MANAGING KNOWLEDGE IN THE CONTEXT OF SUSTAINABLE CONSTRUCTION

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SUMMARY: *The 21st century has been a growing awareness of the importance of the sustainability agenda. Moreover for construction, it has become increasingly important as clients are pushing for a more sustainable product to complement their organisations' own strategic plans. Sustainable development can be defined as development that meets the needs of the present without compromising the ability of future generations to meet their needs. Sustainable construction is therefore seen as the application of sustainable practices to the activities of the construction sector. One of the key factors in making construction projects more sustainable is overcoming the obstacles of capturing and managing the knowledge required by project teams to effect such change. Managing this knowledge is key to the construction industry because of the unique characteristics of its projects, i.e. multi-disciplinary teams, dynamic participation of team members, heavy reliance on previous experiences/heuristics, the one-off nature of the projects, tight schedules, limited budget, etc. Initiatives within the industry and academic research are developing mechanisms and tools for managing knowledge in construction firms and projects. Such work has so far addressed the issues of capturing, storing, and transferring knowledge. Despite these efforts, there is still very limited understanding of the best ways to foster the creation of knowledge, less so on how to capture it, and even less on how to ensure that knowledge is readily available to individuals, project teams, and companies.*
This paper reports on work carried out as part of the C-SanD project (Creating, Sustaining and Disseminating Knowledge for Sustainable Construction: Tools, Methods and Architecture) conducted at Loughborough University. The project developed a "Sustainability Management Activity Zone" (SMAZ) that maps onto a generic construction process – provided by the Process Protocol method. The paper describes the development of the tool and supporting web portal implementation, evaluation and take-up in the project's industry partners.

KEYWORDS: *Information management, knowledge management, sustainability, construction process.*

1. INTRODUCTION

To attain the goals of sustainable construction requires the industry to intensify its efforts and move towards a knowledge intensive mode. Sustainability goals can only be achieved if construction activities are informed by new resources of knowledge and expertise. Some of this comes in the form of good practice, standards and enhanced process models, but much will have to come from situated and contextual appreciations of sustainability goals and local practices developed across organisational and professional boundaries. To achieve this requires the industry to focus on and achieve new modes of knowledge management, including embedded knowledge creation. This need for knowledge creation within a sustainability context is the main focus of the research reported in this paper.

Over the last decade, construction companies have invested heavily in the improvement of their business processes. New forms of innovative project management, supported by IT, appeared as a response to the ever-growing pressure from clients to deliver high quality facilities on time and on budget. Through this a new activity emerged from the process of managing projects and became a focus of interest: i.e. knowledge management. Despite this interest and the effort put into knowledge management by many leading companies, the discipline is still in its infancy. Many practitioners and researchers have acknowledged the limitations of current approaches and techniques to managing knowledge that relates to and arises from projects (McGee & Prusak, 1993; Laudon & Laudon, 1998; Asprey, 2004; Sor, 2004).

Experience shows that there are not only difficulties in capturing, storing, sharing and re-using all this knowledge in the construction sector, assuming that it exists, but much of it is never 'produced', since no mechanisms or processes exist to foster the social interaction required to give any shape or form to it. The main aim of the paper is therefore to describe the creation of tools that enable the development of organisational practices in the construction sector to promote knowledge creation, prior to sharing and re-use, along with the tools to support such a process. The knowledge domain that the paper will focus on is the promotion of sustainable development in the construction industry in areas that include, but do are not exclusive to the project, the minimisation of waste, materials recycling and energy conservation in the design, construction and operation of buildings. These were chosen as they were seen by the industry as areas that may provide the greatest benefit for the minimum input.

2. SUSTAINABLE DEVELOPMENT

There are many definitions of sustainable development. According to Sage (1998), sustainable development refers to the fulfilment of human needs through simultaneous socio-economic and technological progress and conservation of the earth's natural systems. Sustainable world progress is dependent upon continued economic, social, cultural, and technological progress. To achieve this, careful attention must also be paid to the preservation of the earth's natural resources. Sustainable development is a term generally associated with the achievement of increased techno-economic growth coupled with the preservation of the natural capital that is comprised of environmental and natural resources.

Sustainability requires the development of enlightened institutions and infrastructure and appropriate management of risks, uncertainties, and knowledge imperfections to assure intergenerational equity, intragenerational equity, and conservation of the ability of earth's natural systems to serve humankind (Sage, 1998). Chaharbaghi & Willis (1999) presented different perspectives of sustainable development, illustrated in FIG. 1, which shows different views of sustainable development from different professionals.

DETR (2000) argue that sustainable development is about ensuring a better quality of life for everyone, now and for generations to come, through:

- Social progress which recognises the needs of everyone;
- Effective protection of the environment;
- Prudent use of natural resources; and
- Maintenance of high and stable levels of economic growth and employment.

