ORGANIZATIONAL AND CONTRACTUAL IMPLICATIONS OF PROCESS IMPROVEMENT IN CONSTRUCTION THROUGH ELECTRONIC INFORMATION MANAGEMENT

W. Gielingh¹, R. Vrijhoef¹, H. de Ridder²

¹Centre for Process Innovation in Building and Construction, Delft University of Technology; TNO Built Environment and Geosciences, P.O. Box 49, NL-2600 AA Delft, The Netherlands.
²Centre for Process Innovation in Building and Construction, Delft University of Technology, Faculty of Civil Engineering, P.O. Box 5048, NL-2600 GA Delft, The Netherlands.
E-mail: wgielingh@tiscali.nl

ABSTRACT: New practices in construction improving business processes have been supported by new ICT more and more often. This implies a transition “from paper to electronic” media. However, in practice, this transition has not been straightforward. Even within the framework of integrated contracts, such as turn-key, DBFMO contract types and also prime contracting, the contractual and organizational relationships between parties in the supply chain have appeared to be diverse, causing implications and difficulties with regards to ownership, liability and maintainability of information. It has appeared that different contract types have different consequences for business processes as well as the supporting ICT. Companies that are involved in multiple projects of different kinds may be discouraged to invest in new practices and tools, which reduces the potential benefits offered by new contract types. This paper analyzes the complexity of process improvements through application of integrated electronic information management in the supply chain combined with the introduction of novel contract types, and the organizational and contractual implications caused.

Keywords: construction supply chain, knowledge and information management, legal issues, business process improvement.

1. FROM INTEGRATED CONTRACTS TO INTEGRATED CONSTRUCTION

1.1 The rationale behind integrated contracts

A major factor that hinders the construction sector to improve its overall performance is the traditional separation between design on the one hand, and subsequent project and lifecycle processes, including construction, operation, maintenance, refurbishment and demolition. Classic design-bid-build contracts hinder the exchange of knowledge about lifecycle processes to the design phase, i.e. the upstream knowledge flow. But also the downstream knowledge flow...
is hindered. Traditional working methods are based on a contract between client and contractor, which is accompanied by a detailed specification of the object – often only in the form of texts and drawings on paper – supposed to be realised through a construction project.

Integrated contracts, such as design-build, possibly extended with other lifecycle phases and financing, or turn-key contracts, are supposed to remove the communication barriers between disciplines and phases. However this does not guarantee a free flow of knowledge or an atmosphere of trust and collaboration between parties involved.

1.2 The rationale behind non-adversarial contracts

A second factor caused by traditional contracts, which hinders process innovation, are the different and often opposed interests between client and parties in a supply chain. Most construction companies today operate as “capacity providers”: they offer human resources with average skills and earn their money through the number of hours spent on a job. In such cases application of more efficient working methods is often not rewarded or worthwhile to invest in. Fixed price contracts do not improve the situation either: they result in a unilateral focus on costs, not on the value delivered to the client.

Opposed interests hinder a free exchange of knowledge and foster an atmosphere of distrust. Incentive based contracts are supposed to remove these barriers. Through incentives that are related with the business objectives of the client, the aim is that all parties in a supply chain are more motivated to work together towards the same goal.

Although an alignment of interests in a project may create a collaborative atmosphere and takes away some hindrances in the exchange of knowledge, it is often not enough to improve business processes and corresponding working practices fundamentally. The same companies may work concurrently in different projects under different contractual conditions, perhaps even for clients and with partners that are competitors of those in the non-adversarial contract. Furthermore, most projects are not sufficiently large and long to justify a change process, nor large investment in tools and human resources. Real process improvement is hardly possible on the basis of one-off projects. It requires changes in long-term business strategies.
1.3 The need for strategic changes in the way construction does its business

Today, main contractors act mostly in a reactive and opportunistic mode. They do not take action before a contract is settled, and the needs of a client are clear and formulated in detail. They do not have much choice either: clients tend to prescribe what they need, and also determine the conditions for a contract. As a consequence, oddly enough, contractors are limited in the organization of their own business processes, own work force and own techniques and tools. Investments in process improvement are mainly restricted to work that is not client-related. Companies that work not directly for investors in new projects - usually suppliers deep in the supply chain - have often more freedom to improve their processes, and may offer solutions in the form of products or services.

