INFORMATION TECHNOLOGY FOR CONSTRUCTION: RECENT WORK AND FUTURE DIRECTIONS

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SUMMARY*: Advancing the application of information technology in construction is a major international research and innovation endeavour of concern to scientific establishments and industry. A significant focal point for this research, in terms of its dissemination and the derivation of a shared research agenda, has been the working commission concerned with IT for construction within the International Council for Innovation and Research in Construction (CIB). Working commission 78 of CIB has been active for about 20 years in holding annual meetings of leading scholars in the field. These annual meetings have allowed the principal research activities from around the world to be presented to expert fora and documented in a series of annual proceedings. More recently, some of the more complete research projects have been reported in an on-line electronic journal published in association with the working commission.*
The meetings have typically allowed debates and discussion to take place regarding the state of progress with key research themes, the emergence of new research themes, and a vision of construction activities in the future to which ongoing research could relate. This paper seeks to capture some of the overall experiences from the activities of this working commission by reviewing the key research issues that have been addressed in recently reported work and seeking to elicit a vision of future IT-enabled construction projects that might inform future research. It reports on an overview of the scope, current approaches and future research agenda that has arisen from consideration of the papers presented, and discussion that took place, at its most recent meetings in South Africa in 2001 and Denmark in 2002.

KEYWORDS: *Information Technology, Construction, Research Agenda, Vision*.

1. INTRODUCTION

Working Commission 78 of CIB is concerned with Information Technology for Construction. The Commission has its origins in a meeting in Stockholm in 1983. For the last 19 years annual meetings of leading international scholars have taken place where research from many countries has been reported. Table 1 lists the meetings that have been held in the period 1990-2002 indicating the conference title and some of the major themes covered. The scope of the group's work is broad in terms of the design, construction and occupancy of constructed facilities, but primarily it relates to the integration and communication of data, information and knowledge in the facility's life-cycle. The mission of the group as a whole is to:

- foster, encourage and promote research and development in the application of integrated IT throughout the life-cycle of the design, construction and occupancy of buildings and related facilities;
- proactively encourage the use of IT in Construction through the demonstration of capabilities developed in collaborative research projects; and
- organise international cooperation in such activities and to promote the communication of these activities and their results.

Table 1. CIB W78 Meetings 1990-2002

Conference Venue	**Year**	**Conference theme**
Japan	1990	Computer Integrated Construction
The Netherlands	1991	The Computer Integrated Future
Canada	1992	Computers and Information in Construction
Singapore	1993	Management of IT for Construction
Finland	1994	Integrated Computer Aided Design
USA	1995	Modelling of Buildings through their Life Cycle
Slovenia	1996	Construction on the Information Highway
Australia	1997	Information Technology Support for Construction Process Reengineering
Sweden	1998	The Life Cycle of Construction IT Innovations
Canada	1999	Durability of Building Materials and Components
Iceland	2000	Taking the Construction Industry into the 21st Century
South Africa	2001	IT In Africa: Adoption and Behaviour
Denmark	2002	Distributing Knowledge in Building

Each of these meetings has typically been attended by between 50-100 leading researchers, government policy advisors and industrialists from 10-20 countries, reporting on extensive portfolios of institutional, national and international research projects and activities. The next section of this paper outlines an overall analysis of the breadth of research issues and major focal points within the research that has been presented at these meetings and how this has developed and evolved over time.

Beyond holding annual meetings, the working commission has undertaken a small number of collaborative projects. These have involved exchanging information resulting from regular international surveys, developing a future vision for construction IT and promoting streams of work and activities in visualisation and standardisation. A further project has been to monitor the regular and ongoing pattern of work covered by the commission through bibliometric analysis of the papers it has published. It is the outcome of some of the recent work in some of these projects, and this bibliometric analysis in particular, that is reported here.

2. PATTERNS OF TECHNOLOGICAL ADVANCEMENT

One can conceive of two complementary perspectives by which we might better understand the overall picture of the way that knowledge in the construction IT discipline, or area of study, has advanced. The first is a technological trajectory perspective. The second is a complementary innovation perspective. The argument advocated here is that in considering the nature of the development of this field of knowledge from a scientometric point of view, the two forms of enquiry can be combined to form a single overall picture by which we might better view and understand how our field has, and is, moving forward.

The trajectory perspective captures the dynamic processes that guide the creation, development and exploitation of technology (for example, see Dosi, 1982; Nelson and Winter, 1977). Abernathy and Utterback (1978), for example, articulate the evolution of a technology from a fluid phase through a transitional phase to a specific phase. In the fluid phase there are significant technological and market uncertainties. Bespoke design is prevalent, with new technology often crude, expensive and unreliable,

despite being able to meet the requirements of niche applications. Some of our early work in integrated Computer Aided Design (CAD) was pioneering in its science and its application and found some significant application. Despite this we are still now, some twenty years later, continuing to grapple with some of the research and implementation issues concerned with widespread implementation and application of integrated construction environments.

