The Significance and Priorities of IT in Sustainable Construction Development

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Abstract

On a worldwide basis, sustainable construction is increasingly recognised as the primary challenge faced by the development industry. It requires a multi-faceted approach and a magnitude of professional intertwining, in contrast to the current pockets of fragmented knowledge development in areas such as indoor air quality and grey-water management. There is a need to consider the big picture concerning more complex processes, decision making, integration, collaboration, and coordination between hierarchies both internal and external to the industry. The handling of these issues can rely on information technology as a proven tool for managing projects and industry development for construction. Existing IT applications for sustainable development have been limited, with isolated studies on energy modelling, intelligent control of systems, and assessment tools for environmental ratings. There needs to be an emphasis on developing a common IT vision for sustainable development and action plans for strategic implementation. There should be expansion of IT application areas prioritising on benchmarking, simulation, process modelling, decision support, communication and education of sustainable construction principles and practices. The level of success in this endeavour will depend on how we demonstrate IT's significance to sustainable development and how we prioritise sustainability constraints appropriate for IT to enable alleviation. This can be aided by the promotion of exemplar projects and international alliancing, as outlined in this paper through some QUT initiatives.

Keywords: IT, sustainable construction, management, industry development

Introduction

The concept and practice of sustainable development has thrived quickly from an inexplicit reference in a national energy policy act to a truly global phenomena in a relatively short time-span of 35 years (Kohler 2002). Its' evolution has coincided with the rapid expansion in knowledge, technologies and practices specific to the construction field. At the same time, it also left behind many gaps such as the difficulties in identifying common priorities, defining appropriate action plans, managing information as well as knowledge, and coordinating global, regional and disciplinary activities of professional and general public interest. There is a need to consider the big picture of sustainable construction integrating processes, starting points, the processes, bottom-lines and targets, variations and optimisation, and the hierarchical coordination between organisations, industries and the society. The handling of these complex issues and activities can be aided by information technology, as a proven tool for managing projects and developing the construction industry.

Substantial research has been carried out on the impact and roles of information technology on construction industry development. Over the past twenty years, IT has proved to be invaluable in providing assistance to construction management professionals (Bröchner 1990 and Björk 1999). Considering the common stakeholders, products and processes, and the services and people involved in sustainable construction, as a future development trend of the construction industry, it is natural for people to aspire to the use of IT in solving some of the problems outlined above. Despite the apparent connection, dedicated research on IT for sustainable construction has been limited. Most so far seem to focus on the specific aspects of applications such as IT as a tool for environmental assessment, ESD based design through CAD, or intelligent control systems for building performance. Many areas in the overall planning, modelling, process support and management of sustainable construction activities and practices are largely unaddressed.

This paper discusses the evolving nature of sustainable construction before reviewing IT applications in the field and the potential of IT. Comparisons between potential priorities of sustainable development and the evidence of IT enabled benefits are also made. With the proven track record of IT, the paper attempts to refer to IT visions and directions of past research in order to outline the significance of applying IT for more effective development of sustainable construction. Future priority development areas of IT are outlined. A set of action plans to move us forward is introduced in terms of trans-disciplinary approaches, industry partnerships and international networking, through examples of activities and initiatives in the Queensland University of Technology.

Evolving Characteristics of Sustainable Construction Development

Brundtland's report of the World Commission on Environment and Development (WCED, 1987) defined sustainable development as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*. This concept was further expanded in the Agenda 21 (Policy plan for environment and sustainable development in the 21st Century) that interweaves political, economic, legal, social and environmental dimensions (Bentivegna et al, 2002). Sustainable construction can also be seen as providing a contribution to poverty alleviation, creating a healthy and safe working environment, equitably distributing social costs and benefits of construction, facilitating employment creation, developing human resources, acquiring financial benefits and uplift for the community (CIB, 1999).

The evolving definition of sustainable construction development concepts exhibits a close correlation with the constraints of management principles. It has the same underpinning of time, quality and cost while adding additional dimensions such as resources, emissions and biodiversity, as a new paradigm. In a global context, further aspects of social equity, cultural issues, governance, environmental quality and economic constraints are also considered (CIB 1999), as illustrated in Figure 1. Depending on the varying view points, these dimensions and aspects can be viewed as overlapping or inter-inking, while supporting overall sustainable construction. This creates an even wider range of interpretations of priorities and opportunities. In addition, there are differences in the view points between economists and environmentalists. The former place reliance on the economic status quo and the central measure of GDP as the proxy for development, while the latter consider the implications towards environmental damage, especially irreversible damage, as the basis of all measures (Mawhinney 2002).

