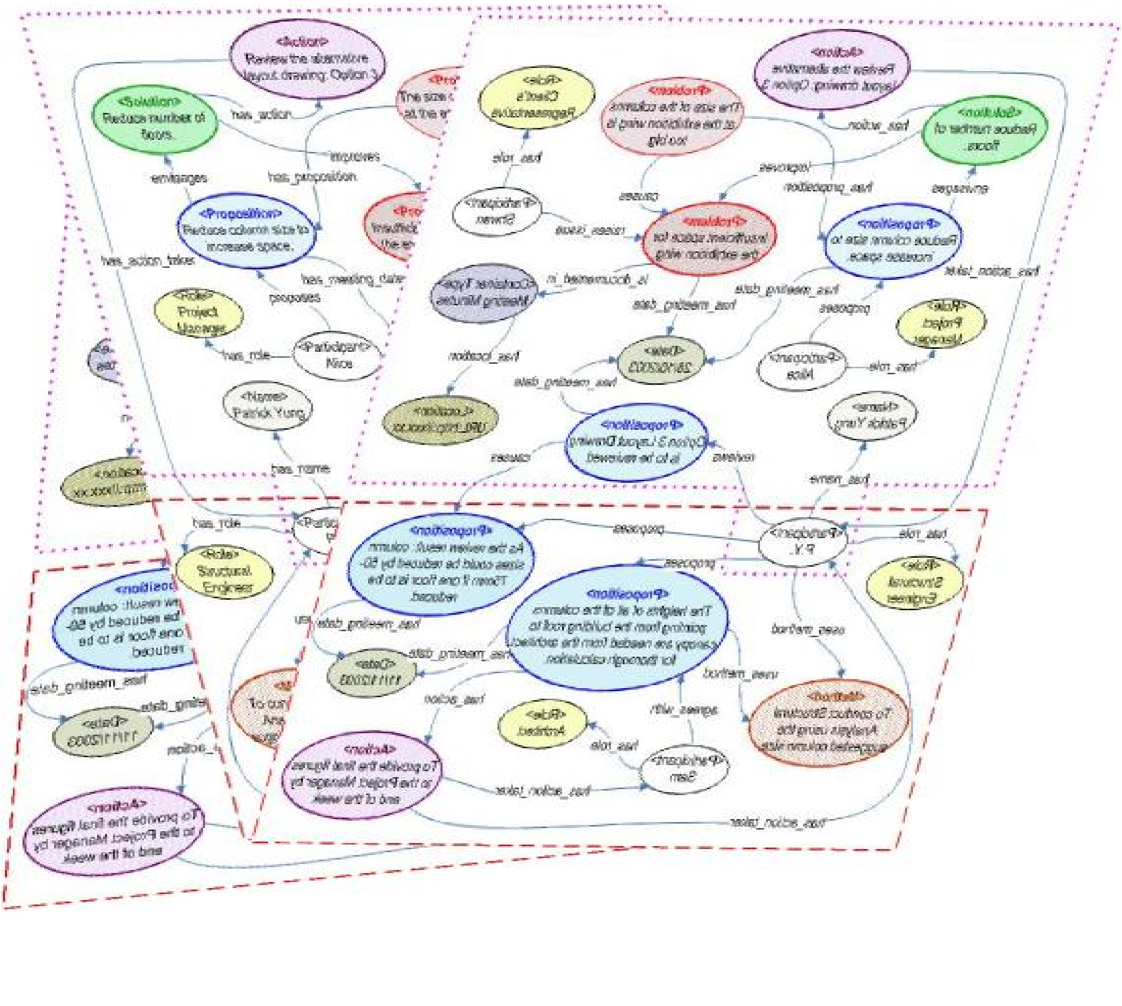
IT-CODE

IT in COllaborative DEsign

PhD Thesis
Defended public at Aalborg University
(220506)

Yoke-Chin Lai



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by

Yoke-Chin Lai

November 2006

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ABSTRACT

The Building Industry is characterized by its project-oriented nature. A project team is usually formed by multidisciplinary professionals who collaborate based on project-basis work agreements. The efficiency of the contract-basis collaboration in different project phases, especially in the early design phase, has been a problematic concern of the building sector. There are several reasons behind these collaboration barriers, each of which has formed the basis of a broad spectrum of research interests. In this thesis, significant writings in the ICT (Information & Communication Technology) implementation aspect have been reviewed to provide insight into the scope and depth of research that has been performed in an attempt to fully understand this area.

How designers have handled design information in real-life situations was studied through several case studies in an attempt to answer the formulated research questions. Observations complemented with semi-structured interviews were decided as the optimum data collection mechanisms based on various practical issues that could not be overlooked. The key step that brought forth the research hypothesis, to improve the designers' practices in more efficient design information handling, was the results of the case studies. The findings of the case studies revealed that the designer's current documentation practices were insufficient to assist tacit design knowledge (e.g., design rationale) transfer. Tacit design knowledge transfer occurs in all types of face-to-face meetings and was found as one of the favourable means of designers to coordinate design progress. These findings have pushed the research forward to another stage where research hypothesis was refined.

The refined hypothesis focused on a higher level of information management improvement, which is defined as total-knowledge-management in the thesis. The concept of total-knowledge-management was inspired by relevant research efforts in the area. A hypothetical approach was defined based on the concept of total-knowledge-management, in an attempt to assist design /decision reasoning capture, dissemination, store and efficient retrieval. Findings from the case studies confirmed that designers have been used to recording meeting contents in a document, which is called meeting minutes. This documentation practice was thus adapted as the blueprint of a prototype, which was the planned research outcome. The prototype was envisioned to be an alternative tool for the designers to manage design information through managing meeting minutes in a slightly different way from the conventionally used mechanism. A comparison between the conventional meeting minutes documentation mechanism with the proposed hypothetical approach is discussed comprehensively in the thesis.

Ontology is the silver bullet of the Semantic Web because it can be used to provide a semantic structure for a resources network that is shared using the World-Wide-Web technology. The advantages of restructuring resources network based on shared conceptualizations represented in ontology were also reviewed. The rapidly developing Semantic Web technology has provided a playing field in which various open-source tools and web-based ontology languages, including the Resource Description Framework and its Schema, usually abbreviated to RDF(S), are equipped. Some of these facilities were first reviewed then applied during the prototype development process. However, this early stage of prototype is only good enough to demonstrate the concept of the hypothetical approach at the time of writing because, among other things, the foundation technology of the Semantic Web is not yet mature. A comprehensive discussion in this regard is given in this thesis. The experience from the prototype development process showed that more effort is required to further improve the currently available ICT, in particular in the human-machine interaction aspect, as suggested in the last section of the thesis.

Keywords: building industry, collaboration, early design, meeting minutes, total-knowledge-management, Semantic Web, ontology.