The early, bespoke, CAD systems were experimental in nature, and they evolved as researchers learnt more about market needs and customers understood more about the potential of the new technology. The transitional phase takes hold as producers (in our case, researchers) learn more about customer requirements through producer-customer interaction and through technology experimentation, some standardisation of components, markets and technology design takes place, and a dominant design emerges, signalling a substantial reduction in uncertainty, experimentation and major design changes. In our domain we can liken this to the widespread efforts towards standardisation through initiatives such as STEP, CAD layering and more recently the move towards Industry Foundation Classes. In the specific phase, technologies built around the dominant design proliferate, and there is more emphasis on associated process innovation, with technology innovation being more incremental in nature. Our increasing emphasis within W78 on process modelling and implementation research may be evidence of this.

In contrast to the technological trajectory approach, the complementary innovation approach argues that the success of an innovation is significantly shaped by other innovations and capabilities that are needed to exploit the innovation (Teece, 1986). Innovation is systemic in nature: to succeed, it must be located in, and develop with, a dynamic network of supportive contexts and capabilities. Tushman and Rosenkopf (1992), for example, propose that the evolution and consolidation of a technology is closely coupled with: the number of interfaces between the innovation and complementary innovations; and, the number of companies in the innovation's local environment that are impacted by it. The enormous steps forward that have been facilitated by the emergence of the internet is an obvious parallel technological innovation of recent times but the earlier emergence of personal computing and ubiquitous processing power may be seen as further examples. The emergence of rapidly widening bandwidth and of widespread visualisation capability may also be predicted to have a profound effect. On the whole though, we could argue that there is some evidence of a combination of the technology trajectory and complementary innovation perspectives underlying the way that Construction IT advancements have evolved over the last 20 years.

3. ANALYSIS OF RESEARCH SUBJECTS COVERED IN CIB W78 MEETINGS

Within construction IT there has been a number of attempts to assemble the data to which the above prism of enquiry might be applied more precisely. The dominant approach to analysing our field of study has been to define what a discipline is concerned with (Björk, 1999; Brandon et al 1997; and Fenves, 1996). Other attempts have been made to do this by collecting seminal works at a point in time (Brandon and Betts, 1995 and Rehak, 1994). As Björk identifies (1999):

> *"there are thus at least two options for defining the domain in a systematic way; a bottom-up bibliographical analysis of what researchers are actually doing or a top-down analysis based on some model of information management in construction. According to the first option it would be possible to provide a "map" of ITC research through a bibliographical analysis of the topics covered in the papers to be found in the leading ITC journals and conference proceedings."*

Björk (1999) draws attention to the problem that much research is likely to focus on technological advancements rather than implementation issues and the effects this has on our use of IT in practice. The analysis here seeks to respond to the challenge posed by Björk by analysing papers published within the scientific community but also considering the practice-based scenario that they might be contributing to.

The W78 workshops have covered a wide and increasingly broad range of topics in the Construction IT domain over its lifetime. With approximately 50 papers a year, except for 1999 and 2000 when the numbers

rose dramatically (partly due to the associated meetings the workshop was held with), researchers and industrialists in this area have covered most of the relevant IT topics. Figure 1 shows the number of papers published over the last ten years for which proceedings were produced.

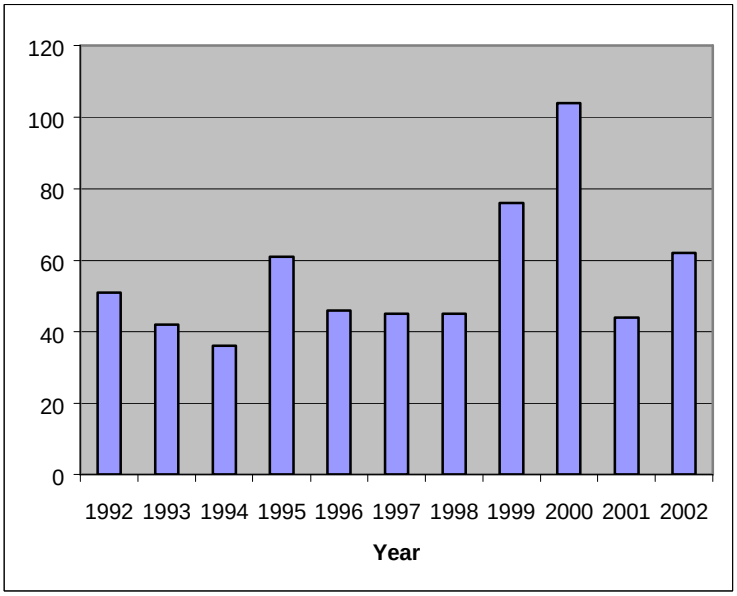

Fig.1: Number of papers at CIB W78 Workshops

Analysing the papers from these twelve workshops by the affiliation of the primary author (see Figure 2) shows a predominance of papers from Europe (approximately 60%) with the UK being the greatest contributor of papers. There is a very strong contribution from Nordic researchers (those from Finland, Sweden, Denmark, Norway, and Iceland) and a fair representation from North America. Surprisingly, the contribution from Asia is not high and not surprisingly the representation from less developed nations (within Africa, South America, and the Middle East) is constantly low.