Despite the difference in definition and views, the development of sustainable construction needs to follow certain project development patterns from need identification and conception, through design, planning and construction, to commissioning, maintenance, and deconstruction. Additional constraints in wider contexts, and the changing priorities specific to sustainable construction, will inevitably increase the complexity of management of development processes. Table 1 shows an example of some of these constraints, typical priorities and complexities more specific to sustainable construction.

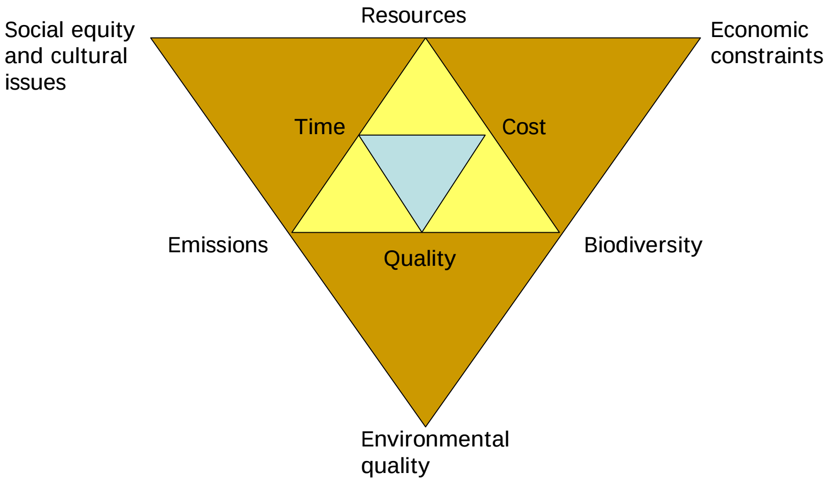

Figure 1. The expansion of key management principles in sustainable construction

Central to sustainability problems is the prediction, direction and control of current, evolving and future technology development. In addition, the processes of change, adaptation and growth and the management of these processes are also defining elements in the evolution of sustainable construction (Yang et al 2003). Along the way, the development will also need to:

- Understand natural systems and their interrelations with human environments
- Identify priority needs from human needs and aspirations of a general public that is not adequately informed;
- Deal with additional risks and potential in the adoption of new materials, technologies and practices;
- Cope with flexibility required for changing legislation, standards, codes and governance;
- Improve continuously the technical know-how among professionals;
- Cope with varying interpretation, preference, priorities and prejudice towards sustainability principles; and
- Respond to difficulties in defining universally acceptable role models because of the differences above and changing public expectations.

Constraints	Some of the priorities	Typical complexities
Resource depletion	Reduction of energy consumption during construction and use Conservation of water resources Development of alternative materials	• Lack of awareness and sharing of knowledge and experiences among professionals and trades • Incompatible methods of procurement and construction • Inefficiency in process modelling
Financial target	Lean construction Target setting, information sharing and bench marking Technology innovation	• Dependency on multi-level coordination, and government incentive • The conservative nature of the construction business • Inability to assess and handle risks • Input/benefit analysis
Environmental damage	Design for minimum waste Reduction in construction waste and usage waste Minimise pollution through efficient operation Maintenance and improvement of biodiversity	• Deficiency in comprehending natural systems and phenomena • Inability of design tools • Consumer habits • Legislation and governance • General public awareness
Social context and political stance	Respect for people and nature Health and safety principles Legislation and codes Implementation and incentives Education of professionals and community	• Lack of competence in managing the processes of changing attitude of people and institutions • Lack of appropriate education channels • Inability to establish "best practice"

Table 1. Examples of sustainable construction constraints, priorities and complexities.

The professional construction community have been struggling with many of these above issues as barriers to IT implementation over a long time. The issues are now being extended with broader and more diverse constraints by overlaying the sustainability dimension and issues.

Existing IT applications for Sustainable Development

The diversity and broad spectrum of sustainable construction issues presents an opportunity for many potential application areas for IT. However contrary to the acknowledged benefits IT may bring to the construction industry, existing literature on the use of IT for sustainable construction issues has been rare. Early IT applications were typically associated with the measurement and evaluation of sustainability targets. The IT Construction Best Practice Programme (ITCBP 2004) has grouped its assessment of these IT tools for sustainability under four categories:

- Energy modelling – eg. computer simulations of energy performance of buildings;
- Intelligent systems – eg. Intelligent and automated building control and operations;
- Assessment tools – eg. assessment of materials' embodied energy;

- Performance indicators – eg. buildings' environmental rating.