RESUMÉ

Byggebranchen er karakteriseret ved sin projektorienterede natur. Normalt er projektgrupper tværfaglige og er sammensat af fagfolk, der samarbejder ud fra kontrakter i det konkrete projekt. Effektiviteten af det kontraktbaserede samarbejde i projektets forskellige faser og især den tidlige designfase har traditionelt været problematisk for bygningsindustrien. Der kan findes mange årsager til den manglende effektivitet i samarbejdet, og de har hver især dannet grundlag for et bredt spektrum af forskning. I denne afhandling gennemgås den væsentlige litteratur inden for implementering af informations- og kommunikationsteknologien (IKT) for at få et indblik i omfanget og dybden af den forskning, der er udført på området, og for at få en dybere forståelse af ovennævnte problemer.

I afhandlingen søges det igennem case studier belyst, hvorledes designere håndterer designinformation i dagligdagen. Observationer suppleret med interviews er valgt som den mest hensigtsmæssige metode til indsamling af data under hensyntagen til de givne praktiske forudsætninger. Analysen af case studierne danner grundlag for formulering af afhandlingens hypotese om forbedring af designernes praksis, således at de opnår en mere effektiv håndtering af designinformationen. Case studierne viste, at designernes nuværende dokumentationspraksis ikke kan kommunikere den tavse designviden. Udveksling af tavs viden forekommer ved alle møder, hvor personerne mødes ansigt til ansigt, som er designernes foretrukne metode til at koordinere udviklingen i designprocessen. Resultaterne af case studierne dannede baggrund for en justering af forskningshypotesen i projektets efterfølgende faser.

Den justerede hypotese fokuserer på en forbedring af informationsstyringen på et højere niveau, defineret som "total-knowledge management" (total vidensstyring) i afhandlingen. Dette koncept er inspireret af anden forskning inden for området. Baseret på konceptet med total vidensstyring defineres en hypotetisk tilgang til understøtning af designprocessen, herunder fastholdelse af beslutningsræsonnement samt udsendelse, lagring og effektiv genfinding heraf. Resultaterne af case studierne bekræfter, at designere har været vant til at registrere mødeindhold i traditionelle dokumenter som mødereferater. Denne dokumentationspraksis danner derfor grundlag for den prototype, som blev udviklet i projektet. Prototypen er tænkt som et alternativt redskab til styring af mødereferater på en lidt anden måde end den konventionelle. I denne afhandling foretages en sammenligning mellem den traditionelle metode til håndtering af dokumenter og den foreslåede hypotetiske tilgang.

Ontologier er et centralt grundlag for det Semantiske Web, da de kan give semantiske strukturer til netværk af ressourcer, som kan deles via World-Wide-Web teknologien. Afhandlingen belyser fordelene ved omstrukturering til et semantisk netværk baseret på en fælles begrebsdannelse repræsenteret i ontologier. Med det hurtigt voksende Semantiske Web er der åbnet et helt nyt område, hvor mange forskellige "open source" redskaber og web-baserede ontologisprog, inklusive Resource Description Framework og dets skemaer RDF(S), kan anvendes. Nogle af disse faciliteter blev først undersøgt og derefter anvendt i udviklingen af ovennævnte prototype. Denne 1. generations prototype kan dog i skrivende stund kun anvendes til at demonstrere konceptet for den hypotetiske tilgang, bl.a. fordi teknolologien bag det Semantiske Web endnu ikke er tilstrækkeligt udviklet. En uddybende diskussion heraf er givet i afhandlingen. Erfaringerne fra udviklingen af prototypen viser, at der er brug for flere ressourcer for at forbedre den tilgængelige IKT, hvor især området vedr. interaktionen mellem menneske og maskine kan forbedres, hvilket også er foreslået i afhandlingens afsluttende del.

PREFACE

Efficient collaboration between the cross-disciplinary stakeholders has always been the ambition of the building sector in order to produce good quality products. Different approaches for improving efficient collaboration, ranging from social to technical, have been attempted in the last few decades in order to fulfil this ambition. The aim of this research study, which was set to improve collaboration at the early design stage, has brought forth the research scope further to explore improvement possibilities from the knowledge management perspective.

Many arguments stated in this thesis were formed by believing that stakeholders (in this case the designers) collaborate more efficiently when they are able to share their knowledge with minimal barriers caused not only by the time and space parameters, but also by the transition state of understanding (i.e. the knowledge transformation processes). The author also believes that capturing tacit knowledge transferred during face-to-face meeting is of importance because it comprises decision reasoning and design rationale that have reuse value. The method the designers usually use to record the face-to-face meeting contents is argued by the author only good enough to document the discussion result; not the progress in which the decision reasoning is embedded. A hypothetical approach is proposed as the primary contribution of this thesis to alter the ubiquitous practice of designers. The hypothetical approach was also devised in an attempt to form a basis for future research in the same direction.

Last but not least, the author gratefully acknowledges all types of help and support given by both project supervisors: Professor Per Christiansson and Associate Professor Kjeld Svidt, some good friends: Janice, Brenda, YuJing, MengYee, Stephen and CheeYew, and needless to say Kelvin and families. Furthermore, the author would like to thank the research group led by Professor Thomas Kvan at the Design & Architectural Department of The University of Hong Kong for all of their invaluable advice, inspirations, suggestions and feedback. Special thanks also go to all informants (interviewees), particularly Associate Professor Erik Bejder, Mr. Jen Ove Skjærbæk, Mr. Keith Futcher, Mr. Nic Bank and Mr. Kin-Choy, for their invaluable time and practical experiences contributed to the case studies.

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Yoke-Chin Lai

January 2006

自序

豁达， 绿化心田

希望， 延续明天

这好些年，日子是刻板的，内心却是彷徨的。 前途茫茫， 总觉得自己老是在同一圈圈里兜游，浑浑噩噩地踌躇于取舍间。 很多时候，走丢了，只好回到原点，重新出发。在这段停停走走的日子里，没敢说学了些什么，耐力倒练了一把。

曾经一度，以为自己也许快疯了。连日来绵绵不歇的压力，似已成形了一个永不妥协的梦魇，张牙舞爪的， 无孔不入． 无时无刻的把自己给缠牢。现在， 心理还算踏实了些。至少， 能感受到这些日来的折腾或许快有个了断了，这漫长的梦魇也该给画上个休止符了。

成也罢， 衰也罢， 这段苦乐参半的日子，在家人的支持与师友的鼓虑下，还是一路给走了过来。 这无数个枯坐 对着电脑干瞪眼的日子，也已深深地在我那有限生命烙下了印记（家中魔镜，向来坦白， 也作此说）。