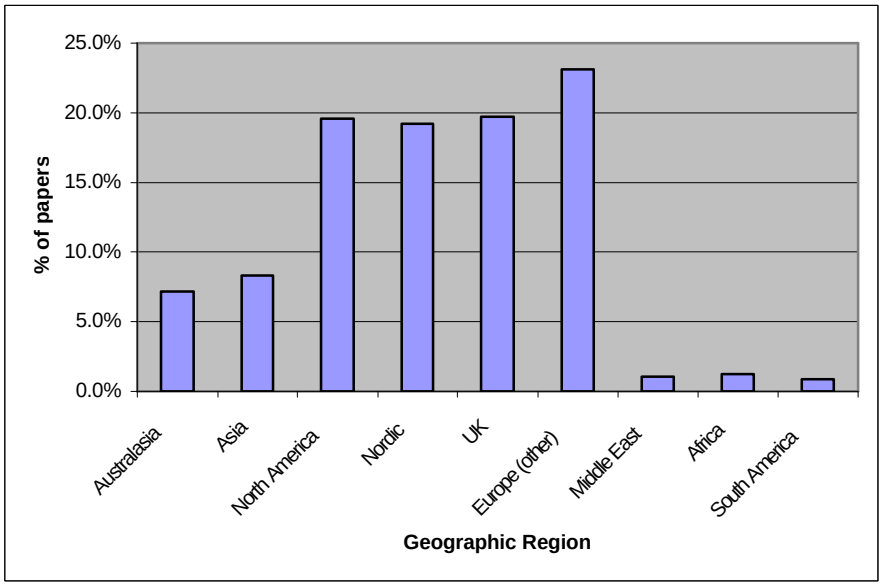

Fig.2: Source of workshop papers averaged over twelve years

Looking at the impact of conference location on the papers submitted allows us to gauge how these percentages could be changed. Figure 3 shows the papers submitted by the workshop hosting country in relationship to other years input. This shows a clear trend of North American researchers supporting conferences within their own region (Canada and USA) with lower levels of support outside their region. South African input increased dramatically in 2001, but is very low for conferences in any other region. Asian and Nordic input is generally higher for conferences within their regions though it is interesting to note some exceptions (e.g., Singapore, and Iceland) where local input to their conference is low (perhaps as the main researchers in the country organise the conference rather than contribute papers).

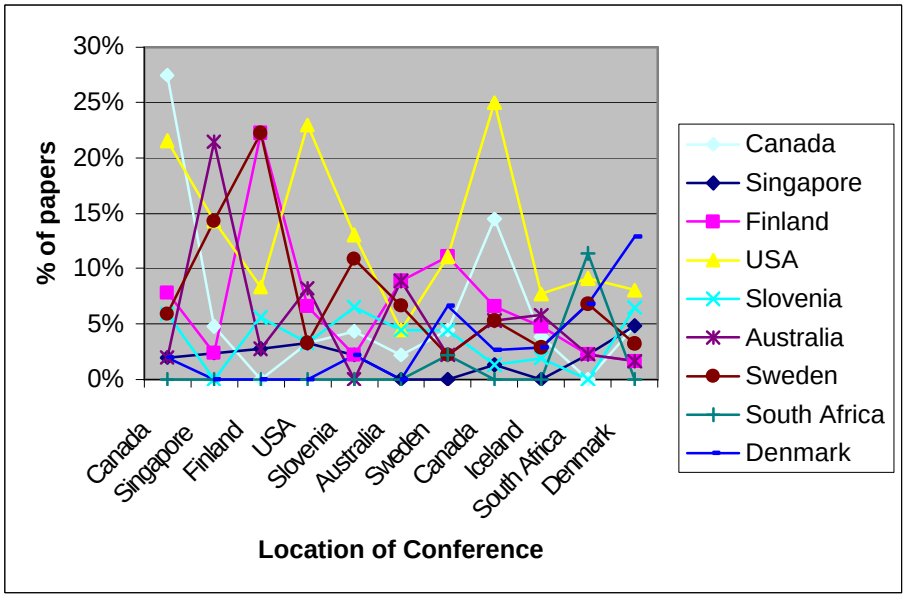

Fig.3: Papers from countries hosting a W78 workshop

Over this period there have been a small number of major themes that are constantly covered as seen in Figure 4. It would appear that there are different reasons for the constancy of each of these themes. The computer integrated construction (CIC) theme is one that has not settled upon a complete solution. Initial work in this area looked at bespoke, and tightly coupled, frameworks for integrated systems, usually integrating only a few very specific design tools. Over the years the scope has broadened to frameworks capable of managing loosely coupled (e.g., Internet-based) integration of design tools utilising the range of evolving data standards. Papers on the construction process have increased fairly steadily in number and importance within W78 to cover a wide variety of topics around IT supported process improvement. Usually the processes examined are for one segment of the industry, though overarching process models have also been mooted. Work on decision support, knowledge-based systems (KBS), and artificial intelligence (AI) in general, reflects construction IT researchers enthusiasm for the potential of AI techniques within the industry. Initial work was on expert systems (mostly for code checking), later papers cover newer AI techniques such as neural networks, case-based reasoning, distributed AI (e.g., agent-based systems) mostly being used for very specific domain problems (e.g., post occupancy evaluation of underground stations).

