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ARTICLE

Challenges for Integrated Design and Delivery Solutions

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Abstract

A new approach of integrated design and delivery solutions (IDDS) aims to radically improve the performance of the construction industries. IDDS builds upon recent trends in the construction industries that have seen the widespread adoption of technologies such as building information modelling (BIM) and innovative processes such as integrated project delivery. However, these innovations are seen to develop in isolation, with little consideration of the overarching interactions between people, process and technology. The IDDS approach is holistic in that it recognizes that it is only through a combination of initiatives such as skill development, process re-engineering, responsive information technology, enhanced interoperability and integrating knowledge management, among others, that radical change can be achieved. To implement IDDS requires step changes in many project aspects, and this gap between current performance and that required for IDDS is highlighted. The research required to bridge the gaps is identified in four major aspects of collaborative processes, workforce skills, integrated information and knowledge management.

■ **Keywords** – Automation; BIM; integrated design; process re-engineering; productivity; skill development

INTRODUCTION

The design, construction and commissioning sectors have been repeatedly analysed as inefficient (Latham, 1994; Egan, 1998; Gallaher *et al.*, 2004). There is unquestionably significant scope to improve the delivery of value to clients, stakeholders (including occupants) and society in general, simultaneously driving down cost and the time to deliver operational constructed facilities. Various initiatives developed from computer-aided design and manufacturing, such as lean construction, modularization, prefabrication and integrated project

delivery, are currently being adopted by some sectors and specializations in construction (Widfeldt *et al.*, 2008; Kunz and Fischer, 2009; Cohen, 2010). However, there has been limited focus on the necessary interrelationships between all of these initiatives.

For example, the adoption of building information modelling (BIM) has been fairly widespread (Young *et al.*, 2008); however, its use in many practices has been analogous to the introduction of computer-aided design (CAD), in that it replicates a current process (drafting) virtually unchanged. Yet BIM

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technologies have the potential to revolutionize current practice through their ability to impact on the majority of processes in a construction project. Hence, to maximize the potential of BIM requires an examination, and potential re-engineering, of all impacted processes and a reassessment of the role of practitioners in each of those processes.

The International Council for Research and Innovation in Building and Construction (CIB) integrated design and delivery solutions (IDDS) priority theme establishes the framework for an integrated and coordinated merger of people, process and technology issues in order to enact a radical and sustained transformation of the construction industries. This framework takes advantage of the technological solutions becoming available, such as BIM, and is seen as the next step beyond what has been achieved in current BIM utilization, as indicated in Figure 1. It also ensures that improvements in construction projects are considered as a holistic combination of people, process and technology, recognizing the intrinsic requirement for all three of these aspects to be addressed in parallel. As such, there is no recognizable end-point for IDDS, but rather an ongoing pattern of reflection and re-engineering based on the evolution of technologies, processes and skills in the industry.

Various elements of the IDDS approach are currently being explored in largely isolated parts of academia and industry, and by certain enlightened

clients. These early adopters are discovering enhanced ways of delivering and gaining value over the full life cycle of the facility. The IDDS approach also challenges traditional industry structures and contractual processes, as it both highlights current inefficiencies and facilitates their resolution, making the most of the workforces' collaborative intelligence. A direct implication of this is that IDDS will expand the construction workforce beyond traditional roles and remove geographic barriers as online training, design and collaboration are developed. Furthermore, as construction becomes more industrialized and integrated there will be increased opportunities for remote manufacture, operation and even maintenance.

This article begins with a vision of exemplary IDDS to realize the full potential benefits, and then describes the current state of four key topics: collaborative processes; enhanced skills; integrated information and automation systems; and knowledge management. The article concludes with a summary of the benefits of IDDS and the actions required to realize these benefits.

