A Note From the Authors

When we invited several key people to write forewords for us we had not expected such positive and relevant responses, or so many. However, each Foreword is well worth reading.

Alongside the Foreword from our Secretary General, we have insights from some of the leading thinkers and practitioners in the field of construction today.

David Philp came to Salford University as a construction company Technical Services Director a few years ago primarily to discuss Lean Construction but we spent a lot more time discussing the fusion of Lean Construction (LC) with Building Information Modelling (BIM) and Integrated Project Delivery (IPD). His boss told us at the inaugural Balfour Beatty BIM Expo that David was so enthused with BIM that he offered to fly tourist class to the USA to do more research (if only academics were permitted to use such discretion). Not surprisingly, David is now Head of the UK BIM Implementation Programme; this is enroute to becoming the most wide-ranging construction change programme in the world.

Phil Bernstein is the architect and lecturer who guided the IPD ideas from Florida to become the national standard for the American Institution of Architects and then tested the standard by running the first project to use it as the client for his own Autodesk building in Waltham, Massachusetts. Phil will tell you that changing mindsets to become collaborative instead of suspecting the motives of your fellow IPD team members took even him a few meetings.

Digby Christian is widely credited as having delivered a challenging hospital project using a holistic approach, which transformed even further during the project. For the client to accept that they should jointly understand and address risk and by doing so could jointly own and control the success or failure of the project is rare. To expand their form of contracting (Integrated Forms of Agreement) to incorporate eleven of the key designers is unheard of. Digby is so passionate that he has written is own requirement for research into IDDS – the development of a conceptual model for the efficient delivery of capital projects and therefore a de-facto test of IDDS itself. We tried to cut Digby down to size but had to agree that he deserved a page of his own.

Finally, Wim Bakens has kindly called our Roadmap inspirational but it is the people who have written our Forewords and contributed to this document who are truly inspirational. Wim and we will only believe this long process to be a success when the resultant IDDS research is fielded in practice, although the steps to get there will also be triumphs in their own way. First, we need engagement of the Coordinators and research teams of the Task Groups & Working Commissions identified in Table 1, together with others with an interest; second, we need funding strategies to enable the research; and third, we need to track progress and, hopefully, success.

Robert Owen, Robert Amor, John Dickinson, Matthijs Prins & Arto Kiviniemi
March 2013
Forewords

Dr Wim Bakens
Secretary General, CIB

If you want to obtain a deeper insight into the very concept of IDDS, if you want to support its further development and application in building and construction practice or if you want to be engaged in the programming, funding or execution of research in support of this, I recommend you read and let yourself be inspired by this IDDS Research Roadmap.

The concept of IDDS – Integrated Design and Delivery Solutions – brings together developments of new concepts, tools and technologies in three different areas:

- Integrated procurement and project delivery
- Integrated IT applications, covering all phases of project development, design, construction and use, especially including the further development of the BIM concept
- Skill enhancement for people working in the building and construction sector.

When these concepts, tools and technologies are fully developed and do become available for application within one visionary framework, a new platform will have been created that will enable the building and construction sector to improve its performances and to enhance its relevance to society in a magnitude greater than from any innovation in building and construction that we have witnessed in the last two or three decades.

With this Research Roadmap, CIB aims to stimulate the research needed worldwide in support of this innovation, and the execution of this research such that its collective outcomes will have maximum impact.

CIB envisages producing such research roadmaps on a regular basis, but this one on IDDS is the first of its kind and consequently its authors were the first to explore and elaborate best possible structures and design for this type of publication. They deserve my thanks and admiration for a publication that will set the standard for many more to follow.

David Philp MSc BSc FRICS FCIOB FGBC
Head of BIM, Mace
Head of BIM Implementation (seconded) HM Government
Professor Glasgow Caledonian University, Scotland
Chair BIM2050 Group (for young professionals)

Our construction landscape is changing rapidly; most noticeably the science of creating and maintaining our assets is undoubtedly entering a new digital renaissance, one that is driven by the need for new efficiencies both in capital & operational expenditure (“totex”) and increasingly altruism around our carbon solutions.

The UK HM Government Construction Strategy (GCS) is leading the way in terms of seeking 15-20% lifecycle savings through a series of client driven interventions. One of the main components of this strategy is the mandating of level 2 “collaborative” Building Information Modelling (BIM) on all centrally procured projects by 2016, arguably the most cohesive centrally driven BIM strategy in the world. The GCS BIM hypothesis is simple: Government as a client can derive significant improvements in cost, value and carbon performance through the use of open sharable asset information.
Whilst information driven transactions (data drops) and digital technologies underpin the strategy, BIM in the UK has very much become a verb, a way of working collaboratively, and one that heralds a cultural change. In the UK level 2 collaborative BIM is a staging post that lets us stress test the hypothesis in terms of commercial transactions, new processes and, principally, changes in behaviours. Ultimately we will, in time, move from the foothills of collaboration to integration. It is essential however that this shift from level 2 to level 3 maturity be thoughtfully transitioned and the stepping stones suitably anchored to ensure a safe journey for both client and supply chain.

The CIB Integrated Design and Delivery Solutions (IDDS) Research Roadmap sets out to establish these key integration themes and help ensure a collegiate framework for researchers as we set out to better this already great industry.

__________________________________

Phil Bernstein
Vice President, Autodesk Strategic Industry Relations
Lecturer in Practice, Yale University School of Architecture

Autodesk believes that the integrated use of interconnected digital technology holds great promise for the AEC sector and will continue to catalyse significant change in design, construction and operational process. We continue to work on such technologies accordingly. But I am also a keen advocate of integrated delivery models they make possible, having been an early exponent of Integrated Project Delivery at our own Headquarters here in Waltham, Massachusetts. That project confirmed our suspicion that digitally enabled, collaborative teams working in concert with shared risks and rewards can radically transform how we build. Thus the three imperatives of IDDS reinforce what I strongly believe are critical priorities for AEC.

This research roadmap targets investigation in sustainability, improved practices and better knowledge capture, all well-understood priorities for innovation. However, the development of a Built Environment Information Fabric is of particular promise. The linkage between GIS, city modelling and various data sets is a huge challenge but will greatly help our understanding of the world and how best to develop and manage how to build it.

This research roadmap is an effective recapitulation of the drivers, enablers, barriers and opportunities for researchers to help develop the sector over the next decade. The CIB already incorporates the efforts of over 5,000 academic and industry researchers globally but researchers outside of the CIB network should also find much here to help them focus their efforts. Such cross-industry efforts will be crucial to find, support and distribute transformational innovation that AEC critically requires.

__________________________________
A Case for IDDS Research from Sutter Health

At Sutter Health we have changed the way we contract for work, now using a single blended team of design and trade professionals from the very beginning of design all the way to the first day of operation of the completed facility. We give that team the responsibility and authority to manage the risks that they control and the profitability of their respective companies is determined by how successful they are in doing this. In return for those companies putting all of their profit at risk, we undertake to not put the companies themselves at risk by guaranteeing to reimburse them for all of their actual costs. Thus Sutter Health takes on the catastrophic downside risk of our projects and manages this risk through establishing integrated, collaborative relationships with our project partners.

Many wonderful things have evolved from this grand conceptual shift in our thinking around contracting. We are getting our projects built on budget; more remarkably we are getting them built on time; and most remarkably of all we are getting 100% of the scope we requested at the start delivered to us at the end. That last factor is the great elephant in the room – so many projects can be dressed up as on time and on budget by colluding with our teams to cut our scope, degrade our visions for the project, or by just one more visit to the board to beg for more money and time. No owner, designer or builder has any incentive to talk about this with the outside world. The only people this gets discussed with are the people inside the system. They may deny it at the speaker’s podium or in their marketing brochures, but they’ll wholeheartedly admit it’s true at the bar.

The success at Sutter Health happened because of the change in the way we contracted. That change required the team to overhaul most of their standard practices and behaviours. They had to find a way to track performance against the owner’s goals, to develop a single BIM from thousands of separate files, to plan work as a single team and to ensure their contract partners would not fail. – They had to undergo fundamental cultural change. All of those changes were made not just because they are the right things to do but also and critically because you can’t be financially successful under this contract model without them. That’s why this contractual change is so important. It establishes a market for everything you are about to undertake to create.

Right now it is only the leading visionary thinkers in the market that are after the tools, information flows, processes and cultural transformations you are about to spend years creating, but the market place in general is not. Because of the way the vast majority of the projects in the world are contracted there is no unarguable, hard-nosed financial need for visionary change.

Therefore I urge you to undertake, as part of your broad research program in support of visionary change, the establishment of an IDDS-based conceptual model of what it means to deliver any capital project successfully. If you do that you can then move on to test existing contracting models and find the behaviours those models incentivize and establish what the best-in-class contracting model is. Of course, feel free to test Sutter Health’s Integrated Form of Agreement contract against it and let me know how it does 😊

If you do this you will be helping to seed the wholesale transformation of the capital delivery market and this will cause thousands of people with billions of dollars to beat down your door for all the fruits of your research - because they are going to need all the outputs from the IDDS Roadmap research programme to be successful within that contract model.

Heed the entreaty of the winged goddess of victory herself and “Just do it”.

Digby Christian
Regional Program Manager,
Sutter Health, Facility Planning & Development
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Cover image courtesy of Sutter Health & Devenney Group Ltd., Architects. Rights reserved.
CIB Integrated Design & Delivery Solutions (IDDS) Research Roadmap

Executive Summary

Changes in the construction sector are creating opportunities in research to maximise the benefits of those changes and to continue the exciting developments in improved people skills, new processes and developing technologies. There are many research centres around the world investigating aspects of the current changes to drive their particular expertise forward. However, the CIB Integrated Design and Delivery Solutions (IDDS) priority research theme takes a higher-level view of the changes and then focuses down on a prioritised set of research targets. These targets have been investigated, re-focused and validated over a period of four years through many workshops, conferences and meetings by a wide ranging group of representatives from approximately 90 industry and research organisations.