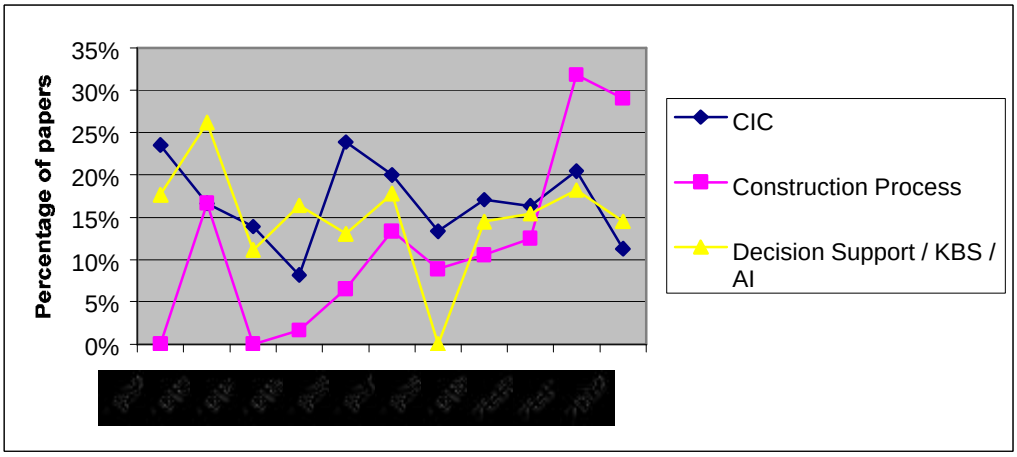

Fig.4: Major themes at W78 workshops

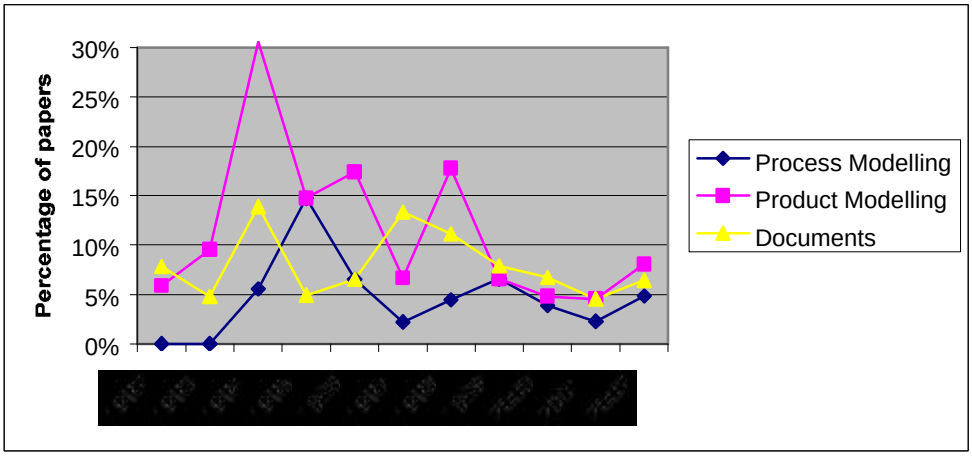

Fig 5: Technical themes at W78 workshops

often within the bounds of international standardisation efforts. It is interesting to note the continued presence of papers on documents within construction. Product models have not managed to usurp the place of documents and work currently presented is concerned with the appropriate handling of documents (albeit in electronic form) for a construction project. While technical themes are still important within W78 workshops there has been a trend to cover a wider set of issues and examine overarching perspectives on Construction IT.

W78 research has included a small number of review topics, which are canvassed periodically at workshops. Figure 6 shows the periodic occurrence of papers on national strategies for Construction IT (including national surveys on Construction IT usage) and on computerised standards encoding and delivery. The periodic reviews of national strategies have been beneficial in benchmarking the evolving usage of IT within the construction industries. Comparisons with these benchmarks have been useful at national levels to highlight the disparity in approach and support between different contexts (e.g., within Europe, or between Australasia and Europe).