目前，生活过得几近颓废， 所期待的不过是另一抹曙光的出现。有期待，或许还是好的！

严冬 （一月） 2006

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ABBREVIATION TABLE

Abbreviation	Terminology
A/E/C	**A**rchitectural/**E**ngineering/**C**onstruction.
AEC	**A**rchitectural/**E**ngineering/**C**onstruction.
AI	**A**rtificial **I**ntelligence.
API	**A**pplication **P**rogram **I**nterface.
ARCHIE	"computational case-based design aid for architecture".
BSI	Institution for British Standards.
CAD	**C**omputer-**A**ided **D**esign.
CAD/CAM	**C**omputer **A**ided **D**esign/**C**omputer-**A**ssisted **M**anufacturing.
CAE	**C**omputer **A**ided **E**ngineering.
CASECAD	"a design support system that assists a human designer in refining specifications by the retrieving relevant cases".
CBR	**C**ase-**B**ased **R**easoning.
CIMSTEEL	**C**omputer **I**ntegrated **M**anufacturing for constructional **STEEL**work.
CLIPS	**C** **L**anguage **I**ntegrated **P**roduction **S**ystem.
COMBINE	**CO**mputer **M**odels for the **B**uilding **IN**dustry in **E**urope.
CRACK	**CR**itiquing **A**pproach to **C**ooperative **K**itchen design.
CSCW	**C**omputer **S**upported **C**ooperative **W**ork.
DAML+OIL	**DA**RPA **M**arkup **L**anguage + **O**ntology **I**nference **L**ayer.
DARPA	**D**efense **A**dvanced **R**esearch **P**rojects **A**gency.
DLML	**D**escription **L**ogic **M**arkup **L**anguage.
DTD	**D**ocument **T**ype **D**efinition.
e-COGNOS	...**e**lectronic **CO**nsistent knowled**G**e ma**N**agement across pr**O**jects and between enterpri**S**es in the construction domain
FBM	**F**eature-**B**ased **M**odelling.
GARM	**G**eneral **A**rchitecture, engineering and construction **R**eference **M**odel.
GEPM	**GE**neric **P**rocess **M**odelling Method.
GUI	**G**raphical **U**ser **I**nterface.
HTML	**H**yper **T**ext **M**arked-up **L**anguage.
HTTP	**H**yper **T**ext **T**ransfer **P**rotocol.
HVAC	**H**eating, **V**entilating and **A**ir **C**onditioning.
IAI	**I**nternational **A**lliance for **I**nteroperability.
ICT	**I**nformation and **C**ommunication **T**echnologies.
IDEF0	**I**ntegrated **DEF**inition method for modeling the decisions, actions, and activities of an organisation or system.
IDM	**I**ntegrated **D**ata **M**odel.
IFC	**I**ndustry **F**oundation **C**lasses.
IGES	**I**nitial **G**raphics **E**xchange **S**pecification.
IMS	**I**nterface **M**anagement **S**ystem.
ISO	International Organisation for Standardisation.
KM	**K**nowledge **M**anagement.
MathML	**Math**ematical **M**arkup **L**anguage.
N3	**N**otation **3**.
NIAM	**N**ijssen **I**nformation **A**nalysis **M**ethod.
NLS	o**NL**ine **S**ystem.
OED	**O**xford **E**nglish **D**ictionary.
OIL	**O**ntology **I**nference **L**ayer.
OKBC	**O**pen **K**nowledge **B**ase-**C**onnectivity.
OMDoc	**O**pen **M**athematical **Doc**uments.

Abbreviation	Terminology
OWL	**W**eb **O**ntology **L**anguage.
PAMPeR	**P**ortfolio and **A**sset **M**anagement: **Pe**rformance **R**equirements
RATAS	The acronym is derived from the Finnish words for "Computer Aided Building Design".
RDBMS	**R**elational **D**ata**B**ase **M**anagement **S**ystem.
RDF	**R**esource **D**escription **F**ramework.
RDFS	**R**esource **D**escription **F**ramework **S**chema.
RIBA	**R**oyal **I**nstitute of **B**ritish **A**rchitects.
RQL	**R**DF **Q**uery **L**anguage.
SCI	The **S**teel **C**onstruction **I**nstitute.
S-CREAM	**S**emi-automatic **CREA**tion of **M**etadata.
SEED	**S**oftware **E**nvironment to support **E**arly building **D**esign.
SeRQL	**Se**same **R**DF **Q**uery **L**anguage.
SHOE	**S**imple **H**TML **O**ntology **E**xtensions.
SOAP	**S**imple **O**bject **A**ccess **P**rotocol.
STEP	**ST**andard for the **E**xchange of **P**roduct model data.
TOTE	**T**est **O**perate **T**est **E**xit.
UI	**U**ser **I**nterface.
UML	**U**nified **M**odelling **L**anguage.
URI	**U**niversal **R**esource **I**dentifier.
W3C	**W**orld **W**ide **W**eb **C**onsortium.
WWW	**W**orld **W**ide **W**eb.
XML	e**X**tensible **M**ark-up **L**anguage.

EXECUTIVE SUMMARY

Knowledge and its management

Knowledge is collective and its importance becomes aware by numerous disciplines including the building industry. Building industry has a complex organisational structure in which success is highly dependent on effective collaboration between individuals from different professional disciplines. Generally, knowledge in this domain is kept at four different levels: the individual-, team-, project-, and organisation-/company-level. As advocated by Polanyi (Polanyi, 1983) and Nonaka (Nonaka and Takeuchi, 1995) knowledge collected at each level has two forms, i.e. implicit and explicit knowledge, respectively. Implicit or tacit knowledge represents personal knowledge stored in the individual's cognitive structures, and therefore is unarticulated. Contrarily, explicit knowledge is knowledge that can be codified and systematically expressed in formal structures compatible with human language.

Knowledge creation and management corresponding to the building industry begins in the early phase of a building project, i.e. the briefing and design phase. Over the years, many systems for describing a design process have been developed. All these systems were somewhat developed based on the two main paradigms for describing design activities, i.e., "design as a rational process" and "design as a reflective process" (Dorst and Dijkhuis, 1995; Simon, 1981; Schön, 1987). A brief analysis of these two different design paradigms will be given in Chapter 3 to provide a basis for defining what design is. Tackling design as a problem solving process was introduced by Simon (1981), in which project actors who are involved tend to solve problems based on accessible knowledge. It is important to ensure that appropriate knowledge is accessible at the correct time in the process (Lawson, 1990). Research has also shown that designers depend largely on the information and knowledge that is easy to access for them (Interview analysis in Chapter 5). According to the personal experiences of interviewees, they are unlikely to seek or share knowledge and expertise if information and knowledge is not easily accessible. Due to such circumstances, most designers are likely to generate local rather than global design environment (Lawson 1990; Chira et al 2004).

The challenge of globalization to collaborative design

Globalisation has increased the complexity of the building industry in which close collaboration among multidisciplinary project actors is required through the entire project. Efficient collaboration at the early design stage exerts big influence on the success of a building project. Since design is an information and knowledge intensive activity, designers require an effective approach to assist them to communicate and coordinate the distributed data, information and knowledge. Such an approach is needed because designers sometimes are unlikely to be aware of how the work of other project actors affects their own work. Furthermore, teamwork is increasingly important with the complexity of design problems mainly due to sharing knowledge, expertise and insights between participants who possess diverse skills may create distributed cognition (Edmonds and Candy, 1994). Some problems associated with design activities, for example, poorly formulated information and knowledge management strategies are intensified by the nature of knowledge distribution, which can be geographically, temporarily, functionally and semantically dispersed. Different approaches have been developed to mediate both the socio-technical and knowledge management problems corresponding to the distributed design environments. One of these approaches is the very popular mechanism which utilises case bases to support conceptual design by facilitating designers to find related precedents (Wood & Agogino, 1996; Maher et al 1996). Some research focuses on a technique that facilitates the representation of design that is based on "text analysis" of design documents (Dong & Agogino, 1997; Wong, 2003). There are also researches that advocate Schön's argument that design is an action-oriented activity which is often tacit and difficult to express, and what can be captured is the reflection-in-action (Schön, 1987). For example, there is an ongoing research that enables designers to map objects from a shared product model (digital 3D model) to multiple semantic representations and to other shared project knowledge (Fruchter, 2002). In general, all of these researches support a common theme which is to improve communication of knowledge between distributed design teams for achieving successful and effective design solutions. A brief description of these approaches will be available in Chapter 3 & 4 of the thesis.