According to Treacy and Wiersema (1992), enterprises can compete in distinctive market disciplines: they can compete on costs, on unique products or services, or on costumer value. These market disciplines have consequences for organizations and business processes. Basically, this scheme results in four distinctive types of business offering (Gielingh 1998, 2005), see Figure 1. The differences between them are strategic:

- Capacity providers offer personnel that can be hired for a period of time.
- Process providers offer processes, to realise projects or parts of it. They create value by the organization and training of human (and the investment in non-human) resources. These resources are strategic and thus independent of specific client orders. The processes that they can execute are variable.
- Product and service providers develop a generic, reusable concept that can be tailored to specific client needs. Processes and the organization of a supply chain are optimized and are part of the business strategy. They are thus independent of client orders.
- Providers of client value understand the business of their clients and help them to be successful. An important enabler for this market discipline is lifecycle support: to take responsibility for the performance of a facility during its intended lifetime. Products and services are independent of client orders and are optimized to deliver performance and value.
Fig. 1. Levels of performance and business offering

The aforementioned market disciplines and business offerings should not be confused with integrated and incentive based contracting, such as described in paragraphs 1.1. and 1.2. Integrated construction projects, such as DBMFOT types, may still be executed as a capacity or a process offering. The mere fact that a contract is extended to the full product lifecycle, removes communication barriers as well as conflicts of interest, does not yet imply that processes are optimized, nor that the provider is capable to offer significantly more value to the client’s business. In fact, if integrated and non-adversarial contracts are exceptions to the rule of non-integrated and adversarial contracts, there is no urgency for the provider to invest in new business, products or markets. Hence, new contract types have just a marginal impact on the performance of construction as long as they are not standard practice, and as long as providers are not proactive in the development of new business offerings.

Although main contractors in construction predominantly operate as capacity or process providers, there are several suppliers to construction that already work at higher performance levels. Examples of product providers are suppliers of building elements or building systems. Some suppliers of vertical and horizontal transportation systems (elevators, escalators, travelators) are in the transition to provide customer value and lifecycle performance. In such cases, they have strategic contracts with clients that are independent of a main contractor.
2. BUSINESS OPTIMIZATION THROUGH ELECTRONIC INFORMATION MANAGEMENT

From hereon, it is assumed that a provider aims at some form of optimization, which may range from the management of resources, up to total lifecycle processes and the offering of costumer value. The implications of different kinds of business offerings and contracts will then be re-examined. It is not possible to discuss in this paper all the possibilities for optimization. Many factors determine what make particular projects or businesses “optimal”. However, it is possible to state that mostly any solution for optimization is supported by ICT applications and the transfer or sharing of information in electronic form. Two factors that all solutions for optimization have in common are the increase of knowledge flows and electronic information management.

2.1 Optimization of the knowledge flows

Chapter 1.1 introduced the need for optimization of knowledge flows between disciplines. The upstream knowledge flow can be supported by organisational measures, such as the formation of integrated, multidisciplinary teams, and the execution of work in parallel, i.e. concurrent engineering. If the supply chain is included in, collaborative engineering becomes relevant as well, i.e. concurrent engineering across the borders of individual organizations.

The downstream knowledge flow can be improved by offering design specifications in a form that is directly useful for procurement, work preparation, pre-assembly, on-site construction, commissioning, decommissioning, maintenance and operation. All of these downstream processes require fit-for-purpose modifications of the design specification. Moreover, the construction phase requires the dimension of time (4D models) and sometimes even additional dimensions like finance/costs etc. (nD models), so that specifications can be aligned with planning of time, costs etc. Operation and maintenance require ‘as-is’ descriptions of the artefact, which are usually not the same as the original design specifications. Design specifications, 4D or nD models, and ‘as-is’ descriptions of a facility can play a crucial role in the contractual agreements between parties in a project.

2.2 Rationale of electronic information management

Today most specifications are produced with computer applications, such as text-editors, drafting applications and 3D design applications.
Most innovative business processes are also enabled by software applications, such as enterprise resource planning. Therefore, it makes sense to communicate specifications and other data not through paper media but in electronic form.

Electronic information management (EIM) enables the application of workflow management (WFM): the use of tools that support the logistics of information in an enterprise. There are many obvious reasons for introducing EIM and WFM in construction. The communication and distribution of electronic media are much faster than paper-based media, so that time can be saved. Furthermore, if all parties in a project have access to a single common data source, it can be ensured that they all work with the same specifications. Errors that are caused by people, who work with different, inconsistent documents, can thus be avoided. Also, the transition from existing working practices to EDM/WFM is relatively easy while most documents are produced with computer applications.

