more fitting terms. Description 1 followed a logic of concretisation according to 'drawing convention' ('projection' as plan, section etc.). Description 2 departs from this convention and interprets designing as the configuration of a component to a whole mirroring an industrialisation of the building process. That is, the design process is both informed by, and itself informs, the production of elements and parts; the parts themselves constitute to the construction of the project information in terms of the design (modelling) activities undertaken. This method of design can be said to follow a rationalisation of the building process as a flow of information part to whole, breaking the 'form to detail' convention. The two descriptions are now developed to make a new conceptual construction 2 : the 'Prescriptive' and the 'Descriptive'.

Prescriptive modelling follows an incremental development of a compositionary 'framed view' defining the extents for a chain of decomposition. At the end of this chain we end up with specific design objects coming from the building industry made specifically for the project and based on the architects information in CAD model. *Prescriptive* is defined in terms of the 'construction of projection' in accord with drawing convention. Here an area of special architectural *interest* is framed, where the act of framing a part of a section or plan defines a 'generic model object' for a process of transformation. Object in this description can be interpreted both as a representation of a building element as the construction of a view of interest, where one follows logically from the framing of the other. This decomposition can be read as progressing top to bottom progressing through a number of 'levels of state'. Starting with the idea of a 'level 1 Primary Object', an area of interest is framed in terms of defining the overall relationships between elements *telling a story of the architectural values of the project as constructional information.* This initial framed model (possibly a horizontal or vertical arrangement for defining a placement of artefacts) is used to 'explore' a number of possible solution(s) emerging from geometrical and functional constraints. These define a basis for a solution as 'level 2 Basis Objects'. This convergence on a fitting solution defines 'level 3 Aspect Objects', which can decompose into a fourth level of 'detailed views'. This is not a classification of construction parts but of (named and) framed design representations,

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following the thinking processes of identification in terms of illustrating the story of why elements need to 'talk' to each other. The element relationships are never identified, since it is the arrangement of their composition that dominates, from which any number of relationships can be identified (by snapping, measuring, dimensioning etc.).

Descriptive modelling supplements prescriptive modelling in terms of the marriage between an object and the specific relationship of the object to the global geometrical context of the overall form. This builds on the practice of decomposing designs into objects as file-referenced information. Key items of model information can be said to be spatially located, where pieces of information are entered as a single description of a model referenced in to other files (one representation per artefact used to compose a number of framed views). As an example, the global information of say, an elevation, is made up of a repetition of component-based objects. The objects themselves are sourced from a configuration and deployment of 'manufactured part' as one description of that part. The part played by the coordination of local part to global geometry then begins a focus for strategic development. D*escriptive* is therefore defined in terms of the modelling of an object in its entirety. It explains how global pictures of the whole are generated from a local part. Descriptive modelling is also hierarchical, but does *not* follow a process of decomposition. Rather, a logic closer to decomposed-composition can be identified where a local part and its relationship to the whole are developed in parallel. This is significant because it identifies HF component selection and configuration *before* form. Form then does not progress from a semi-abstract or LF condition, because it is by its very nature a 'child' of the 'parent' product-part object. In other words, the precise geometry of the component and its relationship component to component is the generator of form as design knowledge embedded in the component, and thus a parent to the form, which is its offspring. The solution, from which information for construction is generated, is here dependent on the 'layering' of component-sourced assemblies as model configuration reflecting building method.

Conclusions

In this paper, a theoretical construction of a 'Practice of Design' questions the ideas of 'complete building representations' and 'form to detail' to which modelling and construction are related. This has been made by observing how we design and develop information for construction as models. This is based on reading the design to construction process as a *transformation* of a model state where the transformations register changes made to models. A generic use of 'Composition Decomposition' has been used that interprets this modelling process as 1. the making of representations and 2. as the making use of a knowledge of parts. In the former, conventional processes describe a building solution as the framing of a strategical 'window' on an association of elements or components together. This is termed 'prescriptive modelling' and identifies a convention continued from the drawing board. Scaled views of a drawing equate to a CAD equivalent view hierarchy: view of section – aspect of whole - frame of interest – detailed view of frame. In the latter this convention is questioned and replaced by the increasing application of manufactured components/parts in building. This is represented as a decomposed composition along the lines conceptual value – modular whole - parent assembly – child component and is termed descriptive modelling. Design can, in these terms, be understood as decomposed composition which uses and updates a components own knowledge of its making and application. This distinction could be used for assessing a knowledge-based modelling basis for supporting more expert bases for design and construction. In both cases, the relationships between the designing, the thinking and the representing, are kept open and *fluid* (in terms of assessment of the state of the models and component relationships). Modelling, as a process of object transformation in this logic of design, and as a construction of practice, is concluded to be two things: a *flow of information* from the general to the specific and a process of *bridge building* between conceptual and operational dimensions. This is defined as a twin-cycle, or spiral, of process starting on divergent abstract level and ending on a convergent, concrete one.

A scenario can be concluded by interpreting the results of the observation. The production of information by producers on a construction project relates to a flow framework, design involves directing this flow from the appropriate sources. The use of models provides the basis for constructing the bridges between conceptual and operational perspectives that are required to select which information enters the flow. This imparts a third, strategical perspective to design and construction: how to select the tributaries of and direct this flow. The importance in these definitions is in the understanding that construction is a result of

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the construction of information and design as a construction of exploration. In addition to representation, models serve to construct a greater process about generating ideas about how to make a design in terms of these models. This is important, because if model-supportive design ideas can be developed in terms of component/part communication, then strategical design – construction processes could be developed that develops conceptual and operational design knowledge in parallel. The role of the designer can, in these terms, be viewed as optimising value and of seeking a potential for doing so through the coordination of products and services before embarking on design development. This deviates from convention, where products and services only later enter into the design equation following a description of form. Thus convention is viewed as being ineffective. It does not support fluidity in both concepts and building operations and one only need look at such developments as Design For Manufacture in the production industry, to see how other industries tackle similar problems. Design to construction as it is today requires significant modification and re-modification of models to fit into preconceived and rigid frameworks.

Finally, a conclusion is made in terms of asking more questions. Understanding the strategical process as navigating from a local condition to a global one, from a design perspective to a construction one, one of the consequences of a knowledge-information flow could be a critical way to construct a more fitting basis for service. Another consequence is a critical look at existing practice itself. Are existing prescriptive methods of modelling acceptable for flow construction? Is the conventional process of digesting and incorporating multi-sourced information into a conventional design framework sufficient? Are the description of views, selection of key sections, development of specifications and draughting of interfaces between components an acceptable methodology in the light of re-structuralisation of the building and information process? What alternatives can be found that supports transition in both design and building as a structuralisation not of just the models, but also and perhaps more importantly, the modelling process? It is argued that answering these questions ultimately affords an opportunity for communicating knowledge in construction information and increasing building value.

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