ACHIEVING A STATE OF IDDS

Successful implementation of IDDS will move the industry towards ongoing and iterative changes in each of the project phases, such as: conceptual planning and making the business case; all parts of design, supply chain management, construction, commissioning; operation; retrofit; and decommissioning. For each of these phases, key changes in the structure and culture of the project team, including the firms that contribute its members, create a favourable context for IDDS. Examples of these changes include: a team approach; support for innovation and tolerance of failure in a team; strong lateral linkages and decentralized decision making; networks of commitment; and new forms of contracting, transparency and risk management (including insurance models).

This favourable context allows integrated work processes, facilitated by advanced information systems, shared models and involving people with special skills, in terms of both trades and professions, and management and leadership.

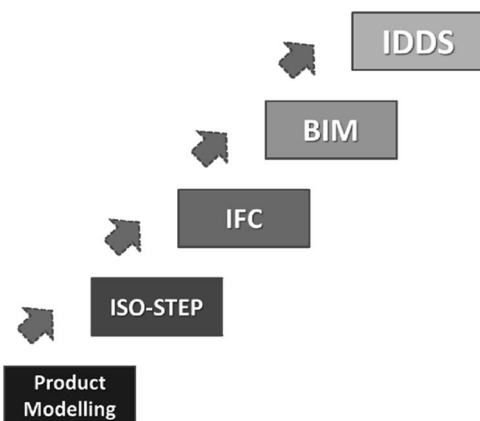


FIGURE 1 Evolution of IDDS

Above all, the future state of IDDS supports and fosters learning and continual improvement internally and across the sector through the use of knowledge management and iterative feedback. This vision of the effects of these elements on a future exemplary IDDS project is described briefly below. The cultural change required to achieve IDDS is challenging, especially in the development of trust within what is currently often a risk-shedding and distrusting sector. However, sufficient successful integrated projects have been delivered to prove that such a transformation can occur (Cohen, 2010).

The following sections further describe each of the four main elements that have been identified as vital components of IDDS. While the IDDS framework expects that these elements are considered in combination for real projects, they are split into the readily recognizable aspects of collaborative processes, enhanced skills, integrated information and automated systems, and knowledge management for the purposes of description in this article. For each element, the description includes current conditions and a brief summary of the expected future path to achieving IDDS.

COLLABORATIVE PROCESSES CURRENT CONDITIONS

There are examples where first-tier contractors operate in an integrated manner on individual projects, or where temporary joint ventures are established, although these remain comparatively rare, despite seeming to offer financial, time and delivered quality benefits through more integrated processes (Gilligan and Kunz, 2007; Eastman *et al.*, 2008). Even rarer are examples of vertically integrated supply chains and work packaging strategies that support IDDS. Unfortunately, the culture of distrust and litigation prevails and impedes experimentation and progress with these new paradigms. What does exist is often at the initiative of exceptional individuals, although examples of clients forcing such an approach (e.g. through the use of framework agreements) do exist.

In general, silo mentalities and cultures prevail and document-based information exchange across professions and throughout supply chains ensures that information and, particularly, any associated

intelligence, coordination and agility is either corrupted or even lost. Thus decisions are frequently made autonomously without multidisciplinary participation, and in the absence of holistic or comprehensive and accurate knowledge. The use of an iteratively and incrementally developed design, pulled from an end user or client perspective, is virtually impossible within current structures, or at least rarely achieved.

Designers, engineers and advisers often need to collaborate, although rational formal procedures on how to integrate through collaboration are often lacking. Collaboration mechanisms are typically reliant on the particular coordination responsibilities of the main designer, although these vary and may be informally defined. 4D-CAD and BIM are now often used to integrate design information and reduce design errors (artefact collisions, functional requirements, etc.); however, unified solutions are not at a stage where real knowledge sharing and knowledge development is supported for the design, construction and operation stream(s). Integrated procurement routes, such as private finance initiatives, ensure that designers, engineers and advisers are starting to collaborate with contractors and suppliers more often. These types of procurement model facilitate effective team communication and collaboration and iterative integration of stakeholder ideas and feedback. There is some research evidence that such procurement approaches can yield improvements in time and cost (Vasters *et al.*, 2010). However, the lack of tools to measure and benchmark quality and design integration, as a value to be achieved, hampers proper measurement of any quality improvements.