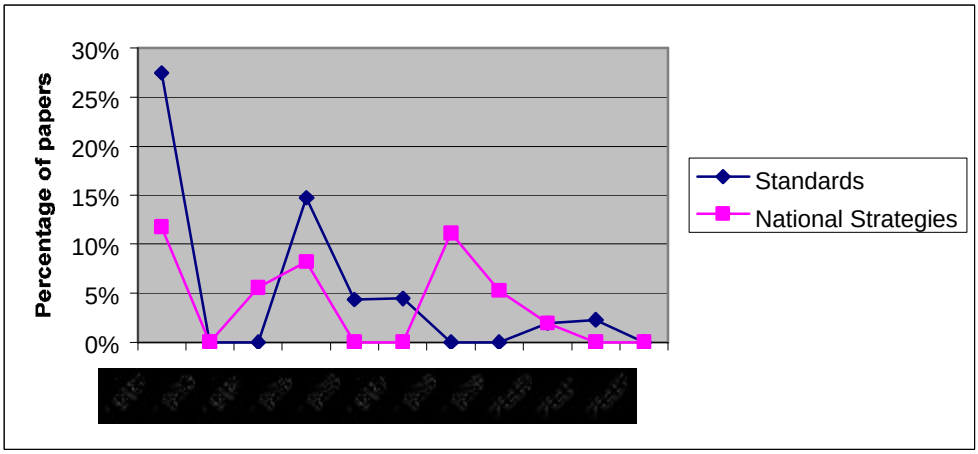

Fig. 6: Cyclic topics at W78 workshops

There is a range of topics where there are only a small number of researchers working and presenting. This tends to give bursts of activity in the topic as is illustrated in Figure 7. Reports on classification systems (national and transnational) and classification development frameworks appear in small numbers, though fairly regularly. Work on provision of multiple views and mapping between views has identified different approaches and the scope of the problem, but never gained wide interest or fully addressed the issue.

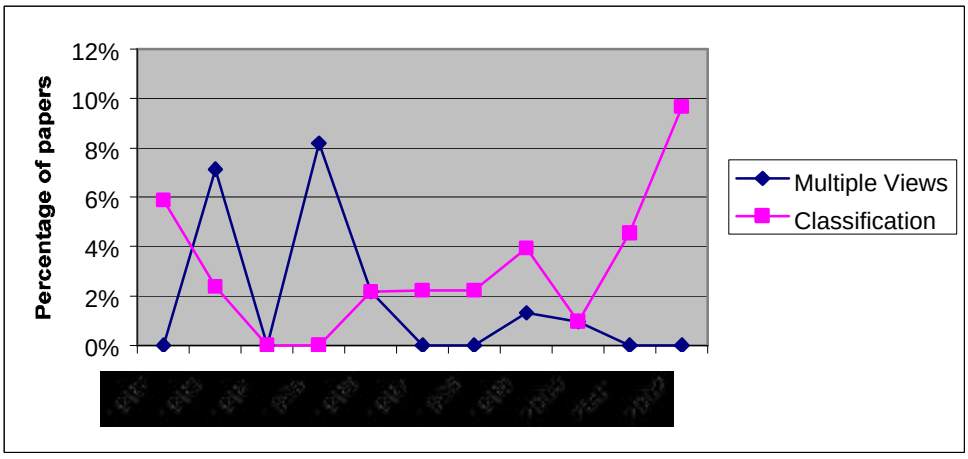

Fig. 7:Recurring topics at W78 workshops

Alongside these major themes there has been a suite of technical themes, which are constantly addressed. Figure 5 shows papers in product and process models and modelling as well as documentation and information management. Earlier workshops discussed techniques and strategies for product and process modelling before moving more towards papers looking at the development of models for specific areas,

Within this period it is interesting to note the changes in approach and favour of international standardisation efforts. Figure 8 shows a fairly constant stream of papers regarding the progress of ISO-STEP standards for construction, which is displaced by the recently formed, and fairly universally supported, IAI initiative. Note that while several papers in the 2000 and 2001 workshops described projects utilising the IAI's IFCs, none of them were primarily on the IFC standard and its evolution. The impression is of a fairly broad acceptance of the IFC standards across construction IT projects, with a few groups still working with the ISO-STEP standards, which have been more formally ratified.

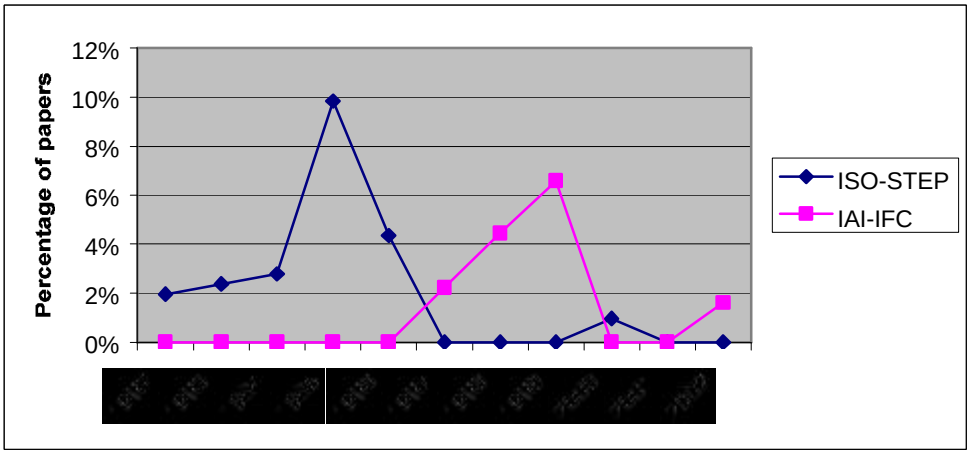

Fig.8: Changing times at W78 workshops

Research results presented in W78 have reflected, and mirrored in popularity, the wider issues being confronted in the IT world. Figure 9 shows the demise of papers tackling the issue of object-oriented (OO) representations of construction information, or the application of OO to system development, which is now an established and widely recognised technique within the industry. Interestingly, the applicability of VR to construction was reviewed in 1992, but it is not until 1996 that we see research and applications in the use of VR becoming evident. The impact of the Internet and its potential for construction industries was noted in 1995 and has elicited an increasing stream of research since then, reflecting the continued interest in the Internet within all domains. This might be seen as evidence of an increasingly strong complementary innovation approach within our research.

