KNOWLEDGE BASED INTEGRATION IN DESIGN AND CONSTRUCTION
"A CONCEPTUAL FRAMEWORK TO ANALYSE DESIGN INTEGRATION"

J.W.F. (Hans) Wamelink ¹ and John L. Heintz ²

ABSTRACT
Integration is an essential feature of design activity and is traditionally regarded as one of the key tasks of the architect. This is particularly important now, as the spatial, functional, and technical aspects of the building design and construction become increasingly complex and the number of parties involved increases. Little is known about the actual course of the integration process during the design activity, though this is a source of many possible errors. Improved design integration may be expected to lead to a faster building process, fewer building errors and higher architectural quality.

This paper describes the conceptual framework for a study to determine whether the degree of integration differs in different types of building contracts by investigating the integration process in traditional and integrated forms of building procurement. The cases studied will be largely characterised by complex project engineering, as a result of which integration is one of the main keys to success. During the study, special attention will be paid to the way the various partners make knowledge available to each-other during the design process.

KEY WORDS
integrated design, knowledge management, collaboration

INTRODUCTION
The term integration can carry a number of meanings in the design and construction context. It can refer to a variety of procurement contract types which are intended to provide the client with an integrated building provision service. It can refer to the degree to which a design team acts as an integrated whole rather than a loose coalition of independent organizations. Or it can refer to the integration of building systems designs into a single complete and coherent building design. It is often held that these three forms of integration are coeval, that each of these forms of integration facilitates the success of the others. Specifically it is often asserted that the use of integrated contracts will bring about a higher degree of team integration and a better result in the process of building systems integration. This paper outlines a research methodology to explore the relationship between these forms of integration, and specifically how knowledge – knowledge sharing, knowledge integration and knowledge creation – plays a central role in building design integration. We refer to the approach to building design in which knowledge integration and knowledge creation plays an explicit role in the integration of building serves as knowledge based integration.

The most prominent argument for integrated project contracts is that the integration of the diverse parties in the building procurement process into a unified contractual structure will make it possible for the team to engage in a higher degree of design integration, and

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result in a better, higher quality or less costly, design for the client. This argument assumes a positive relationship between the degree of design team integration and the presence of knowledge creation processes. These two forms of integration are assumed to be positively reinforcing, thus an increase of knowledge creation processes will bring about a greater degree of design team integration, and vice versa. This relationship has been brought into question by recent research (Baiden, Price et al. 2006). The project described here will focus on the building system integration and examine the relationship between contractual integration, design team integration and the quality of the design produced thereby. In proposing this project we will be building upon the work carried out by a number of scholars in the United Kingdom that has been very important in clarifying the issues surrounding design integration (Moore and Dainty 1999; Moore and Dainty 2001; Baiden, Price et al. 2006; Koutsikouri, Dainty et al. 2006).

**Building contract types**

There are a variety of contractual approaches to building procurement. These vary in their degree of integration. Design-build contracts can be arrayed on a simple scale from a zero point corresponding to the traditional contract to a maximum degree of integration represented by the Design-Build-Finance-Maintain-Operate contract. (Geerlings 2006) But not all contract types lie on this simple scale. The Construction Management approach practiced in the UK, and the Bouwteam approach practiced in the Netherlands do not lie on this scale, as although they do not integrate the contracts into a single point responsibility, they also integrate the design team through alternatives to the traditional contractual arrangements.

<table>
<thead>
<tr>
<th>Contract Type</th>
<th>Design team integration</th>
<th>Contractual integration</th>
<th>Financial integration</th>
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</thead>
<tbody>
<tr>
<td>Traditional</td>
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</tr>
<tr>
<td>Bouwteam</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction Management</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td>Design-Build</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Design-Build-Finance-Maintain-Operate</td>
<td>possible</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Interestingly, where as Bouwteam and Construction Management do not rely on contractual integration to achieve design team integration, Design-Build-Finance contracts may recreate the traditional contract form, with the developer dealing with the design professionals in a traditional manner, while at the same time dealing with the client as an integrated building provider. This variety of approaches also suggests that we should question the assumed causal relationship between contractual integration and design team integration. It may be that they are not exclusively linked to each other.