This roadmap prioritises and details the research to be performed, why and by whom. In particular, some 25 CIB Working Commissions and Task Groups are explained as having potential roles in the delivery of this research theme. We are extremely privileged to have been urged on by such distinguished construction professionals in their forewords and the case for research.

The outcomes of such research, once put into practice should be significantly shortened timespans from conception of need to occupation of new or revised structures. As time is money, the owners will get their investments into productive use sooner, which means a shorter payback time. In addition, there will inevitably be a reduction in construction costs as productivity increases. The improvements in reliable delivery and improved quality currently being seen in relatively simplistic use of Building information Modelling (BIM) (compared to full IDDS) will inevitably continue its on-going trajectory of improvement. We should also consider the wider economic contribution to society that will stem from such improvements and, finally, and by no means unimportantly, the reliable modelling and delivery of sustainability at both the building and estate/area scale will significantly improve carbon footprints and other sustainable outcomes.

Whilst there are huge opportunities for early adopters, the primary risk will be the expansion of the gap between those working in this way and those who are not so advanced or who even refuse to progress. However, a similar issue arises between industry, clients, educators and trainers; the latter have particular challenges, having existed for many years in a sector that has had relatively few technological changes.

However, the opportunities to address the significant and widely varying wastes within the structure of the construction sector and within and across projects are huge and timely. Whilst this Roadmap is specifically targeted at the Standing Commissions and Task Groups of the CIB, it is hoped that there are elements for research and applied research across academia and industry.

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1 For example, with reference to BIM: Although non-users dropped from 51% of the industry in 2009 to only 29% in 2012, more of them are hardening their resistance, especially among non-using architects where 38% say they will not use BIM. McGraw-Hill (2012) The Business Value of BIM in North America: Multi-Year Trend Analysis and User Ratings (2007 – 2012)
Prepared By

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Mark Palmer (National Institute of Standards and Technology, US)
Neil Pawsey (Fiatech, US & UK)
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Under the authority of CIB:
Secretary General Dr Wim Bakens
President Professor John V McCarthy AO
& The CIB Board
1 Conceptual Framework

This global priority theme is aimed at transforming the construction sector through the rapid adoption of new processes, such as Integrated Project Delivery (IPD) and Lean Construction and procurement, together with Building Information Modelling (BIM) and automation technologies, using people with enhanced skills in more productive environments.

The development of IDDS is about radical and continuous improvement, rather than development of a single optimal solution.


The construction sector is undergoing the most significant changes it has experienced in over a century. It is during this change that construction practitioners and researchers have a very real opportunity to influence how the construction sector is transformed and assist its transition into a progressive and productive sector ready to meet the challenges of the next quarter century. Some of the drivers for change, enablers, barriers & opportunities are summarised at Appendix 1.

The focus of the Integrated Design and Delivery Solutions (IDDS) CIB Priority theme is on pursuing a vision of a revitalised sector through the rapid adoption of new processes, developing a workforce with enhanced skills and supported by information and knowledge technologies. The goal is a sector where people with traditional and new skills practice more collaborative and communicative processes, supported by pervasive, but nearly transparent, knowledge and information based technology. These professionals will be working towards continuous improvements across every phase and significant task of the project: conceptual planning and making the business case; all parts of design, supply chain, construction, commissioning; operation; retrofit; and even decommissioning and capturing the lessons learned into subsequent projects.

IDDS has been developed as a grounded concept through workshops and consultations with academia, industry, governments and clients on five continents over four years. Several hundred people have been consulted and prominent academics from around the world have been involved in focussing and nurturing the research theme.

Integrated Design and Delivery Solutions use collaborative work processes and enhanced skills, with integrated data, information, and knowledge management to minimize structural and process inefficiencies and to enhance the value delivered during design, build, and operation, and across projects.


A number of significant societal and technological influences are driving the changes in the sector. The ubiquity of portable connected technology in everyday society has penetrated the construction site and back offices, bringing unprecedented opportunities for the exchange and use of not only basic information carried by voice, but knowledge-rich data transfer through text, images / diagrams
and sophisticated multi-dimensional models. Construction materials and systems have also evolved significantly, often with ambitious targets for new levels of performance measured in terms of immediate cost, ease or time of installation, energy requirements, healthy environments and sustainability. The amount of off-site fabrication continues to grow and is extending well beyond structural elements, such as trusses, to racks of mechanical systems and even to modular units of rooms, complete with interior finishes.

Despite these influences, significant obstacles prevent a smooth transition into a new construction paradigm. Technology capabilities, such as Building Information Modelling (BIM) -enabled applications, are advancing so fast that experienced workers with traditional skill sets are hard pressed to keep abreast of new tools and techniques, especially in sharing project information, while the sophistication and complexity of the designs that can be created using these new tools is likewise becoming a challenge in its own right. In turn, BIM has enabled improved information flows through a project and greater opportunities for formal (such as through the use of Integrated Project Delivery (IPD)) and informal collaboration. Simultaneously, the western world is seeing large numbers of experienced workers retire, taking their experience and understanding of the long-term implications of construction choices out of the workforce. On the other-hand, new workers are bringing an inherent familiarity and comfort with new information and knowledge technologies into the workforce. However, the commercial pressures on software vendors to differentiate development tools and data formats inhibit this exchange of information, particularly between professional specialisations.

Another significant obstacle to progress is the entrenched adversarial nature of the industry; IPD and similar collaborative approaches are used, as yet, on only a small minority of projects. Contracts in common use focus on identifying responsibilities and liabilities, limiting information exchange and majoring on the consequences of failures. Also, projects are often broken into fragmented, serial phases where opportunities to collaborate and optimise results are lost. Likewise, questions remain regarding assurance for professional activities outside the traditional project roles and processes. Naturally, practitioners are concerned with the risk of sharing more than the minimal information they are contracted to, in case they become liable for elements that are not part of their core responsibilities, and because of the potential of having their Intellectual Property (IP) digitally copied. Specialist professional indemnity insurance also reinforces such resistance (see project-based insurance, below).

Traditional approaches typically mean that many issues that could have been prevented through early broad stakeholder involvement are discovered much later, at great expense, at the workface. Even if these barriers are broken down amongst a team on one project, the next project will typically bring together a new team, thus requiring the barriers to be broken down all over again. Vertically integrated organisations and some influential progressive companies have overcome this by assembling a collection of educated partners who they prefer to work with on collaborative projects.
To have the maximum impact, this transformation of the capabilities of the sector needs to be holistic and based on knowledge capture, processing and reuse. It needs to address: new and retrofit projects; residential, commercial, institutional, infrastructure and industrial projects; the whole project life-cycle from concept to decommissioning; and all stakeholder needs and roles, including the owner, operator, architect, contractors, engineers managers, quantity surveyors, supply chain, manufacturers, fabricators, software developers, facility managers and occupants. The three imperatives of IDDS are shown at Figure 1, together with the research areas that need to be further enhanced and/or adopted to render the vision real.

The conceptual framework for the interaction between the three imperatives for improvement is also effectively summed up at Figure 1. Although this period of change is being enabled by new technologies, which in turn are enabling new processes, it is only where we see true collaboration between people and their organisations that significant improvements in both project productivity and quality occur. These may be signalled by a significant reduction in Requests For Information (RFIs) and Contract Change Orders (CCOs), other than those that are caused by the clients emerging requirements, and by increased client satisfaction.

Having explained the drivers and some of the interactions, it is essential that we focus down to a smaller number of research targets that might be achievable; these are shown at Figure 2, and explained further in the Research Trajectories Targets Paper. Whilst targets three and four concentrate on assisting in the changes which are already underway in various places around the world and to variable extents and success rates, one and two are focused down on improving the value delivered by IDDS in the real world. Whilst the Vision for IDDS has been stated, it will be important to measure outcomes for the particular environment in which it is applied in order to ensure continuous improvement in the delivery of outcomes. The specific metrics will differ considerably between countries and construction sectors.
### Figure 2. The Four Priority Research Targets of IDDS

<table>
<thead>
<tr>
<th>Target One</th>
<th>Integrated Design &amp; Delivery Solutions</th>
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</thead>
<tbody>
<tr>
<td><strong>Near-term Research Priority</strong></td>
<td><strong>Mid-term Research Priority</strong></td>
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<tr>
<td>IDDS should enable a more coherent approach to sustainability modelling and achievement, whether at the building or area scale.</td>
<td>Expand human behaviour modelling</td>
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<td></td>
<td>Develop human building interfaces</td>
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<td></td>
<td>Develop performance &amp; consumption models</td>
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<td></td>
<td>Develop knowledge-based architectural programme</td>
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<td></td>
<td>Coherent information flow and reusable knowledge development</td>
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<tr>
<th>Target Two</th>
<th>Define the Built Environment Information Fabric</th>
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<tr>
<td><strong>An information fabric should be developed which extends to campus/city scale models to solve emerging infrastructure network problems and facilitate integration of traditionally disparate domains</strong></td>
<td>Support building operations &amp; assets</td>
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<td></td>
<td>Modelling on installation scale but integration on geographic scale</td>
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<td></td>
<td>Information systems lifecycle &amp; interoperability</td>
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<td></td>
<td>Context-based individualised interaction</td>
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<td></td>
<td>Collaborative project development process &amp; legal framework</td>
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<td></td>
<td>Presentation of information on construction and use</td>
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<th>Target Three</th>
<th>Improve current practices</th>
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<tr>
<td><strong>IDDS must provide the cohesive element to overcome the obstacles of trying to tackle fundamental change to current practices, particularly by developing improved knowledge management</strong></td>
<td>Further adapt industrial design processes for the product and its manufacture</td>
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<td></td>
<td>Design, construction &amp; supply chain improvement</td>
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<td></td>
<td>Technological development</td>
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<tr>
<td></td>
<td>Electronic submission &amp; approval systems</td>
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<td>Facilities &amp; operations management advances</td>
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<th>Target Four</th>
<th>Cultural change &amp; knowledge management and dissemination</th>
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<td><strong>It is essential that we capture knowledge and re-use it both in practice and education, so that we can foster improvement at the pace of the fastest, rather than at the pace of the slower majority</strong></td>
<td>Industry/enterprise business process re-modelling</td>
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<td>Develop new and expanded collaborative tools/technologies</td>
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<td></td>
<td>Develop new pedagogy for integrated design &amp; construction curriculum</td>
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<td>Types of Knowledge Management needed for technology transfer vs. steady state</td>
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<td>Dissemination &amp; diffusion model</td>
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<td></td>
<td>Performance management &amp; measurement</td>
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### 2 State of the Art

There are many centres of expertise, both in research and in practice in some of the areas which go to make up the idealised IDDS but there are very few or none which encompass the holistic IDDS.