FUTURE PATH

To effectively transform to efficient, end-to-end and vertically integrated processes through the use of IDDS will require both structural and process changes in the industry. Improved design and delivery through better coordination and integration will remove the most costly categories of waste in the construction sector, that of waiting time and 'making do' (i.e. finding work-arounds when all planned prerequisites are not available) (Koskela, 2004).

Additionally, information technology tools will need to provide increased capability for knowledge

sharing and development, rather than for just information exchange, aggregation and storage. This will prevent non-ideal adaptations of pre-existing designs and stimulate the efficient (in terms of multidisciplinary design iterations) creation of design value. A key input to these models will be a shared understanding of integrated design value as a deliverable of the team.

Collaborative approaches, linked with an effective knowledge management system, would facilitate options design and engineering, based on alternatives that build both on prior knowledge and on typical alternatives. Further benefits may result from the adoption of new approaches to work processes now being developed in other sectors. These include modularized, transferable, partial solutions and processes or partial/interim product assemblies, termed 'holonic' development and production (Koestler, 1967; Checkland and Scholes, 1999), as well as self-learning factories (Jovane *et al.*, 2009).

ENHANCED SKILLS

CURRENT CONDITIONS

Members of current project teams often bring skills that are focused on design disciplines, construction trades or other functional activities, such as project management or materials management. The increased performance requirements and complexity of constructed facilities require additional specialists and increase the need for integration skills. Multi-skilling is rare and document-based thinking is prevalent.

Appreciation of linkages between work products in different functional areas, and the ramifications of this interdependency, is limited. Compared with prior projects that used consistent work processes to deliver simpler facilities, fewer people can decipher what is important and develop coherent strategies for integration to realize project objectives over the full life cycle (Baccarini, 1996). Experience-based judgement is declining and few people understand advanced information technology and its implications for integration. Professional development does not keep pace, and few organizations support the development of integration skills. The potential for specialization traps

discourages individual investment in learning about new technology.

FUTURE PATH

Future projects that make effective use of IDDS will require managers, engineers, specialists, suppliers, builders and operators who bring shared knowledge of major work processes on the project, together with skills to integrate these work processes. Project managers tasked with integrated projects will seek out staff with shared technical knowledge and integration experience as key selection criteria. The increased availability of integrated data and information, along with knowledge of prior projects and current requirements, will foster integrated work processes both between and within specific project phases and major activities. The information and knowledge resources and the integration skills of the project team will allow the evaluation of a number of alternatives for the work process and product of each major functional activity for the project. This will result in increased effectiveness in meeting all types of project objectives.

Making the transition to IDDS will involve developing the shared knowledge and skills needed to effectively perform integrated work processes. This will require actions by each major functional area represented on the project team, as well as by researchers and educators. Owners and project managers will need to create a project organization and context that fosters IDDS, including using this capability as an important criterion in selecting team members and the timing (typically earlier) of their involvement. They will also need to insist on a life-cycle view of projects to ensure that earlier work processes will provide the information and knowledge needed for later project phases. Design engineers and technical specialists will need to grasp the major advantages that IDDS can provide and broaden their traditional discipline focus to view an integrated design as the only acceptable solution. Suppliers of permanent equipment and engineered materials will need to adopt a proactive approach to integrating their information and requirements into early project work processes and accepting integrated solutions that are best for the project.

Builders will need to view IDDS as an opportunity, not a burden, and contribute sound and early input to key project decisions that will allow the use of beneficial methods, such as increased off-site work and automation. Operators will also need to get involved early and make their requirements to support operation and maintenance known and considered in project decisions, even to the extent of subsequent retrofit options. Researchers and suppliers of information technology can continue to increase the capability and usability of integration tools, further considering the data, information and knowledge required by each of the project team members and activities. Educators can take advantage of integration tools as potential learning resources, giving the students the dual advantage of gaining experience with work processes and technology for IDDS.