Evolution brings revolution?

The rapid growth of Information and Communication Technologies (ICT) has had both positive and negative impacts on the aspect of knowledge sharing. The growth of technology has extended the capability of the computer from being merely a device for computation to now a portal to information cyberspace. In the 1980s, the personal computer was developed, and was mainly used as a personal device for games, text processing and storage of digital information and data. During the last decade, the computer has become the entry point to a different type of network whose main objective is to facilitate information exchange and business transactions. The internet, particularly the World Wide Web (abbreviated as the web hereafter) has become the source of unstructured, heterogeneous and distributed information, which has increased drastically in volume. The web implements the hypertext (Nelson, 1965) concept and expands it to a worldwide communication medium operating over the Internet. As early as 2001, the web has been envisioned to interweave one billion people not just through using computers but also through other devices, including cars, refrigerators, coffee machines, even clothes (Fensel and Musen, 2001). However, a significant impediment was identified in the future growth of the current web technology; its lack of efficiency in managing the overwhelming amounts of information. The current web technology offers limited support for the computer in accessing and interpreting the actual content of the shared and exchanged information within the web. The main burden of accessing, processing, extracting and interpreting information still remains on the human user. In order to mediate these bottlenecks, Tim Berners-Lee envisioned an extended version of the current web, the Semantic Web, which provides information with well-defined meaning so that automated information access is no longer merely a grand vision of the hypothetical Memex[1] device proposed by Vannevar Bush (1945).

Semantic Web, what is that?

The Semantic Web is envisioned to be a global **database** in which information is structured to be both machine- and human-understandable. This is contrary to the current web, which contains mostly unstructured information. However, the concept of machine-understandable documents does not imply some magical artificial intelligence, which allows machines to comprehend human mumblings (Berners-Lee, 1999; 2001). On the contrary, it only indicates a machine's ability to solve a well-defined problem by performing well-defined operations on existing well-defined data. In order to achieve this vision, human users are required to make extra effort (Berners-Lee, 1999; 2001).

[1] "…a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It resembled a desk.... Within would lie several gigabytes (if not more) of storage space, filled with textual and graphic information, and indexed according to a universal scheme..."

The web and Knowledge Management in the Building Industry

A building project involves numerous phases that progress either in sequence or parallel in order to produce a final product that meets the client requirements. Early design is one of the most important phases because decisions made in this phase have a very strong influence on the quality of the final product. Many researchers in the field of design research have studied for years to map activities that are commonly known as the design process attempting to generate standardized design procedures. Amongst them for example are Markus (1969), Maver (1970), Pahl (1996) and MacMillan (2002). Over the years, several design process maps have been developed all over the world, amongst those for example are the BAA Project Process (BAA, 1995), RIBA Plan of Work (RIBA, 1973), BS:7000 (BSI, 1999). The RIBA Plan of Work has been the accepted practice amongst the practitioners of case studies conducted in this doctoral research study, and therefore it is used as the main reference in regard to the design process in this thesis.

Close collaboration between multidisciplinary actors is very important at every stage of a building project to prevent undesirable chaos from occurring that may influence the development progress at the later stage. Close collaboration during the design stage is even more important because the most significant decisions are made here during the stage. Apart from drafting tools, project actors who are involved in collaborative design require tools for effective and efficient design information communication. Apart from the articulated design information and data, design know-how is of the essence to be shared during the collaborative design process (Fruchter, 2002; Chiu, 2002; Kvan, 2000), and to be reused in the future.

Experiments with numerous approaches have been conducted for years to tackle the best way to design information sharing and transferring. Approaches have ranged from using the traditional media and tools (paper-based construction documents, specifications, physical scale model, sketches and one's memory) to applying the computer dependent digital media and tools (e.g., digital databases, and digital building models). Although no optimum mechanism has yet been found, there is consensus on the need to have a quality design information system. The design information system must be able to manipulate (capture, store, index and retrieve) information that is disseminative through the different types of communication means used, including the conventional face-to-face conversation, the use of telephone and fax machine, to the use of the contemporary Internet technology. Several attempts have been made to manage the project-level information base more effectively, including the concept of project web, which tends to apply the fast developing information and communication technologies (ICT) to manage the project-level information base more efficiently. A comprehensive discussion concerning a project web associated with the technology behind is included in Chapter 5 of the thesis.

Contribution of Semantic Web in the Building Industry

As one of the tasks of the doctoral research study, several case studies were conducted to examine the decision-making process in order to get a glimpse of how the design team members communicate effectively amongst themselves at the early design stage of a building project. Non-obtrusive observations complemented with interviews with the key persons were the activities involved in the case studies whose results associated with their analysis are discussed in Chapter 5 of the thesis. These case studies provided the clues for the need of an innovative information management system that may assist to handle not only the information/data (articulated knowledge), but also the implicit knowledge produced in a project.

The assumption made based on the case studies was – the meeting is the main approach the A/E/C professionals use for collaboration activities such as discussing project-related issues and making decisions based on the discussion content. The case studies also indicated that the implemented web-based project information management systems were document-centric systems. Further, these document-centric systems revealed weaknesses to search, extract and maintain information. As with all other users of the current web technology, the A/E/C professionals who depend on the web-based information management system, without exception, struggle in getting the right information to the right person at the right time. The introduction of the Semantic Web, which is to improve the capability of the current web technology, may provide an aid to overcome this problem. By considering that the design rationale and decision intent are intrinsically embodied in the discussion contents of any design progress meeting. The discussion contents that have been conventionally captured in meeting minutes that appear simply as a piece of plain-text document, can now be structured semantically to make the meaning explicit to the information/knowledge users.

A propositioned prototype and its rationale

Meeting minutes have usually been confined to be the recorded summaries containing the discussion contents of a meeting. The conventional approach implemented to arrange the summaries in tree-structure format results in design intents being implicitly contained in the written plain-text. The implicit design intents could only be interpretable rapidly by those who attended the meeting and actively joined the discussion. For those who did not participate in the meeting, but were interested in following the design progress, extra time must be spent to collate and review the series of the time marked meeting minutes. The conventional meeting minutes are also incapable of integrating pieces of design information that have been produced throughout the early design process. This increases the time needed to review the stitches of meeting minutes in particular when the necessity arises to gather the relevant, but scattering design information. With respect to these shortcomings, it is argued that semantically structured meeting minutes may serve as dynamic records of key design information. The dynamic records may allow the design intents to be explicitly presented instead of implicitly described as in the conventional plain-text records. The semantically structured meeting minutes may serve as a medium for meeting participants to record the discussion contents of a meeting in a way that the knowledge as well as the meta-knowledge can be stored, indexed and retrieved effectively and efficiently. A hypothetical infrastructure is therefore proposed to alter the notes taking approach, which has been conventionally practiced for recording the discussion contents of a meeting.