#### 2.2 Typical and Advanced

The construction sector is by no means homogenous and currently displays a very wide variety of levels of sophistication, varying dramatically within and between regions and countries. Even in companies that are generally recognised as leading edge, their approach can vary significantly between departments and across projects, often depending on the interests or knowledge of the client to drive adoption of advanced approaches on any specific project, or on the skills and aspirations of the project team. There are many world centres that lead in some aspect of IDDS but few, if any which embrace the holistic concept.

In the industrialized world the basic level of professional competency includes a college, university or apprenticeship trained workforce skilled in the specification and design of structures and systems to nationally and regionally codified standards and the subsequent, but mostly site-built, construction of the facility. In terms of business processes, project teams typically exist for the duration of the project and those outside a minimal core team are only brought in as required by individual tasks. Communication remains largely through paper-based drawings or digital images of them, although firms make extensive use of cell phones and Wi-Fi technology to manage logistics and in-field coordination in ways not possible even 10 years ago. Common project practices are largely sequential, often involving distinct design, bid, and build phases with
accompanying loss of participants and knowledge between each phase. Project participants are looking for lowest costs, highest margins and minimal risks (each from their respective organisation’s viewpoint) instead of optimal solutions that bring added value to the eventual facility users, together with reliable steady profits for themselves and assured whole-life performance to the clients.

More representative of the state-of-the-art are progressive companies and some larger integrated firms. These organisations are bucking old trends by bringing together more key stakeholders and major or key sub-contractors earlier in the projects to identify sources of risk and opportunities, and synergies and trade-offs between solutions to multiple performance requirements. These core teams of key stakeholders are kept together for the duration of the project, although their level of involvement may vary over time. Communication between them is done digitally, including through BIM. They make extensive use of public digital infrastructure to share and track information rapidly and reliably between remotely located members. Project practices are more integrated and continuous and often involve design-build or design-build-operate paradigms that provide incentives to find more optimal solutions before construction occurs. Newer programs with life-cycle perspectives like BREEAM (United Kingdom), LEED (United States and Canada), DGNB (Germany) and CASBEE (Japan) add incentives to create more sustainable structures, and compliance may be rewarded by regional programs. Digital design, combined with early input from key stakeholders leads to more opportunities for off-site manufacturing and fabrication of system assemblies, panels, and even entire modules that can be brought to site and rapidly integrated into construction. These prefabricated elements allow for significantly optimised fabrication environments with less waste, higher quality, fewer injuries, more rapid erection and lower costs. More holistic approaches to management, such as Lean Construction, also contribute and are effective in reducing unreliability and waste whilst improving health and safety.

2.3 Leading Edge

Various leaders of the industry have gone significantly further in each or several of these aspects. A few practice IPD (or similar) as an active process in individual projects with select clients. Such collaborative approaches are supported in the USA by contract templates typically published by the Association of General Contractors of America or American Institute of Architects. Under these contracts multiple parties agree to, and are given incentives to strive collaboratively for more optimal solutions to the project goals. Companies employing such frameworks have usually adopted BIM as their preferred medium for knowledge transfer during the project, and most large construction firms have or are adding BIM capabilities to their product lines, although often on an individual project basis, rather than as standard practice. A side effect of large contractors and clients (especially governmental and similar bodies) increasingly using or calling for BIM is that less progressive companies are slowly being exposed to BIM functionality, as they inevitably have to upgrade their software over time and fit in with new business processes imposed from higher up the supply chain. Leading suppliers are also beginning to contribute useful models of their products into the sector for inclusion in models of facilities simplifying specification and sourcing of their products.

BIM has become the expected successor to CAD file exchange and mostly distinguishes itself due to an initial emphasis on unambiguous communication of fundamental information about facilities. Projects using Virtual Design and Construction (VDC), supported by BIM technical capabilities, have delivered significant added value in coordination between major physical systems and their designers and installers due to its solid 3D model representation aspects and parametric properties.
(beyond clash detection) and attached information. VDC has also greatly improved client understanding of the impact of decisions on the final deliverable through easily understood rich visualisations of design variants and their effects. Further developments, largely championed by buildingSMART International, in BIM standards and technological support are pushing towards better capture and encoding of the non-geometrical attributes of building system elements like makes, models, warranties and installation dates needed in specifications and facility management tasks. Major clients, often governments and larger or more sophisticated facility owners are beginning to demand and even legislate for the current and future use of BIM for the improvements in quality and the potential to make more efficient use and better maintain and manage the facilities once occupied. A non-exhaustive (and ever increasing) list of major clients who are demanding a greater deliver value through the use of BIM includes:

- **Australasia**
  - Australia. BuildingSMART is leading an effort in the adoption of BIM but employment currently remains very patchy. Australia has had a history of using Alliancing (which can now be considered a variation of IPD, despite pre-dating it), although with mixed reviews.
  - New Zealand. It is understood that the New Zealand Government are in the early stages of exploring the best approaches for the employment of BIM on Government projects and see it as the cornerstone of a planned productivity improvement by 2020.

- **The Far East**
  - Hong Kong. There is considerable expertise in BIM in Hong Kong, delivered projects, and BIM guidelines (e.g., the Hong Kong Housing Authority). However, implementation remains at a relatively low level. On the other hand, on the mainland there are signs that some of the super cities are being modelled at considerable levels of detail – how much data is attached to the modelled objects is unknown.
  - Japan. Several major design firms and general contractors are leading the use of BIM. Since general contractors in Japan are expected to detail and elaborate drawings issued by design firms, general contractors are also making efforts to utilize BIM in the detailing and construction planning phases. The Architectural Institute of Japan (an academy organization) and other organizations in the industry have some working groups for investigating BIM and related issues.
  - Singapore. Having been a signpost for automated code checking for many years, Singapore is now encouraging the use of BIM, including teaching at Universities.
  - South Korea. There is a progressing programme on the mandate of BIM use on Government projects and considerable standards development.

- **North America**
  - Canada. Canada announced in late 2012 that it would be looking at adapting/adopting the USA’s NBIMS-US Standard.
  - USA. The USA has been quick to understand the value of BIM and various Government client organisations and States have now adopted BIM standards (e.g., the Government Services Administration and US Army Corps of Engineers). Many large contractors and architects have also adopted BIM but most typically still rely on Client pressure to employ it on any particular project. There are some signs that this is changing as some very large contractors recognise the business advantage of having a standard approach, no matter to what extent the client or architect engage with BIM. Lean Construction is also gaining a foothold, as is IPD.
Northwest Europe and the Nordic countries have been at the forefront of technological developments and several now mandate the use of BIM-centric approaches of some type

- Denmark. Guidelines are being developed and the use of BIM being called for by several state agencies, especially for larger projects; BIM use is high and the use of Industry Foundation Classes (IFC) is required for interoperability.
- Finland. Finland is arguably the world leader in the use of BIM. The former Senate Properties guidelines requiring not only BIM but also the use of IFC for interoperability have recently been updated into national Common BIM Requirements (COBIM2012).
- France. BIM is now mandated for public projects and used by a significant main contractor and a huge construction supplies company as market differentiators.
- Germany. There is some adoption of BIM but this varies across agencies and States.
- Netherlands. OpenBIM is now required for Government Building Agency projects, and BIM object servers and communications are being developed.
- Norway. Statsbygg has collaborated with the USA on the development of its own guidelines.
- Sweden. Five Swedish State agencies and companies, responsible for Parliament to theatres, and forests to military installations (including roads), announced in late 2012 that they were coming together to collaborate in promoting the use of BIM.
- UK. Whilst the UK, with very notable exceptions, was somewhat slow in recognising the potential impacts of adopting BIM, it is rapidly moving forward, not least through the Government mandating the use of Level 2 BIM, and all asset information in COBie format, on all of their funded projects by 2016, as illustrated in Figure 3.

The use of digital building models has allowed a few companies to implement active processes and custom technology to capture and reuse construction knowledge and lessons learned between projects. However, there remain significant obstacles to broader attempts to preserve many aspects of contextual knowledge in transactions, e.g. the reasons for decisions. The bulk of codified
knowledge remains trapped in professional silos and throughout the supply chain for reasons of “competitive advantage” and because of limited standards/capabilities for the management of professional knowledge in general. Many aspects of more mundane and current construction knowledge that would benefit from sharing also remain isolated by limitations inherent in existing broad representational BIM standards or formats, including Industry Foundation Classes (IFC) and Construction Operations Building information exchange (COBie). These limitations include the inability to represent appropriate levels of detail for simulation or analysis during design and the lack of representations for details pertinent to specification, manufacturing, assembly, erection and incorporation of building systems from numerous construction trades, including cast in place & pre-cast concrete, MEP systems and solar power systems to name a few.