An interesting study about the impact of electronic information management in construction was published by Baker (1996). Baker describes two almost identical projects for the construction of off-shore facilities. One was executed with support of an Electronic Document Management (EDM) and Workflow Management (WFM) system, the other used traditional (paper) media. The project supported by EDM/WFM was executed in 70% of the time and 70% of the costs compared with the traditional project. Baker’s paper is relevant because it describes probably the purest “placebo controlled” study on the benefits of EDM/WFM for construction. Practically all other published cases of business process improvement lack comparison with a placebo. This is understandable by the face that construction projects are too large and expensive for context free experimentation. But this makes it difficult to estimate the benefits of improvement strategies. Most studies are obscured by the fact that multiple measures are taken concurrently. In such cases, no clear conclusions can be drawn about the impact of one measure compared with another. However, in many cases that report significant improvements in construction, EDM plays a role.

3. BARRIERS, THREATS AND CHALLENGES FOR KNOWLEDGE AND DATA SHARING IN LARGE CONSTRUCTION PROJECTS

The sharing and exchange of information in large construction projects can be very complex. Figure 2 shows, horizontally, the main lifecycle phases of a construction product, and vertically the supply chain. The client is left out of this diagram but will be discussed separately.
Figure 2 identifies several information flows, indicated by arrows and the characters a to n. In a completely disintegrated project – which is often still common practice – all listed exchanges are between different organisations with different and sometimes conflicting interests. Although informal communications make more and more use of electronic media, such as e-mail and internet, formal documents remain in paper form for legal reasons. Optimization of processes through electronic document management, product data management, workflow management and advanced applications, including ERP will not pay off, because different projects will have different configurations of partners and suppliers, and thus require different implementations of working practices and tools. Individual companies cannot force other companies to work with their internal standards and working practices. Practices can thus only be determined by the construction sector as a whole, and this explains why it is so difficult to change construction.
Fig. 3. Integrated contracts, such as DB or DBOM, remove barriers between processes, and enable the application of electronic information management within a closed context.

However integrated contracts enable the improvement of certain processes in the closed context of one or more projects. In DB contracts they enable the input of construction knowledge in design, and the use of design specifications for work preparation and construction (flow b). In DBOM contracts they enable the optimization of flows a, b, c, e, f and i (Figure 3). In addition, supply chain integration enable the optimization of flows of type g, h, j, m and n. As the payback of such innovations takes usually many years, they require long term strategic partnerships with key suppliers.

The client plays of course an important – if not crucial – role in any construction project, but the nature of this role varies from case to case. Often, the client is also the operator of a built facility, and in some cases the client even does first-tier servicing also. In other cases, the client may be an investor with an interest in cash flows between the successive stages, or a government that is interested in the built object as part of a larger area, e.g. a neighbourhood. If the interaction between client and provider takes the form of a performance- or incentive-based contract, it is essential that performance values are recorded in a form that is beyond dispute for the parties involved.

4. ABOUT DISTRIBUTION AND ACCESS OF DATA

In a traditional project, important information is recorded on paper. For each document there is a master, which is copied for distribution to parties involved. If information is exchanged or handed over in
electronic form, the situation is often less simple. This is caused by the fact that computer applications use many different representations for the recording of data. Representations can extend from pure, unformatted text, to formatted text, bitmap graphics, vector graphics, hypermedia, 3-dimensional models, product models and various kinds of databases. Besides, information created by using one application is often not accessible or editable with other applications. This causes exchange and integration problems within a firm, and even more problems if information is exchanged between firms within a project. The issue of integration will not be discussed here. This paper focuses only on the seemingly simple case that a piece of information is transferred electronically from its author to its readers, if they work in different organizations.

![Diagram](image)

*Fig. 4. In the traditional case (left) a master copy is reproduced by means of a photocopier. There are no restrictions with distribution. In the electronic case (right) there are multiple ways to reproduce and distribute the master copy.*

Next, three aspects of the transformation of a master copy to a derived copy will be discussed:

- Original versus neutral formats
- Information push versus information pull
- Full content versus viewing

### 4.1 Original versus neutral formats

If a document is exchanged in its original format, the receiver must have the same software application as the sender. If the author and the receiver work in different organizations, this is often not the case. Even if parties use applications from the same vendor, such as the usual Microsoft applications, the sending and receiving systems may have different configurations or different software versions that cause exchange problems or loss of data.
Fig. 5. If a client or user wishes to receive data in neutral format, for access by applications other than those used by the supplier/author, there is a chance of information loss in the conversion. If the supplier/author is asked to redesign a component or system, a second conversion has to take place, with another risk of information loss. Hence, the neutral data are less suited for use as a master than the data in the original format.