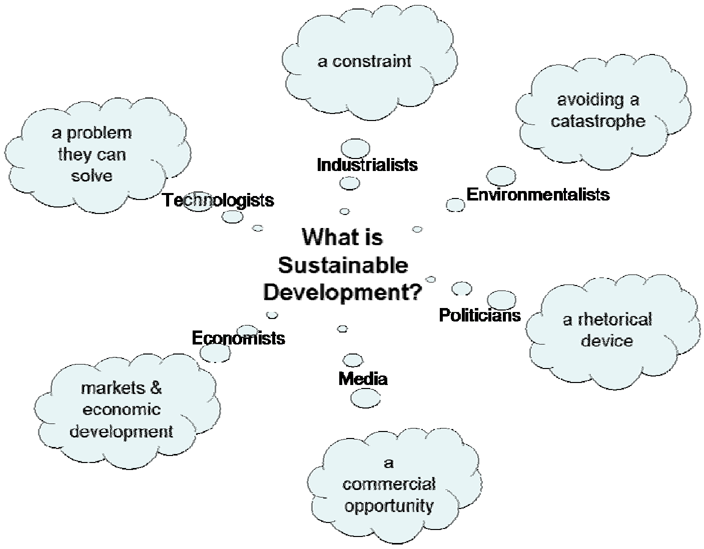

FIG. 1: Images of Sustainable Development (Chaharbaghi & Willis, 1999)

There is a more commonly used definition for sustainable development, which was formulated by the World Commission on Environment and Development (WCED), led by the Norwegian Prime Minister Gro Harlem Brundtland, in 1983. It states that "…*sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs*…" (Chaharbaghi & Willis, 1999). Sustainable development includes three broad components; social, environmental, and economic; often known as the 'triple bottom line', as shown in FIG. 2.

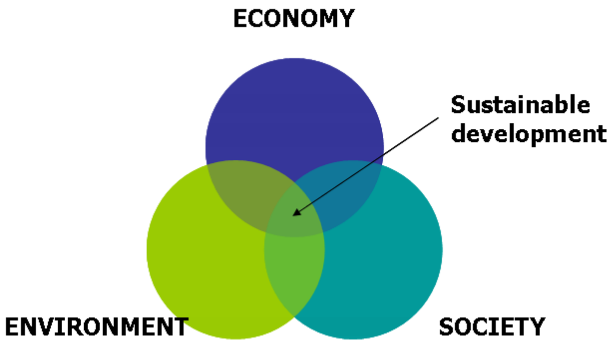

FIG. 2: Themes of sustainable development

Having determined the meaning of sustainable development, the next section focuses more on the application and consequences of sustainable development for the construction industry.

3. SUSTAINABLE CONSTRUCTION

Sustainable construction can be defined as a construction process which incorporates the basic themes of sustainable development (Parkin, 2000; Chaharbaghi & Willis, 1999; Sage, 1998). Such construction processes would thus bring environmental responsibility, social awareness, and economic profitability objectives to the fore in the built environment and facilities for the wider community (Langston & Ding, 2001; Miyatake, 1996; Raynsford, 2000; Chen & Chambers, 1999). The UK Government's strategy for more sustainable construction (DETR, 2000) suggests key factors for action by the construction industry by widening the basic themes. These include design for minimum waste; lean construction; minimise energy in construction and use; do not pollute; preserve and enhance biodiversity; conserve water resources; respect people and local environment; and set targets, monitor and report, in order to benchmark performance (Raynsford, 2000; Langston & Ding, 2001; Miyatake, 1996; Addis & Talbot, 2001; Ofori et al., 2000; Cole, 2000).

Construction has a significant effect on quality of life: its outputs alter the nature, function and appearance of the towns and countryside in which people live and work. The construction, use, repair, maintenance and demolition of such infrastructure consume resources and energy, and generate waste. Typically buildings use approx 50% of all UK energy produced; construction and demolition waste amounts to 17% of the UK total; and 2000 hectares of land per annum are taken for aggregate to be used in the construction process. The UK construction industry employs 1.5 million people, consisting of approx 8% of GDP. The amount of construction materials used annually is equivalent to 6 tonnes per head of population in the UK. The UK government has produced initiatives to champion sustainability within the construction industry to achieve sustainable development targets. Recent research programmes such as 'Partners in Innovation (PII)' (www.pii.org.uk) and others have been funded to support sustainability within the construction industry (Raynsford, 2000). The 'Government Construction Clients Panel' (consisting of representatives with responsibility for procurement for most government bodies) also has a target to achieve sustainability in each project. This enables the government to take a leading role, and showcase good practice in promoting sustainable construction (www.sustainable-development.gov.uk).

The construction industry is moving towards including sustainability aspects into its daily practices and associated processes. This has resulted in a number of construction sector specific sustainability strategies. The aim of such strategies is to develop a common understanding of the sustainability issues and present effective and targeted approaches for each stakeholder to contribute to achieving a more sustainable construction industry. Some of these specific stakeholders are civil engineers, brick and steel manufacturers, building services engineers, cement and concrete manufacturers, etc (www.dti.gov.uk/sustainability; www.brick.org.uk; www.steel-sci.org).