An exemplar for improved project performance can be seen in the Castro Valley Eden Medical Center (see Figure 4). Approaches and resultant achievements include:

- Eleven party Integrated Forms of Agreement (IPD)
- 100% of profit was at risk versus a 50% share of any savings
- Truly collaborative relationships
- Whole team meeting every two weeks for two days
- “All kinds of misunderstanding were uncovered”
- Abandonment of ‘design intent’ as an end in itself
- Lean Construction
- Building Information Modelling
- Need to deliver 30% faster to beat regulatory change (seismic)
- Triple victory: on budget; on time; and with all goals intact

(Source: Personal correspondence, Digby Christian, Sutter Health (2011))

![Figure 4. Castro Valley Eden Medical Center (Sutter Health 2011)](image)

Early signs of really advanced and paradigm shifting construction technologies are also emerging, taking construction well beyond the current limited use of off-site modular manufacturing and into a potential for flexible industrialised construction. For example, innovative, scaled-up additive manufacturing processes, such as the concrete 3D printing development programme at Loughborough University (UK) (see Figure 5) provide scope for increased architectural complexity and yet potentially offer hugely reduced work processes, once scaled up for on-site robotic arm deployment.
At the city scale, excellent models already exist for cities such as Stuttgart, Germany and Yan Tai, China and many others are in preparation. Whilst most concentrate on geometries, some (e.g. Salford, UK) go to the extent of embedding a huge range of sociological information, providing a level of understanding of social structures and interactions which would otherwise be far more difficult to assimilate.

2.4 Perceived Problems & Challenges

Educational institutions are beginning to provide BIM programmes, although no industry standard exists for recognising or even certifying the programs or accrediting the graduates, or in terms of Continuing Professional Development (CPD) standards. In fact, there remains considerable debate as to the nature and scope of new BIM-related roles in the industry. Even as these BIM programmes become more established they need to be extended to meet IDDS goals that require construction professionals with far more knowledge management and communication expertise than is common today. For professionals to be effective in monitoring their own performance and to be able to strive for improvements will require measures and supportive tools for benchmarking quality, design integration, life-cycle impacts and completeness of captured knowledge against references or previous work. This feedback needs to be dynamic through tools like dashboards or regular generated reports. With respect to sector practitioners, significant cultural change also needs to be part of realising IDDS goals of creating a cooperative, knowledge preserving and sharing industry, instead of one characterised by adversarial interactions and knowledge hoarding. There is also a need for further education of site workers in terms of understanding BIM versus drawings, collaboration and re-skilling. It also becomes feasible to adjust later-delivered items to reflect ‘as-built’ pragmatic changes (and typical deviations from design, such as pour depths and floor levels) by correcting the ‘as-built’ BIM. Significant re-work can thus be avoided. This, together with enhance design and build-ability would typically also reduce the opportunities for end-of-project claims – this could have a very significant effect on the many small contractors and they need to be educated accordingly.

As the manufacturing industry has shown, integration and collaboration can lead to dramatic improvements in the quality and time required to realise ever more complicated products.
However, they have also shown that dramatic improvements can also continue to be found using lean principles and automation, where appropriate. There is a Lean Construction initiative and its relevance to the goals of IDDS is significant, and efforts need to be made to embrace its principles, even as the construction sector is transformed by the pervasive incorporation of digital enabling technologies. Following on from this, greater supply chain integration becomes a possibility and there are many current attempts at building BIM object libraries to assist with the incorporation of ‘real’ components earlier, rather than using space reservations. (This is controversial in itself as it is often seen to be better to delay supply competition, though with limited true understanding of the overall balance of costs to a project or, more particularly of whole-life costs.) Industry Foundation Classes (IFCs) are increasingly used (but not always) to provide a level of common understanding across these modelled artefacts and components. However, greater development of and investment in IFCs would be of great advantage to the global construction industry, opening up a huge potential market of suppliers. However, component supply is merely one aspect of the supply chain; integration of sub-contractors of widely differing skill levels, particularly at a time of such radical change introduces additional performance risk within projects. There is an urgent need for education and knowledge sharing through case studies to facilitate this change.

Knowledge capture and re-use within projects is helped greatly by the use of BIM, but not if a new model is created at each stage of the process and embedded data, information and knowledge is lost in doing so. In the USA, Mortensen has developed a knowledge-sharing network and Turner has its ‘BIM University’; however, there is a great deal more knowledge sharing research and implementation to be developed. As mentioned previously, silo mentalities 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. Unified solutions are not at a stage when real knowledge sharing and knowledge development is supported for the design, construction and operation stream(s). Considering that “each model is an abstraction for a purpose”, the underlying data, information and knowledge in the shared models should cover all the intended purposes, and enable addition or subtraction as necessary for a particular purpose or stage, but not lost to the project as a whole, including for the life of the delivered building, infrastructure or artefact.

Knowledge can also be seen to be very specific to one market/ contract type/ or project type or size. Indeed, it has more commonly become the case that significant new clients (i.e. government agencies) demand statistical evidence as to whether BIM is even appropriate to their own needs. More case studies and, particularly, meta studies are needed to provide such evidence.

In terms of wide area and city scale modelling there is some difficulty in the fusion or at least interoperability of data and information, not least because Geographic Information Systems (GIS) and BIM have developed on separate paths. The scope of spatial interaction issues is illustrated at Figure 6.
2.5 Leading Centres

In general, the leading centres of building information technology are perceived to be currently in the Nordic countries (e.g., Tekla and Solibri) and the USA (e.g., Autodesk, Bentley, Vela Systemes and Vico). However, there are also capabilities in the rest of Europe, such as Nemetschek/Graphisoft (Germany/Hungary) and Dassault Systemes (France), as well as many smaller companies, such as Asite, CAD-DUCT and Navisworks (the latter two now Autodesk) (all UK), and Construction Virtual Prototyping (Hong Kong). This list is far from exhaustive and the software market place will undoubtedly change over the next few years as new capabilities are developed and companies acquired or merged.

In terms of Lean Construction, the California-based International Group for Lean Construction (and its regional satellites elsewhere in the world) and Lean Construction Institute represent the focus. However Lean Construction is spreading widely around the world, as exemplified by, for example, Grana y Montero in Peru or Sutter Health in the USA. Lean Construction currently represents the key process change in construction, although there is scope for further process development as
whole-life design, construction and operation develops. BIM and Lean Construction used together offer the sort of holistic process approach that other industries commonly take for granted. Integrated Project Delivery (IPD) pulls these approaches together to form and facilitate an overall project contract process. IPD is currently very much centred in the USA, as explained further below.

Although IPD can be seen as a legal structure and framework process, it is also very much a catalyst for collaborative working, which may be argued to have commenced in Australia with Alliancing, although the Heathrow Terminal 5 project in the UK was also clearly very advanced. The Florida contractor-created IPD process was further developed through the Lean Construction Institute and American Institute of Architects in California before being developed as a national standard by the AIA. Other USA frameworks such as the Association of General Contractors’ Consensus Docs and Sutter Health’s Integrated Forms of Agreement are also currently being used in the USA. The UK Government BIM programme now has a very large task group (largely industry-donated) to develop some similar framework, together with multi-decade project insurance; this and all the previously mentioned frameworks are intended to break down barriers and to foster collaboration between parties and people. Whilst IPD does not seem to need BIM (see Figure 7), in practice BIM is typically an integral facilitating mechanism for IPD projects; Lean Construction is also slowly increasing in adoption in IPD, with the Last Planner process having been used as the integrated process between multiple designer specialisations. Early work at Technion (Israel) and the University of Salford (UK) on integrating Last Planner with BIM, in terms of both data and visually, points the way towards future enhanced project management toolsets.

![Figure 7. The Seven Pillars of IPD. After Spata (2010)](image)

In terms of sustainable construction, the International Code Council’s International Green Construction Code can be seen as a key guide to moving construction forward in that way, particularly in the USA.

Academia and research centres have many foci of excellence, including the earliest contributors and guides to this project. VTT in Finland, CIFE at Stanford University, the School of Computer Science at the University of Auckland and the School of the Built Environment at Salford University came together to help guide the development of IDDS through consultation with experts in research and practice around the world. The early team has since expanded and now includes...
many more organisations shown at Appendix 2. Current additional research centres include Delft University of Technology, Queensland University of Technology and Virginia Tech.

3 Future Scenario

Broad development and adoption of IDDS concepts is expected to transform the construction sector. As mentioned earlier, the general expectations can be summarised as:

- Projects being done collaboratively with teams striving for optimal facility performance, realised using sustainable construction methods and materials, thus minimising the total life-cycle cost of the project in terms of money and the environment.
- Knowledge from projects systematically gathered and reused in subsequent projects and made seamlessly available to all project team members and, selectively, for wider education.
- Computer-based technology will be pervasive throughout, and support all activities in the construction sector, principally through visual representation of persistent data, information and knowledge of critical project information for all parties.
- Interoperability for sharing and reuse of project data between trades and phases of a project will be largely transparent due to rich and universally supported standards.

Past white papers on IDDS have viewed the future capabilities of the sector as broken into four categories; Collaborative Processes, Enhanced Skills, Integrated Information and Automation Systems, and Knowledge Management. Collaborative processes will involve the biggest societal change in the sector with serial processes being replaced by vertically integrated collaborative processes (characterised by information flowing freely and effectively between all stakeholders) amongst “virtual” enterprises that exist for the duration of the project, and even across projects. Complete planning and monitoring of project progress will eliminate waiting time and “making do” with incorrect materials.

Trades people will evidence enhanced skills as they participate in integrated work processes using advanced tools to contribute their work to the collective effort, and observe the impact of their contributions virtually on the other team members’ work. They will leverage and add to repositories of the shared knowledge built from past projects, as it applies to the current requirements. Advanced tools and knowledge of major work processes will allow them to evaluate multiple alternatives and select the best for the work process and product.

Knowledge management through codification for reuse, addition and maintenance will be a standard activity leveraging the future digital infrastructure. A greater understanding of the impact of each trade’s decisions will be captured, based on the collaborative nature of projects and the integration of the team’s efforts. This understanding will slowly extend to be multi-company, multi-disciplinary and multi-phased (over project phases) and document both the problems and the solutions. As the knowledge will be codified in a machine-processable form, its application can be partially or wholly automated in advanced tools.