**KNOWLEDGE BASED INTEGRATION**

What then is knowledge based integration? That is best answered by the comparison with what we might call information based integration. Information based integration achieves
integration through shared building information models and provides a number of advantages: it reduces errors, solves version control problems, provides accurate information on the state of the design, and ensures that data formats will not present the design team with great difficulties. All of this is essential to effective building system integration. In routine design, standard buildings, with standard approaches to building services, information based integration may be all that is needed. Such projects will require little in terms of innovative solutions or novel means of integrating the building systems. However, if one is seeking a design solution that seeks to maximize the integration of services, either in a physical sense of making the building systems more compact, or in the more ambitious sense of seeking synergistic relationships between the building systems, one needs to go beyond sharing design information. Knowledge based integration, then, is an approach to building systems integration that is based on sharing disciplinary insights and design argumentation. It seeks to explore design alternatives in an multidisciplinary manner – solving the individual disciplinary design problems in an integrated, synergistic (everyone working together) approach rather than dividing the design problem into disciplinary sub-problems to be solved (to a great extent) independently.

Figure 1: Information based integration versus knowledge based integration

Whereas information based integration makes few impositions on the organization of the design team, knowledge based integration entails design team integration. It moves the locus of problems solving from the individual design firm to the multidisciplinary design team. On the one hand one might expect that this would be an inefficient way to solve design problems. It requires more and longer meetings with more designers present, and a higher rate of communication and information exchange between meetings. The advantages we might seek to realize from knowledge based integration would be two fold, 1) that design teams would arrive at successful design solutions more quickly (expending design fees, to shorten design
time and save on financing costs), and 2) that design teams would reach qualitatively better
design solutions, containing fewer errors and fulfilling the client’s performance requirements
better. Thus the inefficiencies mentioned above may be counter balanced by efficiencies
achieved further down the line and by improved product quality.

Is knowledge based integration (KBI) simply another name for design team integration
(DTI)? Certainly, KBI and DTI have many similarities, and the two are often associated with
each other. One simple answer is that KBI focuses on building systems integration, where DTI
has no particular focus within the design process. DTI is primarily a process oriented
approach, where as KBI has both process and product oriented elements. DTI is about
integration of project information. KBI is about integration of knowledge within the design
team – integration of knowledge of alternatives and evaluations of alternatives -- and goes
beyond the project level. Figure 1 explains the differences between information based
integration and knowledge based integration.

In order to do research in the area of knowledge based integration a few concepts have to
be illuminated. These concepts are: 1) knowledge integration, 2) success factors and success
criteria, and 3) degrees of integration.

KNOWLEDGE AND KNOWLEDGE INTEGRATION
In order to be clear about the nature of the problems to be studied, we must make a
distinction between knowledge and information. In their classic work on knowledge
management Takeuchi and Nonaka distinguish between knowledge and information in the
following manner:

“First, knowledge, unlike information, is about beliefs and commitment. Knowledge is a
function of a particular stance, perspective, or intention. Second, knowledge, unlike
information, is about action. It is always knowledge ‘to some end’. And third, knowledge like
information, is about meaning. It is context-specific and relational.” (Takeuchi and Nonaka
2000)

For the purposes of our study we shall define information as the data produced by the
project participants describing the design. This would include design drawings, specifications,
program, structural services and cost calculations, etc. Although it is important for the
members of the design team to know these data, the data are not the tools with which the
design team makes decisions, either collectively or individually. Tekeuchi en Nonaka put it
this way:

“Thus information is a flow of messages, while knowledge is created by that very flow of
information, anchored in the beliefs and commitment of its holder.” (Takeuchi and Nonaka
2000)

In the context of design we can associate knowledge, as it is understood by Takeuchi and
Nonaka with design reasoning. The grounds, the conditions pertaining at the current stage of
design (the current design itself, and the physical and regulatory environment surrounding it)
and the performance expectations outlined in the architectural program form the basis for a
claim, a new design decision. This is the information on the basis of which design decisions
will be made. But the crucial knowledge which allows designers to choose a course of action
(make a design choice) lies in their tacit and explicit domain knowledge, and their reservoir
of experience and beliefs. In making design decisions designers generate new information – the
design – and also new knowledge – the belief that this design will serve the clients needs
(functionally, or in terms of build-ability, cost, or other determining criteria), and more
general beliefs about the relationships between construction, form, and use. The normal
expectation is that effective knowledge integration will enhance the generation of this new
knowledge – that it will occur more quickly and that the knowledge generated will be more valuable, more insightful.