Examples of pilot studies in these categories include:

- Artificial intelligence for integrated BMS (Clark and Mehta 1997) – The research explored a methodology for integrating the information of building management systems through a single multimedia networking technology and knowledge based systems. The method proves that AI will enhance the control of HVAC for improved human comfort and operational cost efficiency.

- IT and building performance assessment (Maver and McElroy 1999) – computer based simulations of the physical environment for support to design consultants through an Energy Design Advice Scheme (EDAS). Multi-media databases were employed to capture projects as outline case studies.

- BEQUEST toolkit (Betevegna et al 2002) – This is one of the first demonstration software systems designed to support decision makers concerned with urban sustainability. The system is composed of one framework and four models of Protocol, Assessment Methods, Advisors and Glossary and provides a general reference to sustainable design and urban development issues with extensive UK and Italian case studies.

- CSIR Sustainable building CD (CSIR 2003) – A series of computer based tools, guidance, and references that can be used in briefing for sustainable aspects when designing buildings.

- Computer based IB on-line learning, adaptation and control (Hagras, 2003) – A new approach to the implementation of intelligent building agents based on a hierarchical fuzzy genetic multi-embedded agent architecture, which utilises sensory information to learn to perform tasks related to user comfort, energy conservation, and safety.

- IT based infrastructure for water resource assesment (Adriaens et al 2003) – A GIS based remote sensing imagery analysis to assess the vulnerability of potable water supplies as a result of nature-human interaction.

- SBIS (CIB2004) - Recently, iiSBE (the International Initiative for "Sustainable Built Environment) launched SBIS, the sustainable building information system. Essentially an information database, the system is to allow users all over the world to gain access to a rich body of information related to sustainable building in several languages. Several linked files will provide relational access to cover topics such as Advanced Technologies; Methods and Tools; R&D Projects; Policies and Programs; Buildings; People; Events; Documents; and Relevant websites.

The relative scarcity of literature coverage suggests that existing IT applications for sustainable development are still in their infancy. They have been developed on an ad hoc rather than consistent basis such as seen in other areas of construction development. Previous applications tend to be associated with and restricted to specific domains of control systems, and assessment and evaluation of sustainability performance of built assets. The recent review of work in construction IT in CIB programmes has not separately identified sustainability as a big name up until now (Amor et al, 2002).

Over the recent decades, IT has been identified as a key lever in obtaining competitive or strategically advantageous positions at project, institutional or industry levels. Work by Betts, Luck and McGeorge (1999) on long-term IT research priorities clearly identifies sustainability issues as big. One of the scenarios if depicted was of IT Tools that allowed sustainability issues to be modelled for design choices and optimisation. Within the context of sustainable construction development that deals with social/environmental changes as well as technological advances, the full credential of IT including its modelling, processing, interpretation, presentation and reporting power for complex issues and phenomena is yet to be realised.

The Proven IT Potential for the Construction Industry

Over the past few decades, the advancement of IT has made available an array of applications that have considerably lifted the game of the construction industry. Many of these applications benefit from IT based data processing and decision making in management processes. A number of comprehensive assessments on the role of IT and its impact on construction projects development, management and operations have been undertaken (Yang, 1994, Tan, 1997, and Betts 1999). In the late nineties, a two-year industry led study conducted by Construct I.T. documented extensive examples of strategic exploitations of IT in the UK and international construction companies and businesses (Construct IT, 2000). A series of reports from this research concluded that IT will help the construction industry in terms of:

- Business planning
- Marketing and promotion
- Information management
- Procurement
- Finance
- Client management
- Design
- Construction
- Operation and maintenance
- Human resources

Benchmarking studies conducted by Construct I.T. over major construction firms further demonstrate the potential of IT, particularly in strategy, policy and procedures; management, supervision and administration; commercial management; planning, monitoring and control and delivery and materials' handling. At a worldwide level, the unbound potential of IT has been witnessed through some high profile research projects. The University of Salford's *3D* to *nD* modelling project aims to expand from the traditional design process to enable and equip the construction industry with a tool that allows users to create, share, contemplate and apply knowledge from multiple perspectives of user requirements (Construct IT, 2004). IT has also enabled a series of construction automation efforts such as welding robots and Automated Building Construction Systems as experimented by the "big 5" Japanese contractors (CCRR, 1999). There is also considerable coverage of the initial success of IT research for construction knowledge representation, decision making, and artificial intelligence, from the originally domain specific problems to more systematic and comprehensive approaches to construction processes and management routines (Yang, et al 1996).