The integrated information and automation systems theme has been the subtext of all the previous expectations, as technology will be a key enabler. Ubiquitous interoperability throughout the value chain and a project’s life cycle will support progress towards a more holistic view of a construction project for all participants. Furthermore, digital tools will seamlessly integrate work processes and facilitate the evaluation of multiple alternatives to meet the owners’ objectives and priorities for cost, schedule, quality, safety, and sustainability.
Observable symptoms of these fundamental improvements in many projects will include in the near future (~5 years):

- Wide use of clash detection (or clash avoidance) and visualization
- BIM adoption commonly requested by clients or construction contractors (regional differences)
- Wide use of project websites and cloud computing to enable real-time collaboration
- Many suppliers will provide parametric objects for use in design
- Limited industrialised/off-site module preparation
- Handover documentation commonly delivered digitally
- Use of modified existing contracts – covering digital construction documents
- Country/region governments issue IDDS compatible procurement requirements
- Joint architect/engineering degrees in demand
- BIM (BIM+) literacy will be expected from large contractors and architects and engineers
- Digital construction literacy will increase in medium and small supply chain companies
- Increasing use of rapid modelling technology to incorporate existing structures and monitor as-built variations
- Increased use of IFC as a standard because of the need for certifications, conformance to emerging regulations and access to archived data
- CityGML as a standard basis for modelling urban forms

Observable symptoms of these fundamental improvements in most projects will include in the further future (~10 years):

- Life-cycle carbon accounting possible and enforced/ practiced regionally
- Design visualisation commonplace at workface
- Semi-automated scheduling and procurement
- Planning and handover documentation will be provided electronically
- Single point contracts will be used more extensively
- Insurance becomes commonly project based
- Tender notification services/systems fully digital
- Governments accept digital models for all approval processes – planning, code compliance and occupation
- Majority of projects designed and implemented digitally by a technology-savvy workforce
- Joint architecture/ construction project management/ engineering degrees are increasingly demanded, and a necessity
- Failure to be IDDS literate may be a cause for mandatory rejection of bids
- IDDS applied to wide-areas to support planning, design and construction of urban-infrastructure
- Growing emergence of GIS and BIM+ models supporting area planning and monitoring

Many of these developments will be realised not only because of improved information flows but also because of the ability to aggregate or fuse different data sets, both physical and behavioural, and to display such data as combined information. Through the use of large screen and/ or collaborative viewing systems for 3D models (or stereoscopic displays), individual and collective human understanding will be considerably enhanced.
4 Development Strategy
Realisation of the above scenarios will required concerted and focussed efforts by many stakeholders in the construction sector but will also be founded on broader societal and technology changes already in evidence today.

Development of New Practices, Processes and Tools. The construction sector represents a particularly challenging domain for deep collaboration given the short-term nature (the period of one project or less) of most collaborations, and the adversarial nature of the relationships born of the need to maximise profit. Better standard practices and processes need to be developed that promote collaborative efforts on projects. Industry organisations and governing bodies need to participate in developing these practices and formalise them with documentation, training, and embody their principles in contractual documents. To complement these practices, tools are needed to robustly and transparently support and promote knowledge sharing and collaborative development within individual projects amongst stakeholders with diverse objectives and roles. Positive engagement of Project Management bodies would be beneficial to the development of appropriate processes to foster IDDS, whilst tracking of new technologies, such as off-site manufacturing and construction design and build automation will ensure that IDDS develops optimally.

Expanding Skills and Collaboration. Deeper project collaborations allow for project teams to strive to achieve greater immediate value in projects. Many of these improvements will be found through the broadening of traditional discipline foci to consider integrated designs. This is likely to require the involvement of non-traditional stakeholders, such as suppliers. Suppliers will need to take a proactive approach to integrating their information and requirements into early project documents and will have to extend their own skill sets to achieve this. In fact the whole team will require access to the shared knowledge and enhanced skills needed to effectively perform integrated work processes. Clients should also be educated as to the different risks and opportunities of IDDS, as should owners, maintainers and occupiers.

New Standards and Interoperability. Creating, documenting and sharing these more sophisticated and integrated designs will require further development of existing BIM standards to ensure that knowledge covering all major processes is seamlessly exchanged. This advanced semantic interoperability will be overwhelming without more defined “views” of information appropriate for specific classes of applications and particular classes of application and standardised processes. With the whole industry communicating through digital documents, the regulatory and inspection activities will also need to be updated to work with the same documents instead of 2D drawings; integrated information and automation systems thus become more possible and holistic.

Knowledge Development and Transfer Systems. To go beyond the immediate and achieve more value over the entire life-cycle of a facility will require the development of easier (and probably automated) ways to capture, codify, store and re-use knowledge to overcome transitional organisations and workforces.

5 Research Contribution
The development strategy documents a wide range of changes that will impact over the next decade as IDDS develops and takes hold in the industry. However, the research underpinning for the majority of these changes is still in a fairly formative state. For each of the expectations there are numerous possible approaches to be explored with little consensus on which approach will give the
desired outcome and the greatest level of benefit. Even where approaches have been researched many of the identified solutions are sub-optimal and unlikely to be acceptable to those in the industry.

A difficulty in progressing the research to support the proposed development strategy is that, as with the core notions behind IDDS, it needs a cross disciplinary approach. The strategies draw upon research founded on deep understanding of the impact of several disciplines alongside the building and construction fields. Research development and approaches from fields such as Computer Science, Organisational Psychology, Management Science, Law, etc. have to be brought to bear. Researchers capable of doing this are those who can move beyond consideration of research within the silo of their specialist domain and who hold a more holistic view of the impact of their work.

This research challenge fits well with the principles and approaches taken within CIB and for priority themes. With the priority theme pulling together researchers from across a wide range of task groups and working commissions there is already the notion of cross-disciplinary working to address the research problems being identified in IDDS. It is also clear that some of the specialist task groups and working commissions already draw upon the literature of other domains in tackling the matters core to their members (e.g., TG80 on the Legal and Regulatory Aspects of BIM).

Focussing on the three core aspects of IDDS there are a number of CIB task groups and working commissions that align naturally with these aspects. The most likely contributors to each of the areas (listed in alphabetic order) are as identified below against their primary likely interest:

- **People**
  - TG59 People in Construction
  - W089 Building Research and Education
  - W118 Clients and Users in Construction

- **Process**
  - TG67 Statutory Adjudication in Construction
  - TG68 Construction Mediation
  - TG72 Public Private Partnership
  - TG74 New Production and Business Models in Construction
  - TG84 Construction Reform
  - TG85 R&D Investment and Impact
  - W065 Organisation and Management of Construction
  - W092 Procurement Systems
  - W096 Architectural Management
  - W112 Culture in Construction

- **Technology**
  - TG76 Recognising Innovation in Construction
  - TG80 Legal and Regulatory Aspects of BIM
  - TG83 E-Business in Construction
  - W078 Information Technology for Construction
  - W102 Information and Knowledge Management in Building
  - W080 Prediction of Service Life of Building Materials and Components
  - W119 Customised Industrial Construction

- **Cross-cutting**
  - TG66 Energy and the Built Environment
  - W070 Facilities Management & Maintenance
  - W098 Intelligent and Responsive Buildings
This concentration of CIB research interests aligned with the three core IDDS areas indicates that with a clear exposition of the research agenda for IDDS then there will be significant ability to tackle the issues even if the focus for the research contribution just stays within CIB. Viewed from the perspective of prioritisation against the identified four priority targets, Table 1 illustrates possible research priorities against each CIB research group:

<table>
<thead>
<tr>
<th>CIB Task Group/ Working Commission</th>
<th>Target</th>
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<tbody>
<tr>
<td>TG59 People in Construction</td>
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<td>TG66 Energy and the Built Environment</td>
<td>1</td>
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<tr>
<td>TG67 Statutory Adjudication in Construction</td>
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<td>TG72 Public Private Partnership</td>
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<td>TG74 New Production and Business Models in Construction</td>
<td>3 &amp; 4</td>
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<td>TG76 Recognising Innovation in Construction</td>
<td>3 &amp; 4</td>
</tr>
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<td>TG80 Legal and Regulatory Aspects of BIM</td>
<td>3 &amp; 4</td>
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<tr>
<td>TG83 E-Business in Construction</td>
<td>3 &amp; 4</td>
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<td>3 &amp; 4</td>
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<td>TG85 R&amp;D Investment and Impact</td>
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<td>W065 Organisation and Management in Construction</td>
<td>3 &amp; 4</td>
</tr>
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<td>W070 Facilities Management and Maintenance</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>W078 Information Technologies in Construction</td>
<td>3</td>
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<td>W080 Prediction of Service Life of Building Materials and Components</td>
<td>3</td>
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<tr>
<td>W089 Education in the Built Environment</td>
<td>3 &amp; 4</td>
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<td>W092 Procurement Systems</td>
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<td>3 &amp; 4</td>
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<td>W099 Safety and Health in Construction</td>
<td>3 &amp; 4</td>
</tr>
<tr>
<td>W102 Information and Knowledge Management in Building</td>
<td>2 &amp; 3 &amp; 4</td>
</tr>
<tr>
<td>W108 Climate Change in the Built Environment</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>W112 Culture in Construction</td>
<td>3 &amp; 4</td>
</tr>
<tr>
<td>W118 Clients and Users in Construction</td>
<td>3 &amp; 4</td>
</tr>
<tr>
<td>W119 Customised Industrial Construction</td>
<td>3</td>
</tr>
</tbody>
</table>

1. Develop improved sustainability models & measures
2. To define the Built Environment Information Fabric
3. To Improve current practices
4. Cultural change and knowledge management and dissemination
6 Research Agenda

The IDDS research agenda has been envisaged focusing around four priority research targets, all of which draw together a wide range of issues impacting the majority of the industry. All of the targets are interconnected and the interplay between topics has not been possible to disentangle. However, progress in each of the targets leads towards a well-defined outcome for the industry. Some of the targets may be familiar from research agendas from the past decades, but all are recast in terms of IDDS and its potential for the industry. Progressing the research agenda for each of these targets will require a mixture of pure and applied research to ensure the validity of results within practice. The four research targets we are proposing to be central to the research agenda for IDDS are: developing improved sustainability models and measures; defining the Built Environment Information Fabric (BEIF); improving current practices; and engendering cultural change and knowledge management and dissemination.