**Processes of Knowledge Creation**
Patrick Fong has studied knowledge creation in building projects (Fong 2005). He based his research on the knowledge creation model developed by Nonaka and Takeuchi (Nonaka, Takeuchi et al. 1995). This model relates how knowledge can be converted from one form to another within an organization through a series of processes. The four processes are specific to transitions between tacit and explicit forms of knowledge. Knowledge is created in the conversion from one form to another (Takeuchi and Nonaka 2000).

Fong notes the critiques of the Nonaka Takeuchi model provided by Tuomi (Tuomi 1999) and others which suggest that this model takes in adequate account of the socially constructed character of knowledge. He therefore adds three modes of knowledge creation: knowledge sharing, knowledge integration and collective project learning. This brings his list of processes in knowledge creation to five:

- Boundary crossing
- Knowledge sharing
- Knowledge generation
- Knowledge integration
- Collective project learning

Fong defines boundary crossing is interaction by team members across disciplinary (expertise) or organizational boundaries, i.e. between client, consultant and contractor. We can often observe boundary crossing in the form of boundary objects, such as drawings, documents and conversations exchanged between team members. Such interactions are not sufficient to guarantee the exchange or creation of knowledge, but they are a prerequisite. (Fong 2005)

Fong defines knowledge sharing as “a multitude of processes taking place directly without language (socialization) and with language (externalization).” He goes on to say that: “socialization is a valuable mode of sharing knowledge in teams without language through imitation, observation and sharing experiences face to face.” (Fong 2005) The key difference between boundary crossing and knowledge sharing is the degree of social interaction and exchange between the team members.

Knowledge generation is defined as a process of interaction and communication which leads to the generation of new or emergent knowledge. (Fong 2005)

Knowledge integration is “realized by marrying the differing perspectives and knowledge of various disciplines in the design decision-making process.” (Fong 2005) Knowledge integration does not only refer to the integration of knowledge originating from within the team. Complex problems may require the application of knowledge from a wide range of disciplines such as art, engineering, finance, and business.

Collective project learning is the process “in which professionals with extensive experience in self-directed learning learn from the projects in which they are engaged.” (Fong 2005)

Fong’s five processes provide us with a valuable conceptual framework for understanding knowledge creation and integration from a theoretical point of view. However, most of Fong’s processes are not directly observable. Interpretive acts are required to identify knowledge creation processes and to distinguish the different processes from each other. It is therefore necessary to search further for an understanding of design integration which yields more directly observable units.
MECHANISMS OF KNOWLEDGE INTEGRATION

The team of Berends, van der Bij and Weggeman (Berends, Bij et al. 2006) have set out a list of six knowledge integration mechanisms in general business settings. Not all of Berends et al’s categories are applicable to building design and construction projects. Design Support Systems seem to be primarily of use in the reproduction of disciplinary knowledge and do not represent a form of integration across disciplinary boundaries. Thinking along usually occurs informally within a given organization, and therefore has little chance to arise in the inter-organizational problem of building systems integration. This leaves us with four: Sequencing, Directing, Group Problem Solving and Knowledge Transfer. Sequencing tasks refers to the itemisation and assignment of tasks to those organization members who have the relevant knowledge for it. Domain specific sub-problems are solved and these solutions integrated into a global solution. The integration of knowledge occurs implicitly as a result of integrating the solutions. Direction is the process whereby specialists issue rules and operating procedures to guide the work of non-specialists or specialists in other fields. Rules of thumb are an example of this sort of direction, as is the zoning of building sections to allow specialists to work independently of each other. In group problem solving specialists actively collaborate with each other to generate new ideas through combining their knowledge. Knowledge transfer seems self explanatory, yet it is neither as simple as it seems nor is it a guarantee of knowledge integration. Knowledge transfer requires not only the active conveyance of knowledge by one group to another, but the equally or even more active reception and up-take of that knowledge. Berends et al place these mechanisms on a scale of the degree of involvement of other organization members with sequencing requiring a low level of involvement of others, and knowledge transfer requiring the highest level of involvement of others.

When comparing the systems of Fong and Berends et al, it is interesting to note that the extreme intensities of the two scales do not coincide. Berends et al’s most extreme mechanism (in terms of the commitment of organization members) does not encompass Fong’s processes of knowledge creation: knowledge generation, knowledge integration, and collective project learning (Fong 2005). These could only occur in the Group problem solving mechanism. In Berends et al’s account knowledge transfer itself does not guarantee integration. Knowledge integration (and knowledge generation) must occur after transfer and in isolation from other group members. Collective project learning could only occur as a result of a second knowledge transfer process.