The experiences from some leading construction companies have shown that there are strong business benefits for more sustainable construction (WS Atkins, 2001). This is also demonstrated through recent research carried out by Sustainable Construction Task Group (http://projects.bre.co.uk/rrr/), which concluded that there are clear advantages to be gained, but only if sustainability is part of a long-term business plan. This is reinforced by the Building Research Establishment, where research has concluded that "…*being sustainable is as much about efficient profit-orientated practice and value for money as it is about helping the environment*…" (BRE Report, 2002). Such results have given the construction industry an improved awareness of sustainability issues. In 1999, around 150 quality of life indicators were produced to improve the well-being of UK citizens (Audit Commission, 2002). The industry has begun to recognise that monitoring and reporting on sustainability is a vital part of their business. Key Performance Indicators, Environmental Performance Indicators, and the adoption of benchmarking have become increasingly common place, and many companies are now producing environmental and sustainability reports, with corporate social responsibility becoming common practice (www.cbpp.org.uk/cbpp; www.ciria.org.uk; www.m4i.org.uk/m4i/).

4. KNOWLEDGE MANAGEMENT

Knowledge management is a broad and expanding topic (Scarbrough *et al.* 1999). In reviewing the theory and literature of this field many approaches to knowledge management have been identified and categorised in various ways (Carrillo et al. 2004, Udeaja et al., 2004, Anumba & Khan, 2003, Khalfan et al. 2003, Alavi & Leidner 2001, Earl 2001, McAdam & McCreedy 1999, Schultze, 1998). Schultze (1998) engages Burrell & Morgan's (1979) framework in order to identify a two fold typology of knowledge within the debate of knowledge management; objectivist and subjectivist. An objectivist approach views knowledge as an object to be discovered (Hedlund, 1994). In contrast, a subjectivist approach suggests knowledge is inherently identified and linked to human experience and the social practice of knowing, as seen for example in the work of (Tenkasi & Boland, 1996) and (Brown & Duguid, 1998).

The approach taken by Demarest (1997) argues that knowledge is embedded within the organisation not just through individual actors or explicit programmes, but also through social interchange. This, however, still tends to suggest that knowledge is an object that can be embedded and distributed rather than as a change in the perceptions of individual actors who can institute practices that embody and perpetuate their increased understanding.

In relating knowledge management to the construction sector it is important that construction professionals give meanings to fragments of speech or writing that are impenetrable to outsiders for reasons that go beyond a lack of understanding of technical terminology. It is the apprenticeship and induction process of becoming a services engineer or an architect that enables an increasing ability to translate communications into appropriated knowledge, rather than a received instruction. Being a services engineer or an architect means not just having a qualification but more it means being a respected member of a community where judgements are regarded as knowledgeable by others. In this way Dreyfus (2001) describes the process of developing mastery and practical wisdom in a field and the possibilities and limitations of ICTs in enabling such a knowledge process, while Prusak & Cohen (2001) explore this at an organisational level and describe the ability to share understandings as the social capital of a firm.

4.1. Knowledge and Information and Communication Technologies (ICTs)

Many authors argue that improvements in the way knowledge is created and applied cannot be sought through technology alone (Anumba, 2003, Bhatt, 2001; Davenport & Prusak, 1998; McDermott, 1999). However, technological development and innovation still remain central to the research described in this paper. Furthermore, there are examples of the construction industry employing ICTs extensively for information work; ISDN networking, CAD, project management applications and office tools are becoming the standard. Large firms in the construction sector have invested heavily in intranets, and a few more recently (project) extranets – W.S. Atkins's IPRONET for example, as a key informational resource. However, the majority of the construction industry is composed of small specialist firms, and their technology platforms may be at best modest. For the purposes of this paper it is prudent to ask what role ICTs have in supporting knowledge work (Alavi & Leidner, 2001; Bacon & Fitzgerald, 1999), and in the creation, dissemination and application of knowledge within and between organisations.

Initial approaches to employing ICT within knowledge management attempted to marry the capabilities of technology with the generic features of knowledge management, for example considering the Internet as a knowledge repository (Davenport & Prusak, 1998). Other approaches have attempted to 'map' the knowledge existent within an organisation, devising pictures of communication which may be translated (in whole or in part) into ICT solutions (Vail, 1999). But as Hendricks (2001) notes "*…no ICT application deserves the label of a knowledge management tool purely because of its own characteristics. It is essential when valuing ICT applications as knowledge management tools to consider the situation in which they are used…*".

Further criticism of ICT-driven knowledge management approaches preface the objectivist approach to knowledge while ignoring the subjectivist dimension (Blackler, 1995; Hendriks, 2001; Tsoukas, 1996). In contrast to such approaches, these authors argue that for the development of effective knowledge management systems there is a need to build an understanding of the knowledge environment and context, i.e. "*…knowledge is analysed as an active process that is mediated, situated, provisional, pragmatic and contested. The approach suggests that attention should be focused on the systems through which people achieve their knowledge and on the processes through which new knowledge may be generated*." (Blackler, 1995)

Responding to Blackler's call, some authors have conceptualised such systems not as instrumental artefacts but as purposeful human activity systems. Rather than focusing on ICTs as driven by a concern for what people know (or want to know), which in any case proves elusive to describe (Nonaka & Takeuchi, 1995), the research reported on in this paper adopted an approach which focuses on what people do (Blackler *et al.*, 1993).