INTEGRATED INFORMATION AND AUTOMATION SYSTEMS CURRENT CONDITIONS

A small amount of integration, either through the supply chain or along the design path, is supported by current BIM or associated analysis tools. These approaches are typically vendor-specific and tie together a small number of design tools (in comparison with the thousands available in the marketplace), which are unlikely to be the complete set required by any particular grouping of professionals involved in a construction project, let alone a fully integrated team. Creating a wider integration platform usually requires uniquely qualified individuals to be available in one of the companies involved in the project. The IFC product model data standard (IAI, 2010) cuts across CAD vendors and offers limited interoperability for a subset of design and construction processes, and yet requires individuals with special qualifications in each company to ensure the integrity of data exchanged. Due to the limited number of applications supported in current BIM environments, or with interoperable interfaces, the practice of manual re-entry, and checking of data between applications, is both necessary and common. Using current interfaces for automated information exchange can often result in loss of information and

offers no guarantee of the semantic integrity of models being exchanged (let alone retaining the design intent) (Lipman, 2006; Pazlar and Turk, 2006; Amor *et al.*, 2007). Information management with current BIM and interoperability solutions is typically by a document management system, in which a complete model is exchanged and information is managed through interrogation of the different versions of the model being passed between project participants.

With a few exceptions, current value chains for materials and component supply and for construction operations at the project site remain fragmented and individually optimized. Paper specifications and drawings define the technical requirements and configuration for the products of fabrication and construction, but do not facilitate integration of the physical work processes. As a result, opportunities for considering detailed fabrication and assembly during design, performing this work at the best location and making use of appropriate levels of automation are largely lost, lessening the effectiveness of project delivery. In addition, these fragmented work processes often do not produce the data and information needed for the remaining phases of the project life cycle, let alone provide 'as built' (compared with 'as designed') feedback to subsequent stages. Nevertheless, the possibilities of interfacing BIM component specifications directly to computer-aided manufacturing and automated assembly are already being used in isolated cases (Newton, 2008).

FUTURE PATH

Interoperability will have become ubiquitous in the industry when practitioners do not need to understand the complex and sophisticated technology underlying their software tools. This will provide a seamless connection between software tools gathering and updating the view of information required for any particular process in the project. Specialized software professionals will not be required to develop and manage project-specific information exchanges. An interoperability manager from the project team or partnering companies will establish the best approach for project use of the software tools and for information delivery, sharing and handover.

Integrated work processes and information technology will bring major advantages during the planning and design phases of projects. This will continue into the delivery and operations phases in two major ways. First, the benefits from integrating information-intensive work processes during the design will extend to the members of the value chain responsible for materials supply, construction and commissioning, and operation. Second, integrating the physical work processes for fabrication, installation and commissioning of new facilities will further increase the overall performance of the project. However, more fundamental performance improvements will accrue from the dense and accurate information transmission between flexible production resources, when linked with iterative and incremental design to form an information view of construction. Information must flow efficiently from the direction of functional utilization and client or stakeholder requirements backwards, as well as from the design(er) forwards, within carefully optimized design information architectures. Only then can physical activities be optimized and integrated in a holistic manner.

It is not clear how integrated physical work processes will take place during project delivery, although they will begin with the products of integrated design, especially models that include both technical requirements and geometric configuration. Analysis of the scope of work using these product models, along with construction process models, will include evaluating multiple alternatives for the location of work and for the methods of fabrication, installation, systems completion and commissioning. This will result in a work plan that best meets the project objectives, using the optimal combination of physical work processes in the shop and at the project site. These integrated processes will also provide data and information regarding as-fabricated and as-built conditions (in a sufficiently timely manner that subsequent design stages can be re-optimized), along with the required quality documentation. Integrated work processes during project delivery will greatly enhance the team's ability to complete the project in accordance with the owner's objectives and priorities for cost, schedule, quality,

safety and sustainability. Performance of work at the best place, using the best process, offers major opportunities for performance improvements related to each type of objective.