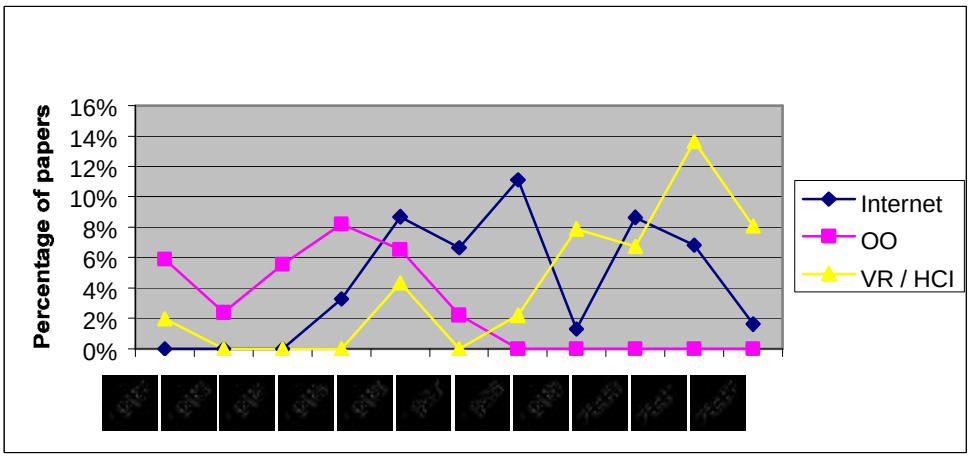

Fig.9: Old and new topics at W78 workshops

It is difficult to draw hard conclusions from this review of papers over the past ten years of W78 workshops given the small population of papers to work from. However, an overall trend appears to be a move from addressing a range of narrow technical issues to a wider consideration of IT and its impact on the construction industry and its working methods. Technical papers are still in evidence and they cover an increasingly wide range of topics, often mirroring major technology thrusts and breakthrough areas from the general complementary IT arena. We have fewer bespoke experimentations with discrete and distinct technologies. There is a general pattern of mature exploration of integrated technologies and a wider set of technological, human, process and organisational issues associated with their implementation.

This is an extrapolatory view of the implicit and emerging vision that is underlying our research to date. It is a future agenda that emerges from this historical, bibliometric and incremental view and project work within W78.

4. A VISION FOR THE FUTURE ARISING FROM THE WORK OF W78

As we can see from the review of key issues arising from past meetings of the group, research in IT for construction has typically embraced a number of discrete research challenges of a technological and managerial nature, together with issues of application and implementation, and relationships to construction process and product performance.

As technologies and the research approach develops in this area, the implicit vision that underlies the overall research approach becomes more evident. This vision is not fully shared by all the research reported and many points of detail within it would be disputed and have been debated by opposing groups. Differences in visions have led to alternative paradigms that have driven elements of the research presented. As we look forward, there would not be a single shared vision of the nature of construction process and product delivery that all future research would relate to. However, for the benefit of making our respective implicit visions more visible, it is possible to construct scenarios of the future to which our ongoing research efforts may relate. This section of the paper seeks to do that by reporting on an attempt to define a vision arising out of past work by Construct IT in the UK and allowing this to be influenced by the review work from earlier sections of this paper. Other work reported within the group has attempted to define scenarios or visions for the future of how IT might impact on construction processes and products. The works of Froese et al (2001), Walker and Betts (1998) and Waugh et al (1996) are examples.

The Construct IT vision has been drawn from extensive literature review and exposure to industry innovation in the field. It is more completely documented and described in Sarshar et al (2000). It can be depicted in summary form as in Figure 10 below.

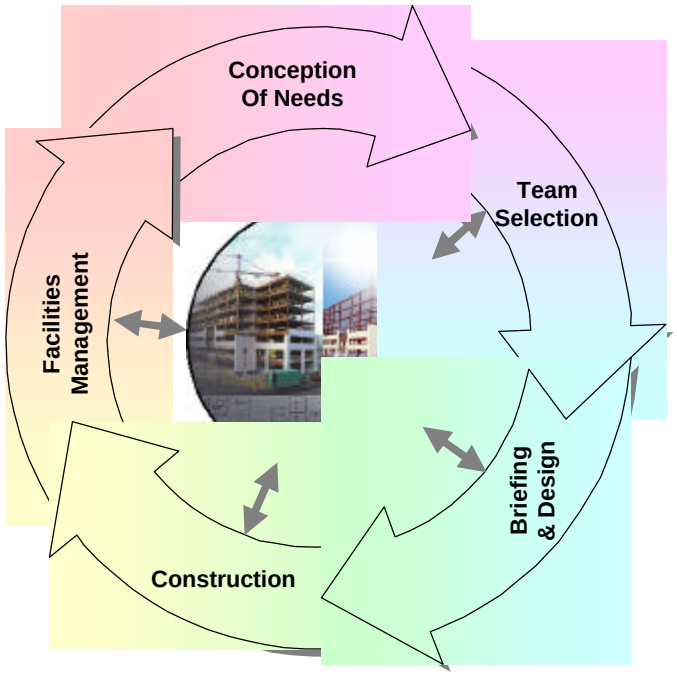

Fig.10: An IT-Enabled Future Construction Process

It contains seven key themes of how further developments in IT may enable projects to be executed differently in the future. These themes are:

- *Product and Process Model driven as opposed to document driven information management on projects:* Currently, construction project information is captured in documents. The construction parties may share these documents using the electronic environment, but problems arise as the volume of documents and their versions increase. The model driven approach is a means of sharing project information via a shared conceptual product / process model. Product and Process Model driven construction does not imply a large unique database, but it implies a shared conceptual model, which is implemented in different applications.
- *Life-cycle thinking and seamless transition of information and processes between life-cycle phases:* In current construction projects there is a little communication and knowledge sharing between the project life-cycle phases. IT is the major element that allows seamless information sharing between the phases of the life-cycle. This underlies much of the past thinking towards CIC frameworks and is a key outcome of an OO approach.
- *Use of past knowledge (information) in new developments:* In construction, it is essential to rely on past project knowledge and information when dealing with new projects. The implication of this theme is that the industry will require strategic systems, which allows capturing of previous knowledge. The adoption of AI techniques are key to this theme.
- *Dramatic changes in procurement philosophies as a result of the Internet:* The increased use of the Internet opens new business opportunities for construction organisations such as 'Project Information Exchange', 'e-Trading' and 'e-Tendering'. In the new era, just-in-time procurement strategies will be more prevalent. This issue has been substantially triggered in our recent W78 work by the emergence of this key complementary innovation.
- *Improved communications in all life-cycle phases through visualisation:* Communication between the construction parties relies mainly on drawings and specifications. Visualisation, on the other hand, makes communications more effective and accessible. For more effective results, visualisation is best combined with a model driven (integrated) construction environment. Again, a key complementary innovation that has profoundly impacted our vision of the future.
- *Increased opportunities for simulation and what-if analysis:* Simulation is an important tool that helps the construction manager to analyse productivity measurement, risk analysis, resource allocation, site planning etc. Moreover, simulation in construction will improve feasibility, planning and scheduling.
- *Increased capabilities for change management and process improvement:* To achieve all the items above, construction organisations will need to implement fundamental structural changes to processes and organisational management as well as address issues of human resource development. A key aspect that arises from our technology trajectory having reached a more specific phase from which a basis is possible for change management and process improvement scenarios to be explored.

This forward-looking synthesis of a W78 vision of the future is the outcome of a second stream of synthesising W78 project work. This is very substantially inter-related and integral with our historical analysis.

5. MAJOR CURRENT THEMES

From the preceding analysis of past papers and the future synthesis of an IT vision, it is possible to identify three inter-related key current themes behind the work of W78 as a working commission. These are:

- The modelling of processes and products and the integration of this with visualisation and standardisation of information life-cycles;
- Issues associated with implementation, adoption and behaviour and the management of technology; and
- Reengineering of processes and the search for integrated supply chains.

These three themes were used as the basis for debate and discussion by the authors at a the conference of W78 in South Africa (Coetzee, 2001). With regard to each, it is possible to give an overview of the current

scope and issues, the current approaches being taken within research, and the future research challenges which we face.

5.1 Modelling of process and products integrated with visualisation and simulation of information life-cycles

This theme is concerned with the creation of a representation of buildings and projects which is easily communicated within a project. These developing representations must cover the requirements of industry professionals: across all the domains with their alternate viewpoints; across all countries with differing construction practices; across the enormous variety of building types; and across the diversity of project types. They must also cover the requirements of the wide range of design tools and CAD systems utilised in the industry. This includes physically-based representations for simulation as well as supporting visualisation, planning, consideration of alternates, etc. This requires a good understanding of current processes and methods of optimising them.

Product and process modelling paradigms are available and many models have been developed over the last decade for specific sub-processes. Currently, however, there is a strong thread arguing for the need for flexible and extensible models in contrast to the traditional product modelling approach. Flexible approaches include feature-based modelling, intelligent templates, and type-extensible systems. The supporting arguments for these approaches are around the need for: flexibility, variable information requirements, and exploration of alternates. This contrasts with the low versatility, high complexity and incompleteness of current product models. Open questions seem to centre around how wide the requirement is for this approach in a project (e.g., is it purely for architects) and what do these flexible models mean for information transfer, especially as the semantics of the dynamically extended model are not defined.

Product and process modelling in its current form seems to have matured and be in fairly widespread use. Product and process models are developed within research projects as a matter of course (in previous years the actual development of these models would have constituted a research paper). However, recently there has been a noticeable lack of presentation on integrated models and integrated project databases with the preferred approach seemingly being to utilise bespoke translators for all possible mappings.

A noticeable trend is a shift away from formal semantics in projects. There are many calls for the use of flexible data models and, for example, the use of XML to help provide flexibility in information content. Alongside the call for flexibility, this highlights a need to handle and live with inconsistency of information and models across the life of a project.