To overcome the hurdle of exchange between applications from different vendors, it is possible to use a neutral format. However, in the conversion from the application format to the neutral format, there is a serious risk that data or data semantics are lost. Developers of standards for data sharing or exchange are very well aware of this problem, but consider it usually as a flaw that can – and should - be repaired. A European workshop (Gielingh and Goult 1993) and Esprit project PISA (Gielingh et al. 1995) revealed that this problem is more fundamental. Due to this risk of information loss, neutral formats are less suited for use as a master copy than the original format used for design.

Fig. 6. If the original format is used as a master copy, there are less risks of information loss due to conversion. At least, the master itself will always be available to produce any kind of format, fit-for-use. This has on its turn consequences – for contracts and ICT - for ownership and role of the creator of this information, such as a supplier.
4.2 Information push versus information pull

Information push implies that a master document is reproduced several times, and that these reproductions are sent to the receiver. This is the case with paper documents, and also with the distribution of information via e-mail. Information push has two major disadvantages: 1) multiple copies of a document circulate in the organization. Each owner of a copy may have to store and archive its copy, and 2) if changes are made in the master document, copies of older versions that were distributed in the organization will become obsolete. This causes a risk that people work with obsolete or inconsistent information.

Information pull implies that no reproductions are made, but that all users have direct access to the master copy. This scenario is enabled for electronic documents stored and shared on extranets with multiple secured access, or on local intranets. Information pull does not have the two disadvantages that information push has: users are not any longer responsible for storage or archiving of documents, and there is less risk of working with different or obsolete versions of information. However it introduces another issue, namely the risk that earlier versions (legacy data) are overwritten by new versions, so that the history behind new versions is lost. This specific issue is addressed by data warehousing technology. A data warehouse is capable to store the latest versions as well as their history, and makes these master copies available for information pull by authorized users.

4.3 Exchange or sharing versus viewing

In stead of sharing or exchanging information, it is also possible to provide a viewing function for the data. This means that not the content, but an image of the content is provided. A well known standard today for documents is the Portable Data Format (PDF) developed by Adobe. This is not a neutral format in the sense as discussed earlier, because it does represent only an image of the document, with sufficient structure to prevent loss of detail, which is the case with bitmap images for instance. Once a document is transformed into PDF, it is not suited for re-editing anymore, and only few things can be changed still.
5. ON KNOWLEDGE AND INFORMATION OWNERSHIP AND LEGAL ASPECTS

In a traditional construction project, a supplier will hand over information in paper form. The client will then own and physically possess this paper copy. That copy may be considered as the master copy for all future work. This is not necessarily the case with electronic media. As it may be required to change the design for new product versions or for product alterations during its lifecycle, it is recommended that the original electronic source is used for making these changes. A conversion to neutral formats implies a risk of information loss, such as discussed in 4.1. A transfer of the original source to the client makes no sense because the client may not have the applications in which these data are created.

The concept of ownership should therefore be differentiated. For instance, a pump supplier delivers a pump and corresponding information to its client, but remains intellectual owner of the design. In that case, a project consortium that builds a facility for a client plays an intermediate role. It uses some information for its own processes (design, planning, installation, commissioning, maintenance) and passes other information on to the client (for operation, quality control and legal purposes).

Three levels of ownership of knowledge and information can be distinguished, comparable with that of the publication of books:

1) intellectual ownership (to be compared with the author-rights of a book),
2) distribution ownership (to be compared with the publishing rights of a book), and
3) usage ownership (to be compared with the rights of owning a physical copy of a book).

These three levels are also relevant for the information infrastructure of a project. If a project is executed under a lifecycle oriented contract (DBM or beyond), it is possible that not only the main provider, but also suppliers take lifecycle responsibility for their products. The original owner or author of a piece of information may then take lifecycle responsibility for the content of the corresponding information also. Given the conclusions from 4.1 he will do this with the application through which the original information was produced.
Fig. 7. The data (or document) derivation hierarchy and the three main ownership levels. The fences between author, distributor and user depict transaction points between organizations, possibly working under different contractual conditions.

However, if the work is contracted based on a traditional design-bid-build contract, where the responsibility of the design organization stops at the point of bidding, the master copies must be handed over to the contractor who is responsible for execution. After completion, the as-built documentation is handed over to the owner, operator and/or maintenance organization. If the responsibilities of the authors of these documents stop after handover, it is not any longer possible to use the original software application by which it was produced. Exchange of the electronic document in original format is usually not desirable, because the receiver may not have the corresponding application. The exchange in standard format – if available and useful - may result in information loss.