The construction industry is an information rich industry. The potential of IT will lie in its ability to improve the way we work (by sharing and processing) and influencing the way we change (by testing, evaluating and presenting alternative approaches). The potential will also be best realized under the right conditions such as dynamic changes in technological advancement, commercial globalization, social advancement in aspirations and education, and political motivations. The sustainable construction arena is becoming a home-ground for the ever increasing innovation of building systems and materials, world-wide recognition of ESD principles and targets, and changing public expectations and societal demands. Therefore it presents a prospect for not only improved IT applications but also long term strategies of embracing IT as a tool to promote and further develop sustainable construction.

New Priorities of IT in Sustainable Construction Development

With regard to IT applications for the construction industry, the CIB Working Commission W078 has been active for over 20 years. Its' research agenda and annual meetings were represented by many regions in the world and have a high degree of authority. A recent review of research activities and future visionary directions (Sarshar, 2000) has suggested six themes of future directions of generic use of IT for construction as:

1. *Model driven as opposed to document driven information management on projects;*
2. *Life cycle thinking and seamless transition of information and processes between life cycle phases;*
3. *Use of past knowledge (information) in new developments;*
4. *Dramatic changes in procurement philosophies, as a result of the internet;*
5. *Improved communications in all life cycle phases, through visualisation;*
6. *Increased opportunities for simulation and what if analysis; and*
7. *Increased capabilities for change management and process improvement.*

Aligning these themes with the current issues and constraints identified earlier will result in an illustration of compatibilities, or match, between sustainable construction problems on hand and IT technologies suited for the industry (Table 2).

Constraints	Typical complexities	Strategic fit with future IT themes	Potential IT tools and technologies
Resource depletion	• Lack of awareness and sharing of knowledge and experiences among professionals and trades • Incompatible methods of procurement and construction • Inefficiency in process modelling	**1, 3, 4, 7**	• EDI • Internet and intranet • Simulation • Energy simulation
Financial target	• Dependency on multi-level coordination, and government incentive • The conservative nature of the construction business • Inability to assess and handle risks • Input/benefit analysis	**3, 5, 6**	• Integration • Cost modelling • Decision support • On-line sharing of product info.
Environmental damage	• Deficiency in comprehending natural systems and phenomena • Inability of design tools • Consumer habits • Legislation and governance • General public awareness	**2, 5, 6,**	• Synthesisation • *3D* to *nD* analysis • Product modelling • Virtual reality
Social context & political stance	• Lack of competence in managing the processes of changing attitude of people and institutions • Lack of appropriate education channels • Inability to establish, compare and communicate "best practices"	**7, 2**	• Expert systems • Knowledge representation • Integrated databases

Table 2. Examples of Applicable IT themes and Potential Tools for Sustainable Construction

In addition to assessment and evaluation, information technology can also be used to improve other aspects of sustainable construction development such as the difficulties of foreseeing design and project outcomes, the lack of comparative standards caused by non-unified interpretations, and the fragmentation of R&D interests due to the lack of information sharing, technical know-how, and education. In general, IT can be used in four main aspects of work that are most significant for the next stages of sustainable construction development. The four aspects are simulation and process modelling, scoping and benchmarking studies, communication, and integration.

- IT as a simulation and modelling tool

  Even within the stakeholders of specific projects, sustainable construction may have different interpretations and priorities. For many, sustainable construction is about management rather than sacrifice. In order to manage sustainable construction projects to becoming more efficient and responsive to business needs of the clients, it is essential to agree on and adhere to essential processes and procedures. There are great opportunities to enlist IT for product modelling for efficient and constructive representation of professional agenda of the entire team. Process modelling can apply to the management of people, innovation and change. Modelling can also assist in design, planning, construction, and operation of new technologies and products for the testing products, consideration of buildability issues, coordination of processes, and simulation of perceived outcomes.

- IT as a scoping and benchmarking tool

  A global challenge for sustainable construction is the variance in interpreting principles, bottom lines, start points, processes and expected outcomes (Mawhinney, 2002). In real world projects, this often translates into differing and at times, contradicting measurement standards, unjustified focuses, and imbalances of resource input and time. Scoping studies and benchmarking will develop agreeable platforms on which people, projects, regions and industries will operate. IT can help produce and deploy a range of benchmarking systems beyond the current green rating systems, to include interactive design guides, environmental assessment standards, checklist of code compliances, and performance rating schemes. It will specifically help with using past knowledge for current and emerging development scenarios.