6.2 Developing Improved Sustainability Models and Measures

Sustainable architecture, and associated approaches to improving the sustainability of the built environment and performance of the environment as a whole, requires significant changes to past approaches and the levels of information available for decision-making. The IDDS approach can provide an underlying platform to help ensure sustainability in the A/E/C industries and as such provides a significant demonstration of the benefits to be found from IDDS. This is especially pertinent as sustainability has the ears and minds of the world’s scientists and politicians. The development of improved sustainability models and measures should be seen as a mid-term goal of IDDS and will require research in the following areas:

- Development of a more coherent approach to sustainability. While a wide range of tools and techniques exist which allow a focus on individual aspects of sustainability the ability to incorporate the analyses and decisions across the available tools is lacking. This can lead to sub-optimal decisions and difficulties in ensuring a holistic viewpoint is taken for design decisions.
- Demonstration of the return on investment (ROI). For sustainability the ROI is measured not only in operational dollars but also in environmental impact, total cost, occupant health, reduced regional infrastructure requirements, etc.
- Improved simulation models to more correctly predict as-built performance. The current disjunction between simulation tools and as-built performance means that simulation is typically used in a comparative mode to identify potential benefits of design variations rather than as an accurate indication of performance in use. Incorporating all major factors in an analysis could lead to simulations that can be relied upon as an exact indicator of actual performance.
- Development of Human Building Interfaces (HBI) to provide feedback to human occupants of facilities and engage them in sustainable operations. Few buildings engage with all the occupants in regards to their performance and impacts of local decisions on the performance of the building as a whole. BMS are typically monitored at a building level and occupants are often not empowered to make individual changes, or to see the impact of their activities.
- Incorporation of individual human behaviour into resource modelling and control. Standard profiles used in current approaches are very granular and difficult to moderate for known behaviours of expected occupants. Investigating more of a sliding scale from template user profiles, to detailed descriptions of particular categories of occupant, through to individual models of actual users could improve the understanding of actual building performance.
• Development of models for process, physical and functional waste. National surveys identify significant waste in almost all aspects of current building and the potential for great savings; for example, the Egan report identified the potential for a 20% reduction in defects year on year in the UK industry. These models could be used to reduce all forms of waste (e.g., cost, quality, time, and rework), limit defects, and ensure efficient operations.

• Creation of sophisticated approaches to measure and model re-use and recycling. The potential impact of such approaches is high and would impact on resources such as water use, electricity, transportation, deconstruction, pollution, and control of scarce resources.

• Promotion and standardisation of sustainable architecture programs across the world’s universities. While many leading universities incorporate aspects of sustainability into their curricula there are many more that have not currently taken this step. There is also remarkably little agreement internationally on the learning outcomes to be achieved in courses in this area. Ensuring a base level of understanding and ability in graduates of these programmes could guarantee sustainability considerations becoming a normal part of all design.

6.3 Defining the Built Environment Information Fabric (BEIF)

The ability to incorporate information from multiple disparate sources enables a significant step up in the ability to comprehend a built form within the complete context of its placement in the environment. An information fabric which extends the context of information from that clustered around an individual building through to city scale models will be required to solve emerging infrastructure network problems and facilitate integration of traditionally disparate domains. The scope of information sources envisaged would encompass councils and territorial authorities, transport authorities, utilities, land information resources, geotechnical resources, environmental resources, climate resources, etc. Example applications include support for contingency planning, mitigation, response and recovery, and for the modelling of traffic, energy and water (and pollution) flows and wider area sustainability modelling and planning. The fabric should use the building as the context but integrated into its surroundings. The concept of BEIF should be seen as a mid to long-term goal of IDDS and will require research in the following areas:

• Understand approaches to improve the operation of the building. This will require extensions to models for the location of components pre and post build, support for sensor data integration across domains, and approaches for predictive maintenance and operations.
  o Refining approaches to tracking assets in the building. Geo-location with mobile devices is becoming more sophisticated allowing for new approaches to localization and identifying the state of movable and fixed assets.
  o Redesigning BMS and other management systems to incorporate notions of a building as an asset with state. There is great potential to redesign the processes utilised for day-to-day operations and enable other domains such as emergency response.
  o Initiate projects to understand how to incorporate sensor systems into the BIM and data mining domains. It is expected that sensors will be managed as assets in their own rights, changing current practice and understandings.
  o Developing new processes and tools recognising the role of people within asset management systems as sources of demand and also as consumers. Redefining building and occupant interaction such as through push instructions (e.g., close windows, current safety issues, asset locations, etc.), as well as pull influences (e.g., user desires, individualised occupant responses, etc.).

• Reworking approaches and notions of modelling, not just on the installation scale, but planning the pathway and integration into the geographic scale.
A significant rethink is required in both the BIM and GIS domains to ensure appropriate linkages between the two domains. Current approaches from the building out, or from the urban scale down to buildings are developing without coordination of the partner domain. The two research communities need to develop joint approaches to beneficial interactions between their worldviews.

- Developing notions of estates management that would include factors such as operations, sustainability and assets, multi-year master plans, etc. This opens up the ability to incorporate improved building and personnel safety into management systems. Such approaches need to consider seriously the impact of confidential information and security planning. Smart, pro-active facility maintenance and response approaches can be pushed out to the more urban scale infrastructure management.
- Development of tools for disaster mitigation and recovery is of increasing concern following a number of high profile disasters in the developed world with poor outcomes due to lack of coordinated information on the ground and for response planning.

- Investigation of protocols to turn a model into a base of information, or knowledge, for users. Accepting that a BIM will be the repository of significant quantities of information about a building across its lifetime it will be necessary to find methods to repurpose this information for the myriad of users of a facility. These users will each have very different needs from the information in the context of their use of the building.
- Research into systems that will manage the long-term coherence of facility information. Information from all stages will need to be durable for a period of 50-100 years. Access to, and mining of, the evolving information base will need to support use cases which may range from investigating initial design rationale, through to particular maintenance work on structures within the building.
- The evolvability of systems consuming building information will need solutions. Over the 50-100 years life of a building there will be upgrades to the intelligent systems managing the building that will demand system migration approaches. In current software architectures this is seen as a path towards plug and play standards linking to and across systems, but other paradigms will evolve in the next decades.
- Standards and agreements will be required to support the very basic underlying structures of the information fabric. This includes aspects which in today’s database research would include: ensuring adequate privacy of sensitive data and access controls for users dealing with the data; ensuring that adequate provenance is recorded for all data and its estimated reliability within the models; modelling of responsibility and risk in relation to data in the system; intrusion detection; and identification and responses to tampering of data.

Development of systems allowing the processing and understanding of data within the models, especially that flowing from sensors over the life of a building, to associate context and develop formalised knowledge about the building. The data, information and imputed knowledge will need to be communicated effectively back through to users through effective visualisation paradigms.

### 6.4 Improving Current Practices

Numerous studies and implementations show that fundamental process improvement, such as industrialisation of construction and supply chain integration, is neither readily adopted in the sector nor easy to get right. However, such radical change is essential in order to achieve significant improvements in cost effectiveness and waste and energy reduction. IDDS can help to provide the cohesive element to overcome the obstacles of trying to tackle fundamental change to current
practices, particularly through improved knowledge management. Improving current practices should be seen as a short to mid-term goal of IDDS and will require research in the following areas:

• To further adapt industrial design processes for the product and its manufacture. There are excellent signs of innovation in construction but seems to be a marked reluctance to deploy radical innovations widely, with the possible exception of some modern construction systems. To ensure that wider adoption and deployment proceed it will be necessary to foster agile, iterative, incremental, concurrent design involving all those who will have a role in designing, delivering and operating the building, not just the architect/design consultant. They can then identify barriers and opportunities to employ production system development simultaneously with design. Processes can then be extended and waste significantly reduced by extending lean production throughout the process beyond lean construction and Last Planner, and supporting its wider deployment. Study and support of industrialised production to improve resource use & sustainability should be pursued, e.g.: appropriate prefabrication of structural, piping, and duct systems for all residential and commercial construction. Prefabrication assemblies for housing, non-housing, medical, and industrial use should be studied. Motivation and inclusion of the whole supply chain should be justified, to include smaller companies to embrace IDDS change via: mandate – e.g., as in Scandinavia, the USA and UK; incentivisation – e.g. discounted fees; and the development of new business models/structures.

• Investigating emerging approaches to design improvement. Studies to date indicate that design processes are being affected by the introduction of BIM and IDDS style approaches. While some changes may be seen as the natural refinement of roles, others may be impacts of technological innovations where approaches to ameliorate the impact are developed. For early design phases work could be undertaken on reusable object libraries containing the attributes and information for objects that are typically being required by BIM tools at the stage when architects do not typically make these decisions. Generative and parametric design tools appear to codify important aspects of design intent and more explicit and domain specific tools may be developed to help with this change. The move towards code compliance checking could be refined to enable early designs to gain some measure of evaluation rather than having to wait until the detailed design phase has completed. The shift in workload to architects for BIM detailing requirements might also need to be recognised with more equitable models for the sharing of cost and risk between collaborating designers, builders and operators for the development or even the life of the building. Trade-offs between detail and conceptual design may need to be addressed by examining practices that affect the uncertainty in information at this phase and which lead to a lack of confidence in BIM. An approach that could be examined, in comparison to current BIM, is encapsulating notions of level-of-detail (LOD) at various phases of a design, adopted across disciplines to ensure appropriate and complete information flows. Conceptually this could allow for staged model hand-over being defined by LOD stage completion. Alongside approaches to providing code compliance advice at early stages, further work on simulation and optimization approaches for early design phases should be investigated. As the decisions at early design phases have the greatest effect on building performance, it would be beneficial to ensure that simulation systems could be accessed at these stages, though with appropriate caveats on the uncertainty of results, and being able to refine this as further decisions are made in a project. In a similar fashion, it is expected that technical criteria could be specified and automatically checked and maintained across the design phases of a building. Constraint-based systems provide some inroads to the specification and maintenance of well-specified criteria for particular aspects of a building’s design. The IDDS approach envisages greater collaboration and coordination across all professionals in a project, which has implications on the processes and support tools for managing versions of BIM and the granularity of change notification. Numerous approaches to the handling of changes, change
coordination, milestones, etc. have been developed in domains such as the database field and these may be adapted or modified to suit the needs of the A/E/C professions. In inspecting information flows and BIM impacts there would also seem to be potentials for the elimination of duplicate design processes, for example, by including fabricators during the design stage. These information flows may also see integrated product data sets available as open templates to the supply chain, or the inclusion of supplier and procurement experience within context of the BIM.