Table 2: A comparison of Fong’s knowledge creation processes (vertical axis) to Berend et al’s knowledge integration mechanisms (horizontal axis).

<table>
<thead>
<tr>
<th></th>
<th>Sequencing</th>
<th>Directing</th>
<th>Group problem solving</th>
<th>Knowledge transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary Crossing</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Knowledge Sharing</td>
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<td>x</td>
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<tr>
<td>Knowledge Generation</td>
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<tr>
<td>Knowledge Integration</td>
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<tr>
<td>Collective Project Learning</td>
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The advantage of Berends et al’s mechanisms is that they are simpler objects than Fong’s processes – more directly observable. Both rely on the use of boundary objects to identify their processes or mechanisms. While identifying each would rely on the evidence of boundary objects and interviews or observations, Fong’s processes are at a higher level of abstraction and would require a greater degree of interpretation to distinguish and identify.

Berends et al stress the conditions for successful knowledge integration. Two conditions are fundamental. First, organization members need to recognize opportunities for knowledge integration. Second, organization members must share an understanding of the nature of the problem. The specialization of organization members not only enables an organization to acquire the range of required expertise, it also creates diverging thought worlds and frames of reference. A basic level of common knowledge and a shared conceptual framework may help to overcome these barriers. Boundaries between groups and practices may create serious barriers to knowledge integration. This last is confirmed specifically for the construction industry by (Baiden, Price et al. 2006).

**SUCCESS FACTORS**

Conditions for the successful application of business strategies are also referred to as success factors. Success factors have been defined as the critical key areas where “things” must go right for the business to flourish’ (Koutsikouri, Dainty et al. 2006) Rockart (1979:85). Traditionally this has been take to refer to the three basic aspects of project management: budget, time and quality. But it is necessary to distinguish between the success factors which lead to successful projects, and the *success criteria* which are used to measure project success (Cooke-Davis 2002). Thus, although success factors and success criteria commonly address similar issues, we must clearly delineate the differences between cause and effect.

A second distinction that must be made is between “1) the internal characteristics of project organization such as time cost and performance goals, and 2) the external characteristics, such as customer satisfaction.” (Shenhar, Dvir et al. 2001; Koutsikouri, Dainty et al. 2006; Meredith and Mantel 2006) It is conventionally assumed that success as measured by the internal project characteristics will necessarily lead to customer satisfaction, but the Sidney Opera House is a famous example of the potential for a disconnect between the two. More importantly, as building projects are lengthy and client organizations in a constant state of change, it is also possible that meeting the internal project criteria a project may not lead to customer satisfaction as the frequent practice of altering recently completed buildings attests.

This makes it more difficult to settle on a definitive selection of *success criteria*. The internal criteria are easily available for measurement, but not necessarily indicative of the overall end result. The external criteria may be more relevant to a global evaluation of the project, yet they are less easily employed for direct measurement. In the case of the research proposed here we will limit ourselves to considering a single internal criterium: that of successful building systems integration.

In this study we will focus on one aspect of building design – buildings systems integration. By focusing on this one aspect we reduce the complexity of the problem of establishing external measures of success. We no longer need to combine evaluations over a wide range of building aspects, nor do we need to deal with the difficulties raised by the differences between perceived and actual performance. Rather we need to establish a scale of successful building systems integration. This will be done by reference to authorities e.g. (Barton, Fryer et al. 1983; Bovill 1991) on building systems integration from the era before building information models and shared CAD files were available to assist in this problem. This will allow us to establish relatively objective measures of design success. But cases
studies will be concerned to examine the relationship between success as measured by the
chosen criteria and the presence of success factors associated with knowledge based
integration.