How to stitch meeting minutes to Semantic Web?

Use of ontologies is the key here. Ontologies are the underlying element enabling technology to be used for the Semantic Web. Ontologies interweave human understanding of symbols with their machine processability (Davies et al., 2003). Ontologies were further developed in artificial intelligence to facilitate knowledge sharing and re-use, and have become a popular research topic since the early 1990s. Ontologies have been studied by several artificial intelligence research areas, including knowledge engineering, natural-language processing and knowledge representation. In these recent years, the use of ontologies has become widespread in disciplines such as intelligent information integration, cooperative information systems, information retrieval, e-commerce and knowledge management. Several world-leading institutions have conducted a number of case studies that have proven the successful use of Semantic Web technology in knowledge management. This is briefly depicted in Chapter 6 & 7.

The prototype system described in this thesis is envisioned to function as the medium to provide fast and precise semantic search, and to capture the intent and rationale behind decisions made during the early design process. This system is devised to accomplish the following tasks:

- To integrate information that is distributed in heterogeneous sources without using one central repository to reduce repetition of workload.

To capture and store discussion contents in which the design rationale and decision intent are intrinsically encompassed.
To organise the captured information in a way that is both human and machine readable.
To contextualise the captured information in representation that may improve the human's efficiency to interpret its implicit meaning, as proposed by Shum et al. (2002)

In order to fulfil its tasks, the prototype system was built based on an underlying ontology model so that the discussion contents are organized in a semantic-based network. The rationale of how the ontology model was structured, including the definition of domain, scope and objectives of the model is described in Chapter 6. The rationale of how the concept of Protocol Analysis (Simon et al., 1984) was incorporated to assist reducing the cognitive analysis of the system (the demonstrator) users is explained in Chapter 7. A comprehensive discussion with respect to tools selection for the prototype development is stated in Chapter 8.

In the last chapter (Chapter 9) of this thesis, the limitations of the prototype is analysed based on the available features of the selected tools and ontology languages by elaborating the experiences learned throughout the prototype development process. A future research agenda will hopefully be extended by these delineated experiences so that the capability of the semantic web can be better adopted to further improve collaborative design from multiple perspectives.

1 INTRODUCTION

Nothing happens unless first a dream.

--Carl Sandburg--

1.1 Hypothesis

Semantic Web technology is applicable in the building industry to support collaboration whose efficiency relies on the efficiency of knowledge transfer between the multidisciplinary stakeholders. An infrastructure, which may facilitate tacit knowledge transfer by making explicit the meta-knowledge that an individual uses subconsciously to formalise reasoning conducted in face-to-face meeting/s, can be devised based on the Semantic Web technology to alter the conventional meeting notes taking approach.

1.2 Background

The building industry is very project-oriented in nature, and it is organized on actor streams wherein actors are involved in several projects at the same time (Wetherill et al., 2002). Actors involved in the same project are sometimes thousands of miles apart and practicing different working methods based on their respective professional roles. In addition, most projects can be characterized as organizations that are established on a temporary contract basis and therefore they are based mainly on short-term business relationships.

The early stage of a building project starts with the client briefing to (conceptual) design and is inherently iterative. Decisions made at the early stage of a product development process have severe influences on the quality of the product (Cohen, 1995; Boverket & BFR, 1994). Design is therefore considered an important decision instrument in expressing product features and production information (Formoso et al., 1998). In order to improve the performance of the design process, numerous initiatives have been taken including the partnering concept which focuses on stimulating collaboration amongst stakeholders from the very beginning of a project. The partnering concept argues that a shared value particularly in the context of project related knowledge tends to improve collaboration amongst stakeholders and plays a key role in creating a successful design. A shared value as such enables stakeholders to make fast and accurate decisions while conducting design activities, which reduces the potential for negative costly impacts in the later project stages.

Knowledge, both tacit and explicit, is one of the important shared assets generated throughout a building project based on various types of interactions (human-human and human-artefact) amongst stakeholders who have different professional backgrounds and interests. Knowledge also has been acknowledged as one of the most important strategic resources of an organization (Nonaka & Takeuchi, 1995). Developing a mechanism that is able to effectively manipulate (capture, store, search, retrieve) knowledge has therefore been the objective of research conducted in different areas including the building industry (Fruchter, 2002). The fast developing information and communication technology (ICT) expedites the research progress in this aspect by contributing ICT tools that comprise collaborative features such as co-editing, co-browsing, and application sharing attempting to better manage the expanding building information base.

1.3 Problem Definition

Data and information such as briefing notes and sketches generated at the design stage, particularly the early design stage, are mainly informal and not well structured. However, the informal and not well structured data and information are important to reflect the tacit design knowledge. Such weakly structured information in which the design rationale is probably documented is no less important than the structured document such as the final drawings and reports that are generated at the end of every meeting. Likewise the tacit and explicit knowledge (Nonaka & Takeuichi, 1995), it is a difficult task to integrate both the weakly- and well-structured information from the perspective of traditional knowledge management (Fensel et al., 2001). Although knowledge management has no absolute definition, it has prevalently been composed of several key activities that aim at organizing knowledge in a way that could facilitate future access (search and retrieval) when needs arise. These activities, for instance knowledge dissemination, focus conventionally on the codified knowledge but neglect the tacit knowledge. Lack of appropriate technologies to expedite the process of capturing, representing and structuring tacit knowledge is one of the pitfalls in traditional knowledge management. Extra effort is thus required to structure information in a way that the tacit meaning embedded within the natural language texts could be made sufficiently explicit so it can be not only human readable but also machine-processable.

The increasing globalization trend may result in project-related machine stored knowledge no longer contained in one centralized repository but distributed in heterogeneous databases that belong to different individuals, discipline groups, project-teams and organizations. The concurrent ICT has achieved this milestone with respect to support shortening the distance between the distributed project team members. Creation and implementation of virtual workspaces developed based on the concurrent ICT are no longer news in these recent years. Geographical and time constraints are thus no longer a real critical issue that concerns the project team in attaining close collaboration. In spite of this, integrating the heterogeneous information sources, particularly those that contain weakly structured information, remains an uneasy task in the building sector (Christiansson, 1998). The building sector is a particularly complicated field for the involved stakeholders to achieve efficient collaboration because of the high degree of flexibility or rather weak organisational structure that is formed to run a project. An excessively flexible organisational structure may complicate the process of integrating the mass quantity of information generated throughout the whole project life that may last from several months to several years. The wide use of low-level technologies mostly adhering to hyperlinks and keywords search (Ding et al., 2003), and the lack of meta-level data structures (Christiansson, 1998) worsen this information non-integrating phenomenon. Due to all of these deficient factors, the building sector requires extra resources to achieve adequate project information management.

1.4 Research Aim

This research will investigate the applicability of the Semantic Web in the building sector to improve cross-disciplinary collaboration of the design team from a knowledge management perspective.