- Investigating emerging approaches to construction improvement could have a significant impact on current approaches. In the simulation space, the development of iterative and incremental simulation or design optimization systems could impact on design processes and through to maintenance where linkages between the BMS and predictive simulation could impact control strategies. Developing simulation systems could give insights into the impact of a range of alternative construction methods for particular design decisions encoded in the digital model. Laser scanning point cloud analysis is a current active research field, with some work looking at ways to automate the scanning and capture of current conditions within a building. This technology is likely to link more closely with BIM for renovation as well as design additions. The BIM and simulation or analysis also have potential in the field of safety, helping achieve goals for injury and death reduction. Ensuring compliance to health and safety regulations for projects across their whole life could be supported by BIM that incorporate construction sequencing for all objects in the model. Sensors and tracking technologies provide for approaches, which automate tracking of all objects, vehicles and personnel on site and can help guarantee collision avoidance. Multiple technologies are available within the space (e.g., exclusion zone monitoring; RFID active tracking; individual personnel alerting systems, etc.) but consensus and development of suitably robust approaches are still to be developed.

- Investigating emerging approaches to supply chain improvement, in particular the expansion of electronic tendering and supply. It is envisaged that this could expand to include suppliers who publish IFC models of components and assemblies available online, or linking through to national product libraries for BIM. Content creators may develop markets with products that are certified to meet national or international standards and guidelines. Content creators may investigate specifying parameterised product descriptions according to manufacturer norms or particular standards and gaining approval or accreditation by nominated associations. Content creators may look to add benefit through linkages to further associated information for each product, such as the carbon footprint, to help model the sustainability impacts of product choice.

- Understanding the impacts of technology development will lead to developments in a range of newly emerging areas. Significant work in the Human-Computer Interaction (HCI) field could be applied to helping develop software interfaces that are well suited to particular construction tasks or categories of professional in the industry. Interfaces in this domain are difficult to engineer correctly given the wide disparity in background and education of professionals in the industry, as well as the complexity and amount of information that needs to be perceived and processed to accomplish tasks. Related to the HCI aspects are the impacts of new on-site computer-aided navigation and location-aware services which are becoming available. The accuracy, sensitivity, ruggedness, etc. of these technologies still need to be improved to enable deployment for normal processes on-site, other than in research prototypes. A number of location-aware processes on site are likely to be transformed by the appearance of these technologies and their connection with the BEIF (e.g., snagging prior to building handover). The BEIF approach also argues for the development of standards for the integration of multi-century data and information on city, regional and national bases. New ways of presenting, navigation and querying this time-series and social influence data will need to be developed and tied to the BIM being placed within a cityscape. We also expect to see the use of whole-life
cycle integration of the building information, including construction, operation, maintenance, re-use, demolition and re-building, as the catalyst for developments. This suggests a need to develop standardized object entities within data modelling and standardized components in construction.

• Incorporating electronic submission and approval systems in all countries. For all planning and approval processes the nominated public agencies should be able to deliver computable specifications of the regulations and local consent conditions. This could allow local checking and certification of designs prior to formal submittal to authorities. All the public agencies should accept digital models for their approval and consenting processes and ensure consistency and traceability through electronic process management for the delivered models. Code compliance checking needs greater sophistication to handle the complexities of performance-based codes as well as the potentially wide range of novel building forms. Approaches to automated communication of failures to reach compliance would also be developed alongside the checking systems. A wide range of information would need to be identified for a particular project, with information drawn from across the industry to provide viewpoints to reflect, for example, specified components and services, tendering for services, legal coverage, insurance coverage, registration of consultancies providing input, etc.

• Investigating emerging approaches to facilities management. This may include prediction of the effective life of the building and facilities from model information and associated and changing information on climate, terrain, neighbouring developments, etc. IDDS could support establishing business models for facility maintenance, operations and asset management, including operations of people working in the buildings. Short-term approaches will enable the re-use of the as-built model for user operations across the life cycle of the building, as well as the standard facility management processes. Improvements in the ability to create accurate as-built BIMs would improve the linkage through to Building Management Systems (BMS) as well as being linked into the BEIF for the lifetime of the building.

6.5 Engendering Cultural Change & Knowledge Management and Dissemination

The culture within the construction sector is generally one of distrust; however, even in projects where there is no collaborative legal framework, early use of BIM is showing a breakdown in traditional adversarial relationships. Engendering cultural change should be seen as a short to mid-term goal of IDDS and will require research in the following areas:

• Engendering industry and enterprise business re-modelling. A large part of this is working on the distrust between professions and identifying approaches to foster a collaborative mind-set for projects. This needs to work both for long term partnering type organisations and for those who are forming a partnership purely for a single project. The impact of this culture change has to reach from the perceptions introduced during training of professionals through to the types of contracts and expectations that exist within a project (e.g., utilising alliancing or similar lean construction process). The latter issue would include examining how to facilitate virtual vertically integrated enterprises for the project and beyond. Trialling existing approaches in new countries and contexts may be part of this research, along with the development of new approaches to achieving these goals. An expected consequence of this type of cultural change is that A/E/C graduates will have to become more multi-skilled to be fully effective in their profession. Initial work on programmes that would achieve this outcome exists in a few innovative programmes, but wider uptake is likely to be required.

• Investigating the potential for changes to the legal frameworks that projects run under. Of particular interest is developing limits on the need for litigation on projects, fitting with the collaborative mind-set that is posited for the industry. Approaches that may aid in this development include the use of model managers controlling all information flows on a project.
With all information on a project in a consistent and up-to-date form, available to all participants, this may be a facilitator of issue resolution across the project. This may also link with processes such as alliancing that ensure a collaborative approach across project partners to achieve dispute avoidance. Another approach that holds potential is to develop processes and underlying technological support for audit trails throughout IDDS systems. This is likely to involve research into new models of what information must, should or could be exchanged and when and between whom. Specification and tracking of information at this level will lead to the establishment of new models of liability and responsibility within projects.

- Investigating the potential for changes to the insurance frameworks that projects run under. A major approach here is to examine the case for changing from professional indemnity insurance to project-based insurance that supports the remodelling of the industry to reduce the distrust between professions.

- Developing new and expanded roles for the industry. One example of this approach would be an expanded role of project managers to coordinate and integrate innovation throughout the entire team, including: risk mitigation, reduced contingencies, reducing and avoiding disputes, and achieving whole-life value. For the majority of professionals in the industry this is also likely to require a change to having model management as a transparent skill-set, again requiring a rethink of educational approaches and the knowledge units that would be expected in professional degrees.

It is essential that A/E/C industries capture knowledge and re-use it both in practice and education, so that we can improve at the pace of the leading edge participants, rather than at the pace of the slower majority. Improving knowledge management and dissemination should be seen as a short to mid-term goal of IDDS and will require research in the following areas:

- Development of a new pedagogy for integrated design and construction curriculum (NB: the USA’s A+CA Alliance is working towards this now, and problem-based learning may offer a solution for some). A powerful approach towards this is to identify ways to integrate education and training more closely to facilitate rapid sector learning. However, this will stress some current educationalists who are not used to such rapid change and approaches to smooth the uptake change will need to be incorporated into the rollout strategy. To ensure that there are sufficient projects to be utilised in this learning style there will need to be developments for data harvesting for project, programme, portfolio and sector performance learning and improvement.

- Develop new design roles that integrate conceptual design and technical implications. This would see a further blending of views from traditional splits between design oriented and building science oriented schools.

- There will be a need to investigate a wide range of business issues and reflect the amalgamated information from these investigations. Examples of issues which need investigation include: the varied strategies for the creation of automated business process modelling to realise benefits from diverse project team members; developing a broad understanding of the mediation requirements of the various professions in the industry across the various phases of typical projects; evaluating the benefits and drawbacks of the wide range of approaches to information security and copyright protection for designs which are interoperated in an IDDS environment; and the benefits of proposed approaches to develop a migration path from large to small projects and organisations.

- Investigate trade-related issues, through for example needs analysis. Work could be undertaken to help specify infrastructure semantics and to develop interoperability descriptions.
• Develop team mental models to improve project collaboration of distributed project teams combined with computer supported collaborative working (CSCW). This is likely to require extensions to current approaches in CSCW to better match requirements of this domain.

• Investigating the types of knowledge management needed for technology transfer versus the steady state support of the industry. Technology transfer approaches need to identify and draw upon innovations across a wide variety of disciplines outside of A/E/C as well as innovations developed across the world within the industry. As disruptive change may come from many directions and through a combination of quite disparate technologies, the prediction of what will impact becomes an immediate challenge. Significant in-house learning occurs within organisations where a body-of-knowledge develops through the on-going experience from projects undertaken. For organisations of all sizes and in long-lasting partnerships, there needs to be more explicit ways of managing knowledge about topics such as: process management, contract documents, standards development, technical training from graphics to objects, job and role descriptions, etc. This capture of organisational knowledge provides for a steady-state description of an organisation’s approach as well as forming the basis to understand the impact of a new technology on the organisation. Sophisticated systems should also be able to identify outside sources and influences that should be understood for a current project. Types of information that might need to be identified include: quality control configuration plans, standards, IT mappings, workspaces (with specific software), libraries (and their specific owners), control cycles for improvement, etc.