Having discussed the issues of sustainability and its relationship with the construction process, knowledge management and ICTs used for projects, the next section describes the research in the C-SanD project that aims to address the complexities of the relationships, and develop tools to manage such relationships.

5. THE CREATING, SUSTAINING AND DISSEMINATING KNOWLEDGE FOR SUSTAINABLE CONSTRUCTION: TOOLS, METHODS AND ARCHITECTURES (C-SAND) PROJECT

5.1. Background

Despite the interest and the effort put into KM by many leading companies, the discipline is still in its infancy. Many practitioners and researchers have acknowledged the limitations of current approaches to managing knowledge in relation to and arising from a construction project (Venters *et. al.*, 2002). Among the key reasons for these limitations are:

- Much construction knowledge, of necessity, resides in the minds of the individuals working within the domain;

- The intent behind decisions is often not recorded or documented. It requires complex processes to track and record the thousands of ad-hoc messages, phone calls, memos, and conversations that comprise much of the project-related information;
- Data is captured during a project and archived at the end of a project; this is necessary but not sufficient for knowledge systems. Knowledge is created by people actively reflecting on the events represented by the project data. The knowledge gained is often poorly organised and buried in details, and there are seldom processes in place for the required reflection. Hence, it becomes difficult to compile and disseminate useful knowledge to other projects;
- People frequently move from one project to another, so it is difficult to track the people who were involved in a recorded decision and who understand the context of making the decision and its implementation; and
- New approaches to the management of knowledge within and between firms imply major changes in individual roles and organizational processes. While the potential gains are desirable, the necessary changes are resisted.

Experiences have shown difficulties in capturing, storing, sharing and re-using all the information and knowledge relating to and arising from a construction project, assuming that it exists, but much of it is never 'produced', since no mechanisms or processes exist to foster the social interaction required to give any shape or form to it. The main focus of the C-SanD project was to develop practices in the construction sector that promoted knowledge creation, prior to sharing and re-use, along with the tools to support such a process. The knowledge domain that the work focused on was the promotion of sustainable development in the construction industry in areas such as the minimisation of waste, materials recycling and energy conservation in the design, construction and operation of buildings (http://www.c-sand.org.uk/).

5.2. Project Aim and Objectives

The aim of the C-SanD project was to foster practices in the construction industry which enabled knowledge creation for subsequent sharing and re-use, and promote sustainable development. Incremental development and implementation of knowledge management tools was carried out using a 'bottom up' soft systems methodology (SSM). This intended to support situated, contextual knowledge creation processes. The aim translated into the following associated objectives.

- An analysis of knowledge creation practices of two of C-SanD industrial partners, model the project and organisational knowledge of two construction projects, and document good and bad practice in knowledge sharing within and between partners and projects;
- The specification of a model-based infrastructure (including a dedicated set of services packaged in the form of an application programme interface (API)) that supports the creation and sharing of project and organisational knowledge, concentrating on sustainability knowledge in particular;
- Development of a framework that facilitates the processes of knowledge creation and re-use at project and organisational level with a focus on sustainability in design and construction;
- Development of "low entry level" tools (affordable and with high usability so that a small company can join larger firms) to create, capture, and re-use project knowledge to promote sustainable development; and
- Implement and evaluate tools in a real life projects to produce recommendations of adopting the proposed approach.

5.3. Methodology

The primary focus of the project was knowledge creation (KC), the potential means by which project experience, organisational practices, environmental influences and imperatives, formal and informal skill sets come together (through technical, organisational and social modalities) to produce new resources of knowledge upon which industry participants can draw. In such an approach knowledge was not seen as a 'raw material' just requiring refinement and packaging prior to distribution, but as requiring its own 'production processes' drawing together different streams of experiences and skills within the different but interconnected modalities.

The project was based on extensive field research and used the following methodology:

- A continuous review of the academic, industrial and web-based literature to maintain an awareness of current developments;

- The collection of case studies of knowledge creation within the collaborating companies, using observation and questionnaires, supplemented with semi-structured interviews;
- Adopting a prototyping approach to the development of the Knowledge Infrastructure Models; and
- Employing an iterative user-and expert-based evaluation of the model and its support tools.