The future of this area appears to be open. New paradigms for modelling, and flexible and dynamic models, are being mooted to address inadequacies of current approaches. The range of impacts that these paradigms will have on the industry, their processes, and the tools they use, will take some time to determine.

5.2 Implementation, adoption, behaviour and the management of technology

This theme is concerned with transferring research results and demonstrating the benefits of research and technology by continuously improving the processes of implementing the results of research and the adoption of new technology by industry. Issues under consideration at the 2001 conference included the definition of value propositions to enhance the transfer of technology, the behaviour of people when confronted with new information technologies, education and training as a means of transferring technology, defining the customer of research and defining the role of information technology as a means of building capacity in developing countries.

The conference concluded that to implement research, it is necessary to develop a structured partnership with a value proposition for both industry and firms. Researchers should consider the following issues when developing a value proposition.

- Defining the customer of the research: It is clear that information technology in construction covers a wide range of technology, process and social issues. It is also concerned with the range of customers that benefit from research. Customers may include multi-national firms with a high-end technological infrastructure base, small-specialised firms and even small artisan firms. The customers may come from developing countries with economies in transition, each with a different socio-economic background but with similar technology and process needs.

- Demonstration projects and case studies: These can play a strong role in developing an understanding of the use of IT in construction. How can W78, through projects and case studies, demonstrate advances in technology and process improvements particularly in industry and through such a process create a base to add value to industry.

- Recognition of good practice: IT benchmarks are quite common and several countries have participated in such benchmarks. Consideration should be given to the development of a structured process for such benchmarks and of recognising good practice. Such a process could be used to promote the take-up of information technology.

- Moving beyond the technology: At its core, W78 will always be dealing with issues of technology. However, when implementing research, it needs to move beyond the technology and consider extending its role to measuring the benefits of information technology and associated process improvement, and developing an understanding of the human issues and the social architecture. Developing the "information technology in construction" knowledge base to include issues beyond the technology itself may add significant value to the work of W78.

- Developing capacity and transferring the knowledge and technology: Education and training are still the most successful means of knowledge and technology transfer, particularly to technologically advanced companies in developed countries. Smaller companies may have a greater need for the knowledge and technology, but cannot afford it.

Developing countries are quite often in need of the knowledge and capability that is available in groups such as W78, but are confronted by a lack of access to such knowledge and affordability constraints. Investigating the needs of developing countries pertaining to the work of W78 in developing countries can form the base for future collaborative projects to incorporate the research needs and develop a value proposition for developing countries.

5.3 Reengineering of processes and integrated supply chains

The scope of this theme includes integrated supply chain management in which some of the key issues are business related as much as they are technology related. There is a strong issue of combining the perspectives of technology, process and people within the focus of supply chain integration and the need to consider supply chains within discrete projects and the multiple project, industry-wide, context.

IT support to project collaboration is a second key aspect of the scope of this theme and a key issue here is the tension between automating current collaborative practices and responding to, or driving, process change. A third theme of process and IT improvement and innovation is evident in issues concerned with fundamental redesign or continuous change and improvement. A final theme emerges from the rapid rise of e-commerce which introduces new technological challenges and widely ranging issues regarding business and process implications.

The current approaches to research within this theme include the documenting of case studies and the identification of barriers to implementation. There is a dilemma within our research as to whether a technology-driven or technology-enabled model of process change is assumed and a further key divergence between the relationship of research and practice. In some areas we can observe leading-edge practice to be far ahead of some of our research in this area whilst in the majority of situations, our research thinking is

far ahead. A key observation would be the relative lack of behavioural and people-oriented research given our understanding of the importance of this in effecting change.

The future research agenda in regard to this theme is clear in some instances and less apparent in others. The research issues with regard to e-commerce and the cultural concerns are not obvious to us. Compelling case studies of process change, methodologies for its implementation, and toolkits for doing so, would appear to be more obvious as research challenges.

6. CONCLUSIONS

CIB W78 is a mature group of international scholars concerned with IT for Construction who, for almost 20 years, have shared research progress, outcomes and challenges. Over that time considerable progress has been made in our understanding of how IT can support improved construction processes and products.

Different topics and issues have come and gone in terms of their relative importance. On the whole we have moved through a trajectory of bespoke experimentation. We have now settled on a dominant integrated paradigm. At the same time we have widely adopted and incorporated newly-emerging, complementary technological innovations. The result is a fairly consistent view of what we are trying to aim for in our research. From this platform we can construct a scenario or vision of how IT may enable future construction products and processes to be more competitively procured. One such vision is presented in this paper.

Research within this field is reaching a pivotal point in terms of its maturity. A much greater sense of shared understanding has developed of researchers within the discipline of what they have done and are doing in relation to each other. A greater sense of shared vision emerges in regard to future direction and remaining challenges and, as is argued within this paper, some clearer picture starts to emerge of the position we have reached with regard to some key themes. Our work has reached a more balanced and integrated mix of issues with regard to technology, process and people.

7. ACKNOWLEDGEMENTS

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