Reaching this future state requires further significant work on many aspects of the computer science and semantic interoperability developed over the past two decades. The data dictionaries and information models that underlie IDDS information exchange will require significant development to cover all major processes. A major effort will also be required to define the information views (including for visual management) required by particular classes of application and standard processes. Sophisticated approaches to model and view-based information management are also required to cope with project structures and the processing times common in the industry. Software developers will need to put significant resources into ensuring the adequacy of their products to exchange semantically consistent views of buildings, and into maintaining configuration management and decision integrity and traceability. The new software tools will also need to tie into knowledge management systems within companies and for the industry.

A very significant gap is the current reliance of 2D drawings for transfer of 'official' information. Solving this problem will require change by clients and regulatory authorities, as well as the industry's supply chain. Eventually, the building model must itself become the basis for contract in terms of design, build and operation. Another related tension arises from the existence of proprietary information and the associated need for security to manage access to that information. This leads to currently unsolved issues around the specification, management and identification of the provenance of information within a project. The flow-on effect of handling provenance information is enabling control of the entry and manipulation of information within a project to those who are tasked with specifying such information and therefore have, perhaps, shared ownership rights to the information throughout the project.

Leading suppliers of materials and components for construction are moving towards partial integration and automation of engineering,

procurement and physical manufacturing and assembly work processes. In some firms this includes extracting information for fabrication from the design model. Further progress will require providing more complete design information models for use in planning and integrated physical work processes throughout the value chain for materials and components, in construction, and during the facility use and maintenance. Another gap is more comprehensive planning and management tools to allow full evaluation of alternatives for integrated physical process during project delivery. Further development of these tools will allow sharing of data and information for a broad range of work tasks during and following project delivery. Examples include detailed configuration for all engineered materials, size and other constraints on fabrication and shipping, plans for material handling and flow to the workplace, most beneficial sequences of installation, acceptance criteria for inspection and measurement, requirements for quality control documentation, priorities for systems' completion and commissioning, and technical requirements for operation and maintenance. Accommodating the different levels of technology adoption and competency across the various sectors and regions of the industry, by providing viable increments to new capabilities, is a key challenge in moving these principles from the few leading organizations to a majority of the construction industry and its stakeholders.

KNOWLEDGE MANAGEMENT CURRENT CONDITIONS

Typical firms have limited, if any, standards for knowledge management. Those that exist are often dictated by management or legal staff without internal experts' and wider stakeholders' contributions. These standards provide little opportunity or encouragement for employees, regardless of position, to provide feedback for their further improvement. Systems and procedures that do exist are usually administrated by management, not distributed to expert staff. Codified knowledge within the typical firm exists within individual groups (discipline, trade, function) and is seldom shared with those in other domains or upstream or downstream partners in the name of 'competitive advantage'. Corporate culture tends to

hide rather than directly address and resolve problems that have occurred on its projects. Capture and reuse of project knowledge is limited to reuse of personnel. There is also a failure to recognize and transmit the true training and learning outcomes required from the education sector.

FUTURE PATH

Applying knowledge management, as done in a few leading firms (Anumba *et al.*, 2005), includes codifying, using and constantly updating critical knowledge and business processes. This is based on continual internal and external stakeholder feedback as 'best practices' and 'lessons learned' over the full life cycle of the project. Employees are rewarded for their input, and corporate culture encourages documentation of knowledge. Problems and solutions with multi-company, multidisciplinary or multi-phased implications are captured in narrative forms. The focus of these activities is concrete actions or the creation of reusable and potentially automatable 'processable rule-sets'.