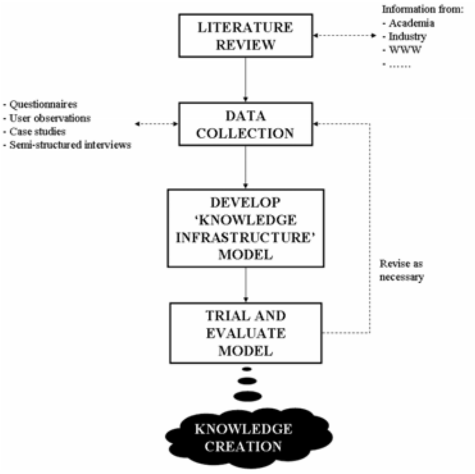

FIG. 3: C-SanD research methodology

The project methodology was based on a combination of Soft Systems Methodology (SSM) for organisational analysis; and incremental and iterative Object Oriented (Unified Modelling Language – UML) modelling for technical components. For the social and organisational aspects, the research drew on contextually rich modelling techniques including Checkland's Mode 2 SSM (Checkland, 1981) with its emphasis on a stream of cultural analysis, involving reflection on the social system, the political system and the intervention itself. The SSM approach provided a framework for integrating and reconciling diverse views on issues as complex as sustainability by enabling the generation and exploration of multiple root definitions of the issues. This mitigated the risk of building a system which was robust in its own terms but did not align to the ways of working in the firm and/or the industry. This was complemented by incremental and iterative based Object Oriented (UML) modelling for technical components. UML, and in particular the application of 'use-cases' and 'object sequence' diagrams, allowed an approach to the building of a knowledge system which was driven by user needs, user roles (actors) and understandings of the users' issues identified through the SSM analysis.

5.4. Initial findings

The project began by interviewing senior management within the collaborating industrial organisations. The first stage of the field work consisted of 16 interviews within ten organisations undertaken by four researchers from three universities. A SSM approach was adopted by the researchers and rich pictures (or scenarios) were produced. These multiple rich pictures represented overlapping and contrasting concepts and presented such richness that it was impossible to gain a satisfactory overall picture. Therefore, the Oval Mapping Technique from Eden & Ackermann (1998) was adopted, which enhanced interaction and promoted further discussion. The discussion resulted in nine clusters being created, each including between four and seventeen concepts. These clusters were then used to identify issues that were modelled through one or more CATWOEs (Customers, Actors, Transformation, Worldview, Owner, and Environmental constraints) and through root definitions (that express the core purpose of a purposeful activity system) as defined in SSM (Checkland, 1981; Checkland & Scholes, 1990).

The participating companies described different individual and organisational perceptions and definitions of sustainability. The most common concepts were: linking sustainability with environmental issues, inter-connected nature of sustainability with value engineering and knowledge management, and energy efficiency. There was a consensus that all construction activities damage the environment, leading to the need to limit this damage, not only to the environment, but also the society and economy. Another common question which arose from the interview analysis was, "…*at what stage should sustainability be considered?...*". Results from the interviews suggested that sustainability should be built-in within a project and should not be a bolt-on. However, how this might be achieved was another question raised.

Analysis of the interview results revealed that often sustainability aims were in conflict with each other. One such conflict is that sustainability sometimes requires costly innovation that conflicts with limited budgets, and hence limits a client's motivation towards sustainable construction is reduced. Other issues highlighted included reducing waste on construction sites – this may be achieved through off-site construction; project de-commissioning; management of sustainability knowledge i.e. its creation, transfer, use, storage, etc.; and weakness of Whole Life Cost (WLC) models (that can demonstrate long term benefits of sustainability) which result in giving priority to capital cost over operational cost.

Interviewees highlighted a number of requirements that need to address to enable the promotion of sustainable construction. Significant requirements suggested include:

- The introduction of sustainability into the design process to encourage sustainable behaviour by clients and end users;
- Incorporating sustainability processes into construction projects that demonstrate significant advantages to businesses on their day-to-day work, in terms of time and cost; and
- Use sustainability criteria for the selection of subcontractors, materials, etc.

Drivers and enablers of sustainable construction were also discussed. Client and community awareness were the most significant drivers identified by the participating construction firms. Motivated clients can steer the industry to deliver sustainable construction projects and the clients' interest could be improved with the help of new tools and techniques that demonstrate the benefits of sustainable construction. On the other hand, the industry needs guidance from the Government in the form of regulations and legislation, which would drive the industry towards sustainability. Another driver for sustainability is the use of new procurement methods such as Private Finance Initiative (PFI), Design, Build & Operate, etc., in which the developer is responsible for maintaining the facility for 25 to 50 years, resulting in the realisation of a low operational cost that can be achieved through sustainable construction. Increased competitiveness through labels such as 'Green Firm' or having 'FTSE4Good' badges are also major drivers towards sustainable construction. Some of the clients and contractors have been using sustainability as a marketing tool for their companies to win more projects.

One of the important issues identified in the interviews was the need for a means to integrate sustainability within the whole life cycle of a building from design through construction to operation. To respond to this, the C-SanD project mapped sustainability issues onto a generic project process (Process Protocol) to identify actions needed at different stages of the building lifecycle so that sustainable goals may be achieved. This mapping is described in the next section.

6. A FRAMEWORK FOR SUSTAINABLE CONSTRUCTION

The aim of the framework for sustainable construction was to bring an awareness of sustainability issues in construction processes at the project level. This was achieved by developing the SMAZ (Sustainability Management Activity Zone) tool. The tool mapped sustainability activities as a management area on the Process Protocol map. This could then potentially drive all construction projects towards sustainable construction practices.