- IT as a communication tool

  The development path of sustainable construction has left many conflicts resulting from the various interpretations of sustainability principles. A key solution to this, and indeed to many other relevant constraints, is the education of the world community. The construction industry is a conservative industry with traditional reluctance to sharing. The novice nature of many sustainable construction endeavours will benefit from a multi-level, industry-wide sharing of data and knowledge. A variety of IT tools such as electronic data interchange, decision support, expert systems, multimedia, can be used to achieve this, in parallel to information processing, promotion and marketing, and education of the general public.

- IT as an integration tool

  Social and political motivations aside, the crux of the issue to the fragmentation in early sustainable construction practices is the lack of able tools to coordinate cross disciplinary and multi-dimensional considerations of natural, human, cultural, religious, and political phenomena. There is a disconnection between smart technologies (eg. intelligent building management systems) and sustainable targets of constructed facilities (eg. cost minimisation). A specialty area of IT development is its integration power. Stemming from CIM (computer integrated manufacturing), the philosophy and implementation strategies of CIC (computer integrated construction) have been tested for over a decade. The maturity of some of these techniques will suit local applications of multi-level linkages of the sustainability agenda. A combination of sequential and radial integration methods can be employed.

The Way Forward

To counteract the various degrees of ambiguity and fragmentation in sustainable construction research, there is a need to showcase agreeable best practices or at a minimum, worked examples as a starting point. An IT vision for the sustainability theme should to be established to reflect the pyramid of construction information and its management needs at project, enterprise and industry levels. Action plans should take on a “team approach”, linking the drivers of change and end-goals of the holistic picture of sustainability with technological focuses and gains. It is also necessary to identify and develop new operational platforms more suited to encompass and represent the qualitative issues of social, environmental, and political dimensions of sustainability.

To ensure the momentum and avoid back pedalling due to regional diversity, an international alliance of researchers and practitioners with a dedicated focus on IT should be established in the sustainable construction arena. Such an alliance must work in conjunction with other prominent international agencies, such as UNICEF, CIB, and iiSBE, with wide representations of all relevant industry sectors, different regions, and more over, all schools of thoughts.

In these two respects, the Faculty of Built Environment and Engineering at the Queensland University of Technology, Australia, has made some initial progress through its focus on the smart sustainable design and construction agenda. Through its five dynamic yet closely related schools that encompass most of the professional disciplines required in construction project development, the Faculty engaged some IT related research and collaboration on sustainable development themes with other disciplinary areas such as commerce, education, science, law and IT. A range of projects with an all encompassing view of sustainability development are being developed. Several international initiatives in providing specific focuses on integration, IT use and holistic development processes, were also facilitated, as briefly introduced below.

Project Name: VR Integration Project
IT tools: Virtual reality, modelling, simulation

> Urban planners need to effectively communicate to stakeholders about the concept of new and futuristic cities and their association with the adjacent built urban environment and transport systems. The ability to do so for new concepts like Light Rail Transit (LRT) systems and their interface with urban planning land uses has often been difficult for decision makers and the community to visualize within their own local environment. The power of a visual 3D walk or ride through virtual representation can within minutes express the whole concept of how, for example, a transit oriented development (TOD) may interface with existing or conceptualized models of urban terrain and associated land uses. VR modelling techniques are the core of this project to aid decision makers and the public to appreciate how transit systems like LRT may interface with planning communities. Options of various transit systems can be shown through conceptual images of a TOD superimposed upon a new green-field or existing brown-field site, as a model for future city development. The opportunities to model implications to energy, water, transport pollution and social issues of sustainability are being explored.

Project Name: the DISCOVER project
IT tools: Internet based data sharing, knowledge representation

> The DISCOVER project is aimed at promoting integrated development of smart and sustainable homes and subdivisions. It responds to some of the current problems facing the Australian housing industry eg, reduced stock of usable land, lack of worked examples, fragmentation of stakeholders, and skill shortage among builders and apprentices. The CRC-CI funded project aims to develop and compile a set of

integrated design and construction guidelines for consultants, builders and home-buyers alike. This is achieved through collaborative research in architecture, interior design, engineering, science, education and construction and particularly through the monitoring, evaluation and assessment of a consistent series of development decisions and home performance data, collected through the design and building process and 12 month occupancy of smart and sustainable homes optimizing a range of home site options within a housing infrastructure. Interdisciplinary university researchers, students, trade apprentices as well as developers, builders and state and local authorities, were involved in the design and construction of smart and sustainable homes. Incorporating build quality and training schemes and changing legislative and endorsement strategies, the project is extracting the knowledge of and capturing decisions for the design and construction guidelines backed up by the first-hand performance data, to produce a computer based knowledge repository and consulting tool, accessible by the community via the internet.