Achieving knowledge management requires effective and easy ways to capture and represent the knowledge as rules to be automated, and lessons to automatically remind employees about such captured knowledge. The transitory workforce, temporary management structures and distributed sites of construction projects require automated collection of data and processing of this into intelligence. The retention of design and supply chain change 'audit trails', and their integration with near-real-time monitoring of status (e.g. through RFID tags or on-site LIDAR scanning) could provide valuable knowledge. However, a mechanism is needed to embed contextual narrative into such a project history. Corporate culture must also change to value staff ideas, encourage reuse and openness between groups, and build practices based on stakeholders' feedback. Industry leaders can also prompt and help educators to better prepare graduates for taking advantage of the knowledge available in progressive firms. The gains achieved through IDDS are likely to foster longer-term business relationships that encourage sharing and growth of knowledge capital and make this process both more probable and less problematic.

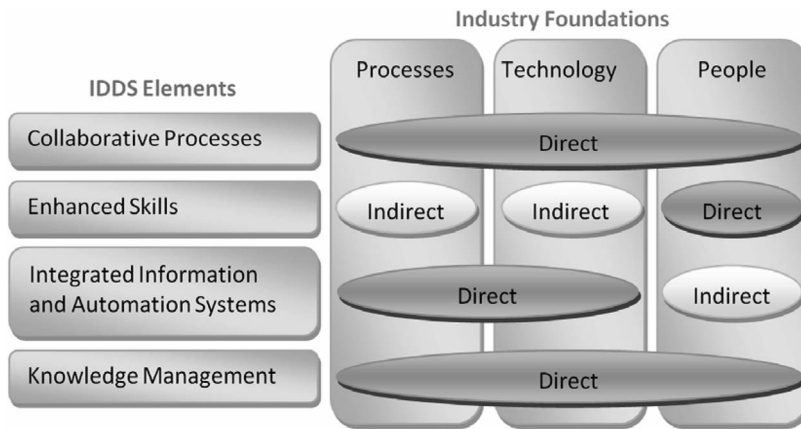


FIGURE 2 Impact of the four key IDDS elements on processes, technology and people
 Source: Owen (2009)

INVOLVING STAKEHOLDERS TO REALIZE WHOLE-LIFE VALUE

As discussed above, the adoption of IDDS by the construction sector has great potential to yield value both to companies in the sector and to clients of the sector. That value can only be measured in the context of these stakeholders and will take the form of savings in time, costs and materials; improved quality and performance of the facility; product optimization or customization; and enhanced reputation. Typical influences of whole-life sustainability can only be modelled, delivered and monitored through the adoption of IDDS. However, this improved delivered value will not come automatically or without significant challenges.

Although identified gaps have been split into industry and research or education topics, they cannot be effectively viewed or addressed in isolation but rather in terms of their potential influence on the construction sector's processes and practices, adopted technologies and people. As illustrated in Figure 2, any attempts to fill gaps identified in one element will necessarily impact, directly or indirectly, on all three industry foundations. Apparent gains in one foundation can be more than offset by consequences or lack of preparation in others. Identifying and addressing specific consequences of changes is non-trivial and cannot be done without the

solid participation of sector stakeholders. Hence, IDDS requires strong linkages between researchers and stakeholders to cooperatively recognize specific needs; co-develop solutions and updated learning and training packages; and apply the results on a continuous and ongoing basis.

CONCLUSIONS

It is clear that significant momentum exists in achieving particular aspects of the necessary precursors to IDDS. There is also a growing alignment of researchers tackling these individual areas to contribute to the more holistic needs of IDDS. This is being promoted and encouraged by organizations such as CIB, in its case with the priority theme on IDDS. In this article, four of the major areas required in IDDS have been identified and the challenges of these areas elucidated, based on the current situation and the potential future once IDDS is fully established. This analysis shows that there is still significant work required in each of the four areas in order to step from the BIM level of operation that is currently being taken up by the industry to the more sophisticated and holistic approach that is IDDS. Future work by the CIB's IDDS working group will look to extend this analysis into a roadmap for IDDS, along with the actions required in the short, medium and long term to achieve this goal.