• Examine how to effectively develop a dissemination and diffusion model for a wide range of topics that are of particular import to the industry. Examples include:
  o Implementation in multiple business sectors
  o Use and delivery of IDDS in housing markets
  o Diffusion models for life-cycle innovation
  o How to develop roles and relationships
  o Facilitate leap-ahead approaches for developing countries
  o Dynamic characterization and the development of design methodologies appropriate to local cultures.
  o Capitalization of local expertise
  o How to characterise cultural sensitivities

• Improve the performance management of the built environment. This requires an establishment of the economic rationale for performance management and benefits that flow from such management. An important step towards this will be characterization of existing case studies and documentation of new case studies that clarify the economic rationale for different interventions in the field of performance management. To help characterize the case studies and the economic rationale work will be needed on the creation of common project metrics to measure consistency of outcomes. This will help ensure that comparisons are made on related projects under the same basis. This may lead to the development of tools to provide support through dashboards and KPIs that can’t be gamed.
Appendix A - Drivers, Enablers, Barriers & Opportunities

Drivers for Change
- Government Demand
- Economic Requisites
- Sustainability
- Innovation Imperatives
- Improving Evidence Base
- Analysis of Opportunities for Improvement
- Harvest Themes from Research

Enablers
- Improved Processes
- Improved People
- Structural
- Improved Technologies
- Programme Outcomes

Barriers
- Normative Professionism
- Professional Indemnity
- Professional Ambiguity
- Devolved (hidden) Risk
- Litigious Nature of Relationships
- Buildings as Artifacts
- Resistance to Innovation
- Change as Risk Instead of Improvement Opportunity

Opportunities
- Programme Outcomes
- Improved Value for Money
- Improved Sustainability
- New Models, Outcomes & Improved Profits
- Greatly Reduced Litigation
- Realistic to Innovation
- Change as Risk Instead of Improvement Opportunity
- Improved Technologies
- Design, Integration & Optimation
- Construction Cost Development
- Knowledge Management
- Improved Evidence Base
- Multi-Skilling
- Improved Value for Money
- Improved Quality & Whole Life Value at Reduced Cost
- Coherent Information Flow & Knowledge Re-use
- More Reliable Outcomes & Improved Profits
- Greatly Reduced Litigation
- Improved Agility & Willingness to Change

Improved Evidence Base
- More Innovative & Competitive Organisations
- Collaborative Mindsets & Multi-Skilled Workforce
- More Reliable Profits
- Improved Value for Money
- Improved Economic Contribution
- Improved Sustainability
- Cultural Change Through Beneficial Experience

Sustainability
- Improved Quality & Whole Life Value at Reduced Cost
- Coherent Information Flow & Knowledge Re-use
- More Reliable Outcomes & Improved Profits
- Greatly Reduced Litigation
- Improved Agility & Willingness to Change

Innovation Imperatives
- Government Demand
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- Sustainability
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Economic Requisites
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Appendix B - Events, Contributions & Consultations

1 Events
The IDDS global priority research theme and this roadmap have been developed and refined through a series of discussions and more formal workshops by several hundred researchers, industrialists and clients, to whom we extend our thanks. The more significant events of the last four years are set out below:

- CIB Board Approval of Integrated Design Solutions (IDS) priority theme, Apr 08
- IDS International Conference & Workshop, VTT/ RIL, Espoo, Finland, May 09
- IDDS White Paper Launch, Presentations & Workshop, CIB WBC, Salford, UK, May 10
- IDDS Development Meeting, CIB Coordinators, Salford, UK, May 10
- IDDS Lectures & Workshops, University of Illinois at Champaign/ US Army Corps of Engineers. Champaign, IL, USA, Sep 10
- CIB W078 27th International Conference, Special IDDS Session, Cairo, Egypt, Nov 10
- Australian Industry IDDS Roundtable Discussion & IDDS Research Symposium, RMIT, Melbourne & IDDS Workshop at CSIRO, Highett, Australia, May 11
- SindusCon-SP 2nd BIM Conference & IDDS Workshops at SindusCON HQ, São Paulo and Universidade Federal do Rio Grande do Sul, Porto Alegre, São Paulo, Brasil, Oct 11
- CIB W078 & W102 Conference & IDDS Workshop, Sophia Antipolis, France, Oct 11
- Built Environment Industry Innovation Council Meeting, BuildingSMART National BIM Roadmap Workshop & IDDS Workshops at Queensland University of Technology and University of Technology Sydney, Australia, March 2012
- Publication of IDDS Research Trajectories Paper, Apr 12
- CIB Board Meeting & IDDS Conference & Workshop, Washington, DC, USA, Apr 12

2 Acknowledgement of Contributions & Consultations
The following people and organisations have had their views and inputs taken into account during the formulation of this roadmap.

2.1 Members of the IDS/IDDS Core Group
Current:
- Coordinator – Associate Professor Robert ‘Bob’ Owen (Queensland University of Technology, AU)
- Joint Coordinator – Associate Professor Dr Robert Amor (University of Auckland, NZ)
- Dr John Dickinson (National Research Council of Canada & Advanced BIM Solutions, CA)
- Dr William ‘Bill’ East (US Army Corps of Engineers ERDC-CERL, US)
- Makoto Kataoka (Shimizu, JP)
- Professor Dr ‘Sami’ Kazi (VTT Technical Research Centre of Finland, FI)
- Professor Dr Arto Kiviniemi (University of Salford UK)
- Professor Robin Drogemuller (Queensland University of Technology, AU)
- Assistant Professor Dr Andrew McCoy (Virginia Tech US)
- Dr Anita Moum (Norwegian University of Science & Technology (NTNU), NO)
- Mark Palmer (National Institute of Standards and Technology, US)
INTRODUCTION

Integrated Design & Delivery Solutions

- Neil Pawsey (Fiatech, US & UK)
- Associate Professor Dr Matthijs Prins (Technical University of Delft, NL)
- Professor Dr Geoffrey Qiping Shen (Hong Kong Polytechnic University, PRC)
- Professor Dr Tom Regan (Texas A&M University, US)

Past:
- Lars Bjørkhaug, SINTEF, NO
- Professor Dr James Garrett, Carnegie Mellon University, US
- Professor Dr Matti Kokkala, VTT Technical Research Centre of Finland, FI
- Professor Dr Kerry London, Deakin University & RMIT, AU
- Damien Merenne Belgian Building Research Institute, BE
- Emeritus Professor Dr ‘Bob’ Tatum Stanford University, US
- Dr Russ Thomas, National Research Council of Canada, CA

2.2 Organisations represented in workshops and consultations:

- Aalto University, FI
- AEC Transformations, US
- American Institute of Architects – New York, US
- Architecture plus Construction Alliance, US
- Artic Star Design, US
- Arup, AU
- Australian Government, AU
- Autodesk, UK & US
- Balfour Beatty Construction, US
- Basu Technology Inc., US
- Baucentrum Urban Studio / Bsa, US
- Belgian Building Research Institute, BE
- BergerABAM, US
- Biscaya Architect, PO
- Brigham Young University, US
- Brighton & Sussex University Hospitals NHS Trust, UK
- Cannon Design, US
- Carnegie Mellon University, US
- Chartered Institute of Building, AU
- Collaborative BIM Advocates, US
- CSIRO, AU
- CSTB, FR
- Dassault Systemes, FR
- Davis Langdon, AECOM, AU
- Deakin University, AU
- DOA – Wisconsin, US
- Dynamic Systems Inc. US
- Escola Politécnica da Universidade de São Paulo, BR
- FIATECH, US
- General Services Administration, US
- GeorgiaTech, US
- GRAPHSOFT, HU, SP & US
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- Halcrow Group, UK
- Hanson Bridgett LLP, US
- Heitzman Architects, US
- Hochtief do Brasil, BR
- HOK, US
- Hong Kong Polytechnic University, PRC
- Italian National research Council, IT
- John Holland Pty Ltd (Leighton Holdings Group), AU
- Lawrence Berkeley National Laboratory, US
- Leighton Holdings, AU
- Lend Lease, AU
- Loughborough University, UK
- McCarthy Building Companies Inc., US
- National Research Centre of Canada, CA
- NORDAC, FR
- Norwegian University of Science & Technology (NTNU), NO
- National Institute of Standards and Technology, US
- Oger International, FR
- Parsons Brinckerhoff Australia Pty Ltd, AU
- Peripheral System Inc., US
- PHI Cubed, US
- PINI, BR
- Queensland State Government, AU
- Queensland University of Technology, AU
- Royal Melbourne Institute of Technology, AU
- Rider Levett Bucknall NSW Pty Ltd, AU
- SBEEnrc, AU
- Shimizu, JP
- SINTEF, NO
- Southland Industries, US
- Stanford University, US
- TechniGraphics Inc., US
- Technion – Israel Institute of Technology University, IS
- The Change Business, UK
- The University of Auckland, NZ
- The University of Melbourne, AU
- Texas A&M University, US
- TNO, NL
- Delft University of Technology, NL
- Turner Construction, US
- United Kingdom Government, UK
- Universidade de São Paulo, BR
- Universidade de São Paulo USP Coordenar Consultoria de acao, BR
- Universidade Federal do Parana, BR
- Universidade Presbiteriana Mackenzie, BR
- Universidade Estadual de Campinas UNICAMP, BR
- University of California, US
- University of Illinois at Urbana Champaign, US
IDDS
Integrated Design & Delivery Solutions

- University of Melbourne, AU
- University of New South Wales, AU
- University of Newcastle, NSW, AU
- University of Salford, UK
- University of South Australia, AU
- University of Sydney, AU
- University of Technology, Sydney, AU
- US Army Corps of Engineers, ERDC-CERL & ITL, US
- Virginia Tech, US
- VTT Technical Research Centre of Finland, FI