Project name: Knowledge based BAS design-maintenance integration
IT tools: Decision making, integration, knowledge elicitation and representation

Increasingly modern office buildings are designed and equipped with intelligent building automation systems (BAS). However, the contrast between life-spans of building structures and the BASs causes ongoing problems to service and maintain the various components and systems. Non-sustainable consequences, such as excessive energy consumption, increased service schedules, and sick building syndromes, may arise because of (1) the lack of knowledge and understanding and sharing of information among design, construction and maintenance processes; (2) difficulties in forecasting future condition and changes in the early design stage; and (3) the lack of data on operational requirement in the delivery stage. A QUT research project was nearing completion to raise the awareness of maintenance issues as a result of design and to provide a strategic alternative to balance design and maintenance for most appropriate decision making in the early design stage for sustainable maintenance. Following extensive surveys to design consultants, building occupants and facility managers, the core of this project has enlisted the help of integrated decision support between design and maintenance stages through knowledge representation.

Project Name: Computer modeling of the impact of climate changes on building performance
IT Tools: Simulation, modelling, integration

Greenhouse gas emissions and associated global climate change is posing a significant concern for the world community. Buildings as part of the infrastructure will need to withstand changing climate conditions for a long time span (50-100 years). This requires current and future building stocks to perform satisfactorily under changing climatic conditions. A research project hopes to establish and quantify how climate change will affect thermal comfort levels for building occupants, building energy uses and carbon emissions of Australian commercial buildings. Using advanced computer modeling techniques, the relationships between building design parameters, local climate changes, building energy usage, CO_2 emission levels, and building design, indoor environmental conditions and outdoor climate changes are being established. This should enable building consultants and developers gain a better understanding of the impact of these design parameters, and adapt appropriate strategies to minimise adverse impacts and optimise benefits.

Project Name: SASBE200 & CIB TG55 linked to W078 and other working commissions
Nature: Provision of global focus and networking through international conference and professional alliance.

SASBE2003 was a CIB co-sponsored international conference aimed at creating a forum for researchers and professionals to consider the wider issues and particularly the linking of intelligent features, systems and technologies with sustainability principles, expectations, processes, and outcomes. Represented by over 120 delegates from 19 countries in six continents, it set a new standard by linking three universities in the UK, USA and Australia to showcase their work and to champion the international perspective of sustainable construction. Its success in 2003 had provided such highlight and momentum that a dedicated international professional alliance, the CIB Task Group on Smart and Sustainable Built Environments, TG55, was established in early 2004. Based at QUT but reaching out to the rest of the world through CIB, TG55 has a special focus on IT as a tool for bridging the current gaps between smart technologies and soft issues of social, financial, environmental sustainability bottom-lines.

Surrounding the establishment of TG55, the potential for synergy is being explored between CIB working commissions and task groups. For example, research work in W098 Intelligent and Responsive Buildings, W100 Environmental assessment of buildings, and W108 Climate change and the built environment all cover certain IT respects in their research. This is in addition to the opportunities for TG55 to join forces with W078, as an established and dedicated IT community, to take the lead in developing international alliances towards on IT applications with a sustainable outlook. The initiative will require support for appropriate mechanism, regional structuring, and endorsement from the CIB and other agencies. This paper attempts to demonstrate this inter-connection for this workshop as a case of developing the synergy into the future.

Conclusion

Ongoing development of sustainable construction will create more knowledge and practical approaches, and at the same time, more havoc and constraints. Rather than sacrifice, appropriate compromise through efficient management is the key solution. IT can help with the management processes because of its key characteristics and proven relevance and significance to the construction industry. There are priority areas of sustainable development that can be dealt with directly and immediately by the deployment of IT tools. Before we see any major uplift from the current state of IT implementations however, there is a need to encourage better communication, reporting and reference to worked examples. International forums and professional alliancing will provide the necessary roadwork for IT as a vehicle to carry sustainable construction into the future stages of development.

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