REFERENCES

- Amor, R., Jiang, Y. and Chen, X., 2007, 'BIM in 2007 – are we there yet?', *Proceedings of the CIB W078 Conference on Bringing ITC Knowledge to Work, Maribor, Slovenia, Rotterdam, CIB*.
- Anumba, C.J., Egbu, C. and Carillo, P. (eds), 2005, *Knowledge Management in Construction*, Oxford, Wiley-Blackwell.
- Baccarini, D., 1996, 'The concept of project complexity – a review', *International Journal of Project Management* **14**(4), 201–204.
- Checkland, P. and Scholes, J., 1999, *Soft Systems Methodology in Action: A 30-year Retrospective*. Chichester, UK and New York, Wiley.
- Cohen, J., 2010, *Integrated Project Delivery: Case Studies*, Sacramento, CA, The American Institute of Architects California Council.
- Eastman, C.M., Teicholz, P., Sacks, R. and Liston, K., 2008, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, Hoboken, NJ, Wiley.
- Egan, J., 1998, *Rethinking Construction: The Report of the Construction Task Force*, London, The Department of Trade and Industry/HMSO.
- Gallaher, M.P., O'Connor, A.C., Dettbarn, Jr. J.L. and Gilday, L.T., 2004, *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry*, Gaithersburg, MD, NIST Building and Fire Research Laboratory.
- Gilligan, B. and Kunz, J., 2007, 'VDC use in 2007: significant value, dramatic growth, and apparent business opportunity', Center for Integrated Facility Engineering Report, Stanford University, Stanford, CA, USA.
- IAI, 2010, *International Alliance for Interoperability*. Available at: www.iai-international.org/ [accessed 30 April 2010].
- Jovane, F., Westkamper, E. and Williams, D., 2009, *The Manufacture Road: Towards Competitive and Sustainable High-Adding-Value Manufacturing*, Berlin, Heidelberg, Springer-Verlag.
- Koestler, A., 1967, *The Ghost in the Machine*, London, Arkana.
- Koskela, L., 2004, 'Making do – the eighth category of waste', *12th Annual Group for Lean Construction Conference, Denmark, IGLC*.
- Kunz, J. and Fischer, M., 2009, 'Virtual design and construction: themes, case studies and implementation suggestions', CIFE Working Paper 097 Version 10, Stanford University, CA.
- Latham, M., 1994, *Constructing The Team, Final Report of the Government / Industry Review of Procurement and Contractual Arrangements in the UK Construction Industry*, London, HMSO.
- Lipman, R.R., 2006, 'Mapping between the CIMsteel integration standards (CIS/2) and industry foundation classes (IFC) product model for structural steel', *Proceedings of the Conference on Computing in Civil and Building Engineering, Montreal, Canada*.
- Newton, C., 2008, 'Learning through prefabrication', *Undisciplined! Proceedings of the Design Research Society Conference, Sheffield, UK*, 283–295.
- Owen, R. L. (ed), 2009, *White Paper on IDDS Integrated Design and Delivery Solutions*, Publication 328. C1B, Rotterdam, The Netherlands.
- Pazlar, T. and Turk, Z., 2006, 'Analysis of the geometric data exchange using the IFC', *Proceedings of EC-PPM, Valencia, Spain*.
- Vasters, R., Prins, M. and Koppels, P.W., 2010, 'Does integrated procurement reduce building cost and project time? ', *CIB World Congress 2010, Salford, UK, CIB*.
- Widfeldt, M., Amen, R., Hjort, S., Kilbo, P., Mellby, C., Shaw, D., Claeson-Jonsson, C. and Magnusson, J., 2008, 'New manufacturing technologies', Manubuild Combined Deliverable D4.2–2,3,4.
- Young, Jr. N.W., Jones, S.A. and Bernstein, H.M., 2008, *Building Information Modelling Trends*. Smart Market report, New York, McGraw-Hill Construction.