1.5 Research Scope

Design is a dialogue between goals and solutions that may simultaneously involve both of the most commonly discussed paradigms, a process of problem solving or reflection-in-action. Massive research has been conducted based on these two paradigms for in-depth study of the relationship between design sketching and cognitive processes. All research shares a common finding that designers tend to take mainly the geometrical aspects as the principal way to represent their design ideas. This finding indirectly leads to the development of different computer-based applications that aims at facilitating designers to output design in the form of drawings at the later design stage. This emphasis on graphics overshadows the role of text in design, which further leads to a research void in the area. In the collaborative design environment, text based communications have shown to be not only essential but also beneficial to design activities (Wong, 2003). This finding shows that text has a no less important role than graphics as a medium in conveying and recording design information. The recorded textual design information exists in different forms, be they e-mail or longer documents such as progress reports and meeting minutes, with the ultimate goal of enabling asynchronous design communications. Followed by this finding, correlation between various aspects including information management, knowledge exploration and collaboration support remains an interesting research area that requires deeper exploration. These are also the aspects on which the research scope of this doctoral study was based.

1.6 Research Method

Organising efficiently the vast amount of design information particularly the one generated during the early design phase is necessary to facilitate the feasibility of reuse. Holding meetings on a regular basis is one of the synchronous communicating approaches favoured by the A/E/C professionals to encourage collaboration. Notes are usually taken by a specific meeting participant summarising the contents of meeting conversation. The recorded hand-written notes will then be transformed to a digital document that provides tree-structure classification on which the organization of the key discussion contents is based. This digital document, which is called, meeting minutes, will then be circulated amongst project participants to allow them to track the design process as well as the project progress. These were the findings generalized from the case studies and interviews undertaken as the data collection mechanisms in this doctoral research. Contextual Design formalisms were used to analyse the collected data in order to study how design teams deal with their perception about knowledge and its role in influencing collaboration efficiency. The findings were also input to the formulation of an alternative meeting contents documentation approach whose underlying knowledge representation framework is ontologies network. Resource Description Framework and its Schema, usually abbreviated to RDF(S), were the web-based ontology languages implemented to devise the Semantic-Web based demonstrator whose objectives were several, while making tacit knowledge transferred in meeting discussions explicit was one among the other objectives.

1.7 Contribution

In this research study, a new role of meeting minutes is proposed. The role of meeting minutes as a meeting by-product that documents the discussion results of meetings is argued by the author to be incapable of integrating design information that increases with the design progress. Meeting minutes scatter in different information sources. With respect to this shortcoming, the author proposes that semantically structured meeting minutes may serve as dynamic records of key design information. These dynamic records may allow the design rationale as well as the reasoning behind decisions to be explicitly presented instead of implicitly described as in the conventional plain-text record. Semantically structured meeting minutes are no longer merely a document in which information is stored in a way that is only human readable but not machine-processable. By adopting the concurrent Semantic Web technologies, the natural language based textual meeting minutes could be structured in a different way so that its contents could be readable to both machines and humans. More importantly, meeting minutes could be used at a higher level to serve as a medium for meeting participants to record discussion contents of a meeting in a way that the relevant knowledge as well as the meta-knowledge could be stored, indexed and retrieved effectively and efficiently.

This study also explores the possibility of Semantic Web technologies supporting collaborative design in an attempt to analyze the contents from group discussions. An infrastructure is hypothesised which is able to change the conventional meeting notes taking approach using the Semantic Web technologies. The underlying concept of the hypothesized infrastructure, which is able to model and analyse the discussion contents based on an ontologies model, is thoroughly discussed in the thesis. A demonstrator is devised based on the said concept to experiment how the ontologies model could make explicit the semantic connections between ideas/information stored in different documents. The demonstrator is also devised to support novel and powerful query of the stored design ideas.

1.8 Thesis Outlines

Chapter 2 in this thesis gives an overview of how the whole research study was undertaken. Explanations in regard to the selection of research methods are also given in this chapter.

Two chapters (Chapter 3 and Chapter 4) are written based on the literature reviews undertaken throughout the research study in order to facilitate the reader to explore the broad coverage. In Chapter 3, the state-of-the-art review with respect to the notion of design and the various efforts conducted in the building sector to improve collaborative design is given. The main theme of Chapter 4 is knowledge management, which is one of the perspectives that the author argues may play a role in improving the efficiency of collaborative design.

In Chapter 5, a thorough discussion with respect to the data collection and analysis mechanisms used in this study is presented. The several steps used for data analysis are represented in different work models in accordance with the Contextual Design formalisms. Based on these work models, the work flows of how the subjects (informants) handle project information were overviewed. Project Web, a type of groupware, was analysed in the aspect of its efficiency to improve collaborative design from the perspective of knowledge management. This analysis is presented before the chapter proceeds to formulate the hypothesis of this study.

Chapter 6 attempts to define what a document-centric knowledge management system is by giving an example of the conventional meeting minutes. The structure of information or codified knowledge contained in a document-centric knowledge management system is also characterized in this chapter as static and insufficient to support tacit knowledge transfer. Ontology, which forms the basis of the Semantic Web, is outlined having the potential to change the hierarchy indexing practice, which is applied for representing knowledge into written texts. In Chapter 7, an annotation approach is proposed to change the hierarchy indexing practice to one called the associative approach. The associate approach is described being alike the natural human mental processes in memorizing and learning.

The main theme of Chapter 8 is to discuss the web-based demonstrator devised according to the hypothetical concept proposed in Chapter 7. The demonstrator is, among other things, to support integration of design information and knowledge through structuring meeting minutes based on ontology models. Chapter 8 demonstrates how meeting contents could be structured (classified and indexed) using the annotation approach proposed in Chapter 7. The demonstrator also shows how the annotation approach was applied to contextualize discussion contents in an attempt to reduce the human user’s efforts to interpret the meaning of the contents.

In Chapter 9, general conclusions and recommendations for future research are given.

2 RESEARCH METHODOLOGY

If you want to make an apple pie from scratch, you must first create the universe.

—Carl Sagan--

The process of a research project is iterative while involving multiple stages that are undertaken not only sequentially, but also in parallel. In this doctoral study, the entire research process constituted several stages including the literature review, preliminary investigation, case studies, and prototype development, as illustrated in Figure 2.1. Before a definite research focus was formulated, the research background of this doctoral study was first examined at pre-study stage by various means, including literature survey and visiting other research groups for experience transfer and viewpoint discussion. The pre-study stage was substantial for the author to gain insights into the current practices that the A/E/C professionals implement in order to achieve the optimum state of multidisciplinary collaboration at the early design stage. A self-explained rich picture diagram (see Figure 2.2) was drawn based on the findings generalised at the pre-study stage. The diagram attempted to portray the findings in a way that the scenarios of the problems faced as well as the efforts implemented to counteract the problems could be visualised. More importantly, the diagram played the role in assisting the design of the main study by indicating the explorable research paths.

The research questions formulated below were the reflections of the preliminary analysis, which was to outline an explorable research scope followed by a research hypothesis:

1. how can IT support collaborative work in the early design phase;
2. how will the individual working method change;
3. how can collaboration competence be strengthened for the designers and other project stakeholders who are involved at the design stage; and
4. how can the design process be documented to serve as an efficient project memory?