6.1. The Need

Although indicators have been previously identified, checklists have been prepared, and assessments have been carried out in order to check sustainability (Brownhill & Rao, 2002; BRE, 2002; Guy And Kibert, 1998; Ove Arup, 2002; M4I, 2000), they do not provide for a structured, phase by phase activity map for construction processes from inception to maintenance, that can guide the industry to use such indicators and checklists in a more effective manner to achieve its sustainability goals. Such a need was identified as very important in the first round of interviews in the C-SanD project.

The same need was also identified as an important aspect in improving sustainability by the engineers working on the project called 'The Engineer of the 21st Century' Inquiry, facilitated by The Forum for the Future in the UK. It was also documented as one of four change challenges in a recent report 'Change Challenges for Sustainability' by the Forum (Bennett & Crudgington, 2003).

6.2. The Process Protocol

The Process Protocol is a generic process map for design and construction. Its basic purpose is to provide a framework for the management of processes on any given construction project. It is essentially a common set of definitions, documentation and procedures that provides the basis for the wide range of organisations involved in a construction project to work together seamlessly. It uses manufacturing experience as a reference point and maps the entire project process from the client's recognition of a new or emerging need through to operations and maintenance of the finished product (Cooper et al., 2004; Lee et al., 2000).

The design and construction process was mapped into eight sub-processes (Activity Zones); Development, Project, Resource, Design, Production, Facilities, Health & Safety, Statutory and Legal, and Process Management; four broad stages, as in Pre-Project, Pre-Construction, Construction and Post-Construction; and ten more detailed phases. These phases reflect the different phases of a typical construction project: Demonstrating the Need; Conception of Need; Outline Feasibility; Substantive Feasibility Study and Outline Financial Authority; Outline Conceptual Design; Full Conceptual Design; Coordinated Design, Procurement, and Full Financial Authority; Production Information; Construction; and Operation and Maintenance. Some of the potential advantages of adopting the Process Protocol as the industry standard are (Cooper et al., 2004; Lee et al., 2000) that it:

- Provides a whole project view;
- Recognises the interdependency of activities throughout the whole project;
- Focuses on the identification, definition, and evaluation of client's requirements;
- Enables co-ordination of the participants and activities in construction projects and identifies the parties responsible and their responsibilities;
- Encourages the establishment of multi-functional teams; and
- Encourages a team environment, and appropriate and timely communication and decision making.

These advantages were the main driver for developing SMAZ as part of the Process Protocol.

6.3. Development of SMAZ

SMAZ was developed first in the form of a table (Khalfan *et. al.*, 2003) and then further refined into an activity zone within the Process Protocol. The final version of SMAZ was achieved as a result of: a comprehensive literature review; the analysis of two rounds of interviews; participating in live project meetings of industrial partners; a review of available sustainability checklists, indicators and assessment tools; in-house workshops with the C-SanD project team; and the validation of iterations with 20 construction related organisations.

The in-house workshops were one of the milestones in the development of SMAZ. Once developed, it was validated within the construction industry to check its relevance, practicality, and use. Organisations such as local councils, consultants, contractors, took part in the validation process. The validation was conducted in two stages: the first stage involved half of the organisations and resulted in an interim version of SMAZ; the second stage involved the other half for more refinements. The selection of organisations was not targeted, except for the project's industrial partners.

6.4. Characteristics of SMAZ

SMAZ was developed in a similar format to the other activities within the Process Protocol, i.e. a set of first and second level activities. (see FIG. 4, Fig. 5). Each phase of the Process Protocol contains one or more activities within the SMAZ tool. A description for the SMAZ tool defines the aim of the zone, deliverables, etc. The first level activities are generic with more specific tasks defined in the second level activities. See Fig. 3 for an example of first level activities, and Fig. 4 for the second level activities.

FIG. 4: Process Protocol showing the additional SMAZ tool.

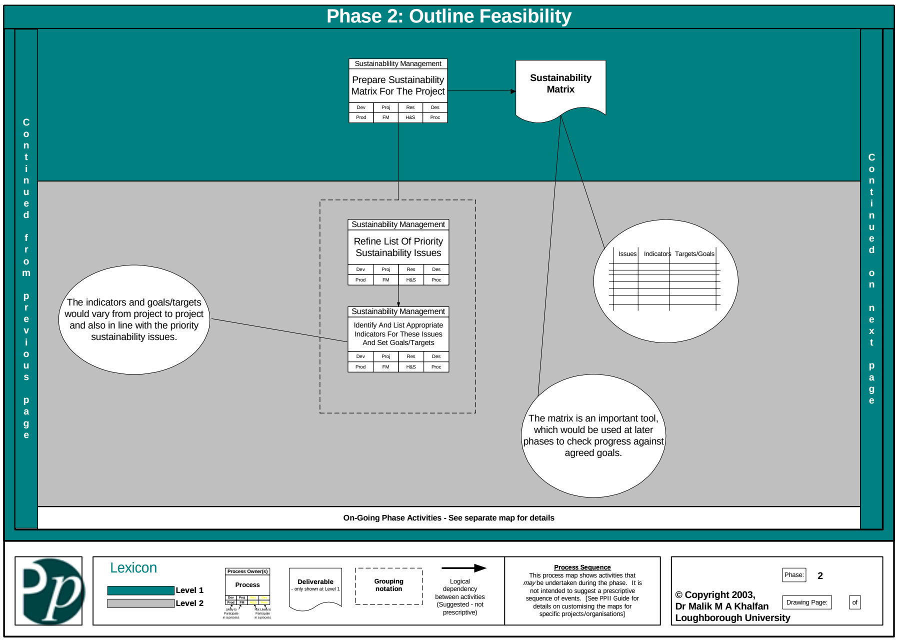

FIG. 5: An example of first level and second level activities of SMAZ (phase 2)