The selection of these success factors will present some difficulty. Relying on the success
factors identified by project participants may not give us the right indicators. Design
professionals show a pronounced preference for success factors derived from their own
professional points of view rather over those associated with their clients’ interests:

“The most striking observation in the study was that when given the freedom to state
any success factor the majority of interviewees emphasized variables relating to internal
characteristics of the project process such as maintaining good relationships, passion for the
project, and a clear understanding of their role. External characteristics of the product or
service itself such as customer focus or product performance were not emerging as critical.
... when faced with pressure, project participants pursue their own goals sometimes without
regard to the customer. Assessment of these observations suggests two concurrent events: 1)
engineers and technicians are more focused on getting the design right than focusing on
product performance which can only be measured when the building is ready to sue, and 2)
the naturalized culture in construction seem to emphasize ‘getting things done’ rather than
reflecting on ‘what is getting done’.” (Koutsikouri, Dainty et al. 2006) Pp. 225-226

These findings are supported by other researchers as well (Cornick and Mather 1999;
Hayes 2002; Baiden, Price et al. 2006). It will therefore be necessary to develop a list of
success factors based on a theoretical understand of knowledge management and knowledge
creation processes rather than on the opinions of design practitioners. We will return to this
issue shortly.

DEGREES OF INTEGRATION

As stated above, it is generally assumed that a greater degree of integration in the contract
form will lead to a greater degree of integration within the design team. British studies,
however, have suggested that “... although well intentioned, many of these attempts [to
integrate the team in the construction industry] have not fully achieved the expected success,
probably because they are frequently superimposed onto environments where adversarial
cultures and attitudes still exist (Moore and Dainty 1999; Moore and Dainty 2001; Baiden,
Price et al. 2006).” It is therefore important that we continue to examine the means by which
we can foster design team integration.

Baiden et al develop a list of integration criteria by surveying the literature. (In their
paper Baiden et al provide the sources for these criteria.)

“The delivery team in a construction project can be described as ‘fully integrated’ when it:
• Has a single focus and objectives for the project;
• Operates without boundaries among the various organization members;
• Works towards mutually beneficial outcomes by ensuring that all members support each
other and achievements are shared throughout the team;
• Is able to predict more accurately, time and cost estimates by fully utilizing the collective
skills and expertise of all parties;
• Shares information freely among its members such that access is not restricted to specific
professions and organizational units within the team;
• Has a flexible member composition and therefore able to respond to change over the
duration of the project;
• Has a new identity and is co-located, usually in a given common space;
• Offers its members equal opportunities to contribute to the delivery process;
• Operates in an atmosphere where relationships are equitable and members are respected;
• Has a ‘no blame’ culture.” (Baiden, Price et al. 2006)

Baiden et al have used this list to evaluate the degree of design team integration in building projects. To each of these dimensions, they have assigned criteria for full, partial or no achievement. Although their study does not show that increased design team integration is manifested in a consistent manner, their scale still permits us to make rough judgments of the degree of integration of a design team. It may however prove that some of these dimensions, such as co-location, may not prove to be relevant in different jurisdictions.

**METHODOLOGICAL OUTLINE**

Having assembled the elements we will need to examine the relationship between the three forms of integration in building design and construction, we can now lay out a research methodology. The project will address the following research questions:

1) Is there a positive relation between contract forms and the degree of team integration?

2) Is there an observable relationship between the degree of team integration and the presence of knowledge creation processes?

3) Is there an observable relationship between the presence of knowledge creation processes and the Correlate critical success factors to knowledge creation processes and of observable critical success factors?

4) Is there a correlation between perceived project success as measured against success criteria, and a) knowledge creation processes, b) degree of integration, and c) contract form?

In order to address these questions we will undertake a number of case studies in which we will attempt to correlate the different levels of integration with the project success as indicated by success criteria. Specifically, we will attempt to correlate the evaluation of the projects by external success criteria associated with building systems integration, with the degree of design team integration, and with the presence of critical success factors associated with knowledge based integration.

The case studies will be completed projects. The contractual forms may be captured by examining the contracts between the various team members. The degree of team integration and the presence of success factors will be measured on the basis if structured interviews with individual members of the design team. These interviews will rely on the recollections of the individual team members, and it may therefore be necessary to conduct multiple interviews to accommodate for the unreliability of memory. The success of building systems integration will be measured by expert opinion based on a set of success criteria developed from the work of authoritative scholars in the area.

**CONCLUSIONS**

This paper sets out the conceptual framework for a research project exploring the relationship between three forms of design integration: contractual integration, design team integration and building systems integration. Drawing on concepts of knowledge management a number of observable mechanisms of knowledge integration are identified. A series of measures of design team integration are borrowed from the work of Baiden et al (2006). And a proposal made for the development of success criteria for building systems integration. These three scales will permit comparison of the three levels of design integration and their effect on project success in case studies of complex engineering projects.
REFERENCES