The hypothesis (see Chapter 1: Introduction) was deduced after rigorous study of the subjects associated with the research questions. The formulated hypothesis was closely correlated with a new emerging research area called Semantic Web, which is a new area that tends to integrate some of the knowledge management strategies to the globally used communication mechanism, the Internet.

2.1 Literature Review

Literature review is an important approach to acquire information about research methods, theories, related works, and so forth. Traditional publications such as books, journals, proceedings, research deliverables/reports, and the electronic publications available via the internet were the key sources of information. In view of the complexity of the research scope (see Chapter 1), the author divided her literature survey into three categories (see Figure 3.1) so that the review could be undertaken consistently and in parallel with some of the research stages. For example, interviews to find out the favourable communication mechanisms used in a design meeting were carried out simultaneously as literatures within the area of knowledge management were reviewed. Moreover, other research methods adopted for the purposes of data gathering, analysis and presentation in order to complete the research study are briefly described in the following paragraphs.

2.2 Research Methods

There are many kinds of research having the nature that can range from applied to pure. In practice, much research will fall somewhere in between these two extremes (Robson, 2002). Choosing the appropriate research strategy with respect to the research nature was an important concern while designing the study. The various research strategies available can be generally classified into the two distinctions between quantitative or qualitative. For this doctoral study, qualitative research methods were decided based on the previously defined research scope, which indicated the exploratory nature. Qualitative methods are appropriate for research whose concern is to explore a subject to gain insight from which theories might emerge. The subject of interest in this doctoral study was to investigate how the multidisciplinary collaboration activities at the early design stage of a building project could be improved. The best way to fulfil the exploratory demand of the research scope was to examine the phenomenon of interest within its real life context. Case studies were therefore chosen as the enquiry strategy (Yin, 1994). In light of enhancing the rigour of the research, the strategy of triangulation through using interviews and observations was implemented for data collection. Observation was chosen as the data collection method in order to comply with the research objectives, which were concerned more with looking at what happens rather than why something happens within the phenomenon of interest (the real world studies). A semi-structured interview was decided as a complementary method that allowed the author to probe the insights of the observation context. This is because an understanding of why something happens will be an additional merit to facilitate the development of a system from which the people under observation will benefit (Beyer et al., 1998).

Finding the appropriate case was not an easy task for the author due to numerous factors, including the concern of confidentiality that the presence of an outsider as the author was not always welcome. The A/E/C practitioners being observed usually considered observation was obtrusive and disturbing. Meanwhile, the author was also aware of the possible complications, particularly observational bias and observer drift that might occur while conducting observations for data collection. Therefore, the author attempted to acquire feedback from the participants under the observation on the interpretation made for the collected data.

2.2.1 Preliminary investigation

The main aim of this research phase was to test the validity of the findings with respect to the literature survey within the building design organisations. The attitudes of the practicing design team members (e.g., architects & engineers) on what they believed were the major problems in connection with the early design activity undertaken in the contemporary design environment were the main concerns of the investigation. The approach used was semi-formal interviews that were conducted with a few key persons of a completed building project. The main aim was to gain insights into the working procedures of the project team, which was established on the multidisciplinary collaboration basis. Although this multiple-interviewees approach could lead to contradictions in some perceived occurrences, it was, however, undoubtedly the optimum means for gaining an overall understanding about the project from an internal perspective. Apart from the interviews, the completed building project was also adopted as the retrospective case studies, in which the factors/parameters that the designers (architects and engineers) took into consideration while translating the client's requirements to technical solutions were of concern. The retrospective case was adapted as the real data for instantiating the database, which was one of the components of the semantic-web based demonstrator, a preliminary prototype system.

2.2.2 Direct observation of design meetings – the Case Studies

As illustrated in Figure 3.1, findings generalised from the preliminary investigation shaped the framework of the demonstrator, which would be an important means of illustrating the research outcome. The framework needed to be refined with more data, which would be gathered through several direct observations. To meet this requirement, three then ongoing projects were sought for examining the collaborative design activities. The design progress meetings of the selected projects were studied using the customised contextual design approach. Customisation of the contextual design approach was required mainly because of the contextual inquiry method (Beyer et al., 1998) being too obtrusive to be implemented in the selected case studies. The actors of the building projects were not likely to be disturbed in their design meetings. Due to this situation, customization had to be made in such a way that both observations and interviews were conducted with the same design team in different time instances. Interviews were conducted to complement the observations so that the doubts and questions raised throughout the observation durations could be clarified. Under such circumstances, interviews with the persons involved were required immediately after the observation or the least within a reasonable time frame, e.g., within a week after the observation.

Notes taking and audio taping were used as the means of recording the designing activities. The practitioners under observation did not favour videotaping because some of the discussions undertaken in the design meetings were considered confidential. The main issues to be observed were the influencing factors of the decision-making process, and the mechanisms used to translate client requirements to technical solutions. The observations were analysed thoroughly afterwards to examine the decision-making pattern of the design team during the discussion and dialogue sessions of the meeting, in which close collaboration activities were undertaken.

A more thorough explanation with respect to the approaches used in the case studies for data gathering and analysis is given in Chapter 4.

2.3 Qualitative Data Analysis & Presentation

As per the research objective, which was to improve the efficiency of cross-disciplinary collaborative design, several possible means were explored, including the Semantic Web technologies, an extension of Internet. The Semantic Web technologies were studied in an attempt to analyze the contents of group discussions. A demonstrator was developed based on the findings generalised from the case studies. The prototype system (demonstrator) was considered one of the research outcomes, in which the collected data were analysed, interpreted, and transformed into a presentable and testable model. Consistent testing and improvement on the prototype system was conducted as a method to evaluate if the research hypothesis was truly deduced. Apart from that, writing of scientific papers became another important part of the research activity for this doctoral research study. The process of writing contributes to the research study as a polishing tool for reflections on the current research practices, including the skills, strategies and methods implemented throughout the entire study. International conferences were the means used to transmit the research results and to acquire constructive feedback and comments on the potential impact that the prototype would impose on the A/E/C industry.