The availability of the SMAZ tool on the internet from the C-SanD project website (www.c-sand.org.uk) provided (and still provides) stakeholders from industry and experts from academia the opportunity to try it on different projects. The development of the SMAZ tool was carried out in such a way that it can be used with or without the Process Protocol. Although it was prepared to be integrated with the Process Protocol, its activities have also been structured in line with the RIBA Plan of Work used in the UK, and also with the more generic design and construction phases (which includes pre-project, design, construction, and post-construction phases) including the BREEAM tool designed specifically with the sustainability agenda in mind. This attribute has made the SMAZ tool generic, such that it can be used worldwide with the possibility of being adopted into any design and construction process framework.

6.5. Using SMAZ

The following are considerations which should be kept in mind whilst using the SMAZ tool:

- The SMAZ tool is specifically developed for use at construction project level, but some of its activities could be translated for use at the organisation level;
- The construction project team needs to be practical in its vision while identifying the issues, indicators and targets in the early phases;
- The targets set during the initial phases should be ‘SMART’ targets, i.e. Specific, Measurable, Achievable, Realistic, Time-bound.
- The SMAZ tool can also be used for demolition or refurbishment projects.
- The mission statement, sustainability matrix, checklist, strategy, etc. could be part of a sustainability plan, which could be documented into the project brief, and/or the project development plan.

The SMAZ tool is very simple to use, but requires one person (manager/champion/consultant) to oversee its implementation throughout the whole project.

7. C-SAND PORTAL

A part of the stated aim of the C-SanD project was to provide tools for knowledge management, specifically in the field of sustainability and its relationship with the construction industry. To achieve this it was necessary to integrate many information sources and potentially any number of third party tools into a single unified application. This meant that the first technical goal was to design and implement an ‘integration platform’ that could later be employed to access tools and subsequently information identified as useful for sustainable construction.

In the design of such a platform, there were two broad requirements identified:

1. Disparate sources and formats of information need to be represented in a uniform fashion through tools.
2. Different tools from different places were implemented in different languages and used different communication protocols.

The first requirement could be achieved by creating an abstraction mechanism that represents the salient points/meaning of a resource in a standard format. To this end a Knowledge Representation (KR) was designed. A KR is an object that has a small set of static properties and the facility to ‘take-on’ any number of dynamic properties defined arbitrarily to describe a particular resource to which the KR refers. Dynamic properties are defined in an XML schema and read in at runtime to produce templates for KR’s of different types.

The second was achieved through the integration of tools into the C-SanD platform. These tools included a neutral interface description and message protocol to avoid having to program custom components for each tool. Fortunately, the evolving standards in the Web Services arena provided such a set of interface descriptions and protocol languages that are being widely adopted by many organisations around the world. It was decided to use Web Services as the model of choice for integrating tools into the C-SanD platform.

FIG. 6 shows a high level view of the overall architecture of the C-SanD platform arranged into three principal layers. Central to the operation of the whole platform is the Kernel layer, which contains logic to create and manipulate KR instances and communicate with external services via Web Services protocols. This layer also comprises a number of inbuilt components for searching the set of known KR instances, disseminating notifications of change to KR instances or flagging general items of interest, building user profiles and managing the set of services available through the platform.