The handover of data in an electronic form has legal aspects. First, data in electronic form can be changed easily. In the case of a legal dispute, it may be a question whether or not an original document is modified. Second, in a legal dispute, it may be a question which electronic copy is the master; is it the copy in its original format, or is it the one in neutral format? The latter question is not only relevant because either copy may have been modified since its creation, but also because a conversion may lead to information loss.
6. RESEARCH AND PRACTICE

The technical aspects of this subject were investigated by the European PISA project in the early 90-ies. PISA is an acronym for *Platform for Information Sharing by CIME Applications*, CIME an acronym for *Computer Integrated Manufacturing and Engineering*. This project was executed by a consortium formed by car maker BMW, IT companies Digital Equipment, Pafec and Cap Gemini, research organizations Adepa, Caddetc and TNO, and Karlsruhe University. It aimed at making ISO standard 10303 STEP useful for industrial applications. During this project it appeared that a standard such as STEP could not guarantee a flow of information between different users, organizations and information systems, without any loss of content or meaning. It revealed that this problem is intrinsic to any schema-based standard, and will therefore not be restricted to ISO 10303 alone. The problem is ultimately addressed in STEP by Conformance Classes and testing procedures, but this solution will not be adequate for communication between heterogeneous applications and different organizations (Gielingh et al. 1995, and Gielingh and Goult, 1993).

With today’s technology, standards cannot prevent loss of information content and meaning in an exchange. Or, to say the least: it is not yet proven that standards work well under all circumstances. Since PISA, this subject is not widely covered by additional research. More recent research led by Robert Amor of the University of Auckland suggests comparable problems with the IAI-IFC’s (Amor 2005, 2006). His results are not yet published.

In any case, there is a need for additional research that predicts the quality and effectiveness of electronic information transfer for different implementation scenario’s. It cannot be assumed that information transfer works without any problems. Major questions that are left open, are liability for loss of information or meaning, and whether organizational or procedural solutions can be developed that minimize or avoid problems.

The practical dimension of this subject was experienced by the first author of this paper in a major construction project, in his role as management consultant. The Groningen Long Term project for NAM (a joint venture of oil and gas companies Shell and Exxon) addresses the renovation of 29 gas production clusters in the northern part of the Netherlands. It is based on an integrated Design-Build-Maintain contract, and executed by a consortium that includes Jacobs Engineering, Stork, Siemens and Yokogawa. This huge project enabled the application of innovative business processes and technology, and revealed many of the organisational, technological and process related issues that are discussed in this paper.
The GLT project revealed that also the legal aspects of data exchange in major projects require special attention, especially in Construction. In most other industrial sectors there is usually a single company that takes responsibility for the entire supply chain, and which has an interest in optimizing this supply chain. Although clients and main contractors in Construction will (or at least: should) have a similar interest, their span of control is usually limited. For this reason, the impact of contractual agreements, including aspects of responsibility and liability, needs further research.

7. CONCLUSIONS

This paper has presented the implication of distribution and access of data for the management and organization of electronic information and communication. A traditional design-bid-build contract requires the handover of information between different firms in the construction supply chain and the life cycle of the building. While the responsibility of each firm stops after the results are handed over to the next firm in the supply chain, it is often not possible to manage information in its original format as a master copy. The transfer of information from one firm to the next often causes a loss of information and affects the usefulness of that information. Because electronic data transactions cause lots of trouble and effort in an often traditional construction sector, it is likely that the sector will stick to the usage of paper as a primary medium for legally important information, instead of shifting to electronic media.

Advanced and integrated contracts, such as DBOM contracts, preferably in combination with strategic supplier contracts, make it possible to manage the master data in their original format. The role of standards will then change. They do not necessarily have to support an error-free handover of data without the loss of information between firms, but they do support the generation of user views, and thus improve the information sharing between firms.

Differences between contract types have an impact on the way and the level to which information is organized and shared. This has consequences for the organisation of the data infrastructure and the standards that support this infrastructure. As a result, while construction companies are involved in several projects of different kinds and sizes with changing project partners, are confronted with continuously changing requirements for their information infrastructure. Large investments in extensive and highly integrated infrastructures will not quickly pay off, especially not if it is to be adapted to the different consortia for different projects. If the application of advanced tools for project integration in construction projects is hindered by such factors, it will also be difficult to support
new working practices that reduce costs and result in higher client value. Further research needs to address this dilemma, and offer possible solutions for the problems identified in this paper. This research needs to be aimed at the development of adaptable and modular information systems, as well as the introduction of concepts that promote more stable production organisation between firms and across projects, including supply chain integration, extended enterprises, project-independent project organisation, repetitive business strategies and strategic cooperation.

8. REFERENCES