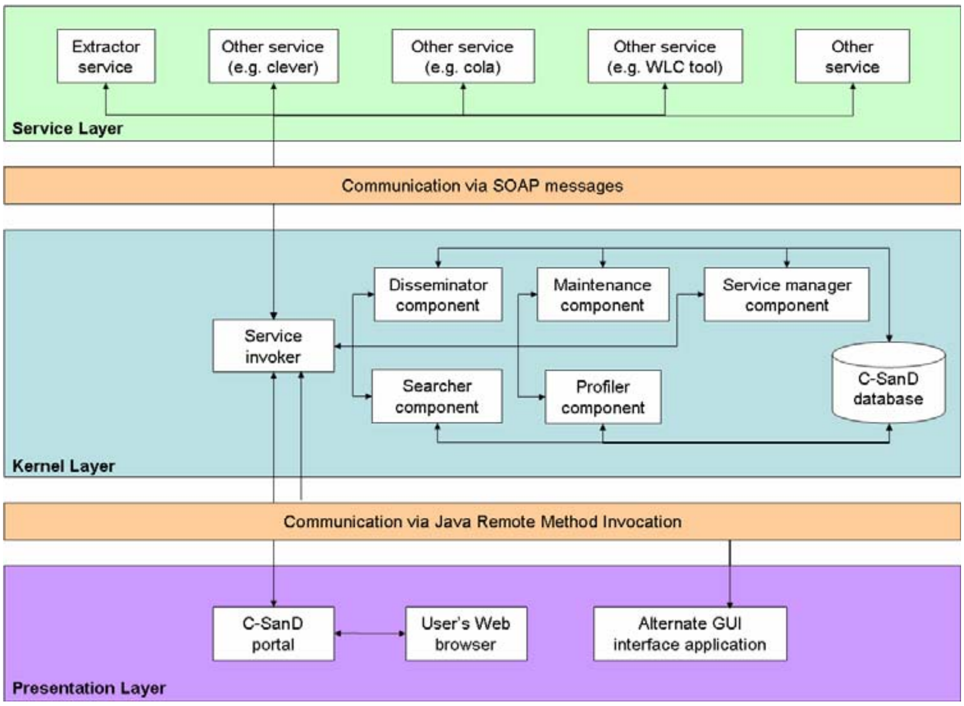

FIG. 6: The C-SanD portal system architecture

The Service layer is where external tools exist and as such its constituents are currently largely undefined. The one component identified for this layer is the Extractor Service. This is a service that is used to retrieve as much information as possible from a given resource such that it may build a KR to represent it. C-SanD currently has an implementation of this service that can extract metadata and summary information from a number of common office and Internet document formats.

Finally, the Presentation layer is designed as the user's view of the platform contents and functionality. A version implemented as a Web portal using Java Server Pages accessible via a Web browser was developed. It was decided to implement a separate presentation layer so that any number of different presentation layers for different client devices and delivery styles may be developed. For example, it may be desirable to access C-SanD functionality from an application such as AutoCAD™. In this instance a custom extension to AutoCAD™ would act as the presentation layer for C-SanD and integrate it seamlessly into the application environment.

8. FIELD TESTS AND USER TRIALS

The system deployment and evaluation followed a three stage process. The first 'Pre-population of the portal' aimed to pre-populate the portal with C-SanD relevant data. In its raw state the portal does not encapsulate any knowledge about sustainability. If the tool was to be useful, it needed some structure of understanding. The portal works both by searching through previously retrieved results and also by going out onto the web (or into corporate data stores) – 'spidering'. The first spiders were not very instructive as there was little to direct them. This first stage seeding exercise assisted users in companies to make quick use of the portal.

Following the first working version of the portal, stage two: focus group sessions were held with staff from four of the industrial collaborators. The purpose of these sessions was both to gather feedback on interface design and usability aspects of the portal and to refine the understanding of how workgroups develop and share knowledge in the course of their day-to-day activities, and how sustainability issues arise and are dealt with in the life of projects.

This was followed by stage three: development iterations of the portal and extended trials of the C-SanD portal with Sustainability groups at participating industrial collaborators. These consisted of small interest groups.

The three stage process proved interesting and informative to the C-SanD project team. A summary of the findings from the responses given in the trials are:

- The underlying concept was welcomed – all respondents considered that "…*overall, this type of computer support would be useful to my workgroup*…";
- There were major problems in the design of the user interface (recognised by the research team, but more time was needed than predicted to develop the prototype layers, so the interface design suffered) that prevented users getting benefit from the concept. This led to highly negative responses to such questions as "…*my interaction with the C-SanD portal was clear and understandable*…" and "…*I found the C-SanD portal flexible to interact with*…";
- The groupwork functions were rated more highly than the information retrieval functions – there were positive responses to the questions about interest groups and ability to flag items to colleagues; and
- Opinions on aiding business efficiency and the contribution to sustainability were mixed.

9. CONCLUSIONS

This paper has shown that although indicators, checklists and assessment tools for sustainability in construction are readily available, there is still a need for a structured approach for the implementation of sustainability practices and methods within construction projects. This need was determined from interviews conducted within the C-Sand project, analysed and subsequently translated into a sustainability management tool for construction projects. The tool encapsulated activities and tasks deemed necessary to improve sustainability within construction projects by providing stakeholders with processes on a number of levels. The first level activities are generic with more specific tasks defined in the sub-activities. The sustainability management activity zone can also be used as a stand alone tool. The SMAZ tool was tested in the industrial partner organisations where it proved positive. Particular aspects that were highlighted in the tests were:

- The ability to introduce sustainability into any design process encourages sustainable behaviour by clients and end users;
- Incorporating sustainability processes into construction projects has demonstrated advantages in day-to-day work; and
- It is beneficial to use the sustainability criteria in the selection of subcontractors, materials, etc.

In addition to the SMAZ tool a prototype web portal has been described in the paper. The portal was developed to aid stakeholders in the creation and management of their sustainability knowledge on construction projects. Through a series of iterations the portal was tested and refined with the industrial partners. From these tests the users determined that the portal was 'likely' to provide them with a useful tool to aid them implement sustainability in projects.

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