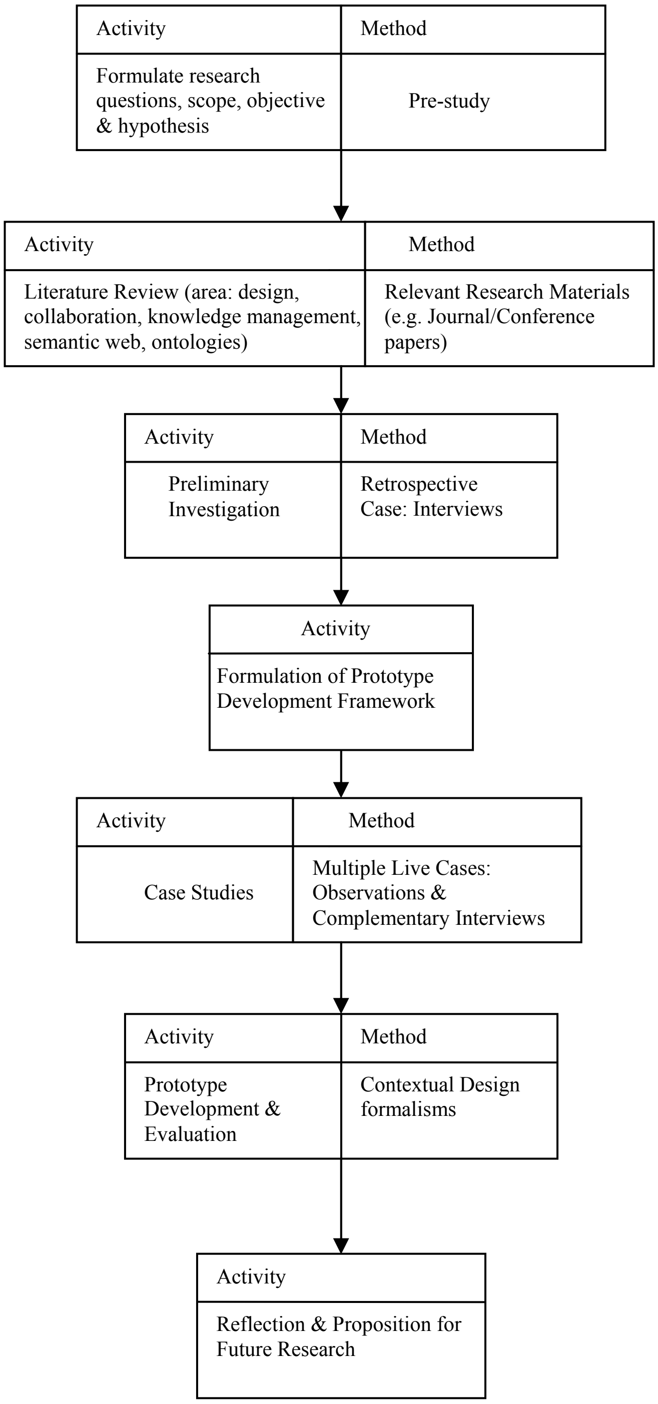


Figure 2.1: The Flow Diagram of the Research Methodology

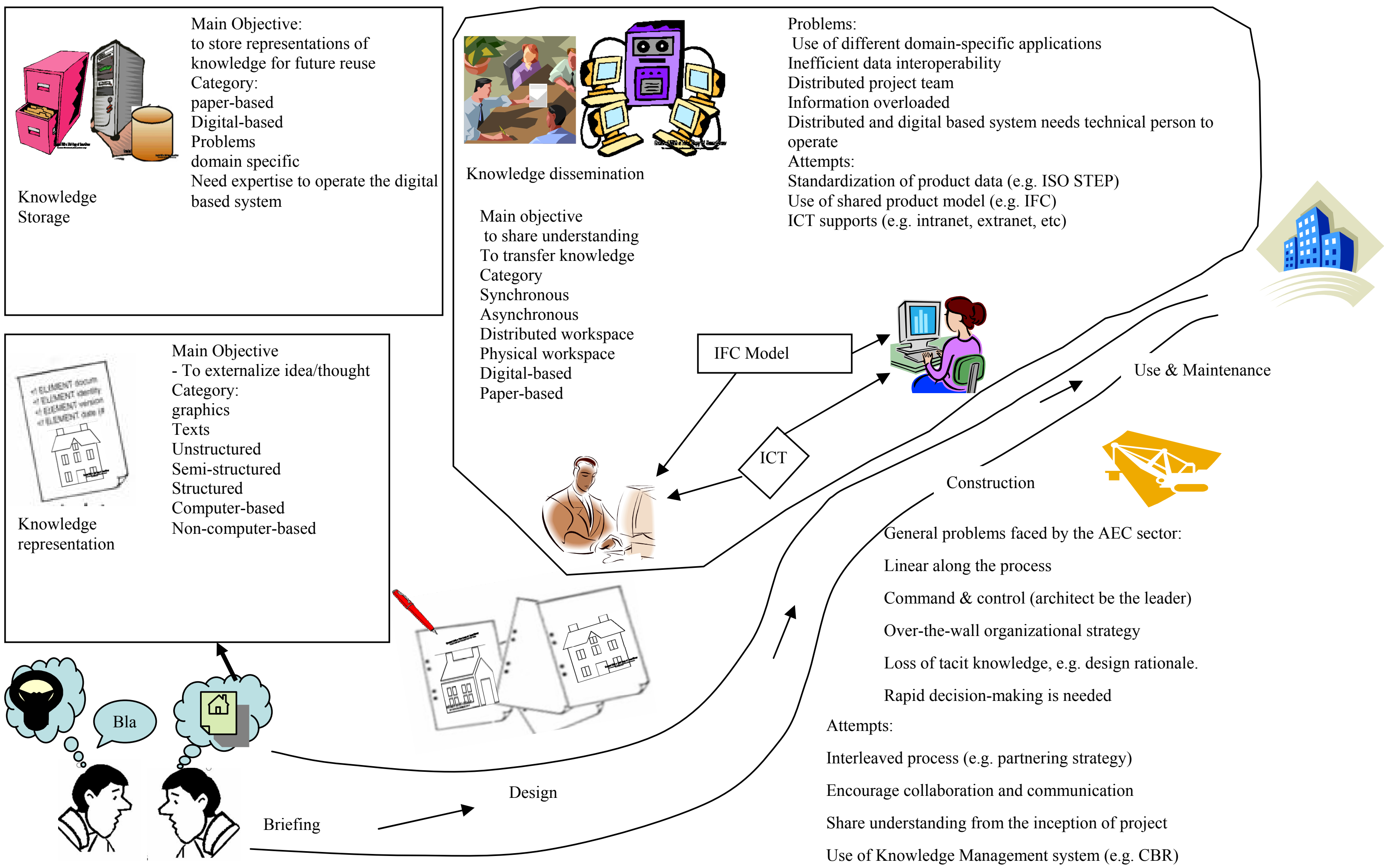


Figure 2.2: The current practices and attempts undertaken in the AEC sector to solve the identified problems

3 DESIGN AND COLLABORATION

Every positive value has its price in negative terms…The genius of Einstein leads to Hiroshima.

--Pablo Picasso--

3.1 Psychology of Problem Solving

Over the decades, many attempts have been made to describe the complex design process. Amongst those, "design is a rational problem-solving process" introduced by Simon (1969) and "design is reflection-in-action" perceived by Schön (1983) are the two most popular paradigms that underlie most of the research paths in the area. However, which paradigm of these two is more apt for its best description of design practice remains an argument amongst many designers. The following sections will provide an introduction into the cognitive psychology and heuristics of humans to gain a better understanding of the behaviour of designers particularly when they find solutions to their design problems. In cognitive psychology, a problem is characterized by three components: an undesirable initial state, a desirable goal state, and the obstacles that prevent a transformation from the undesirable initial state to the desirable goal state at a particular time point (Newell and Simon, 1972). Solving a problem requires a certain amount of factual knowledge about the domain of the problem part of which has already been transferred into memory and is then called the epistemic structure. To find the solutions for a particular problem, a designer also needs certain procedures or methods that involve the heuristic structure of human thought including both the explicit and tacit knowledge. However, in most cases the designer finds a solution not based on a fixed plan, but randomly based on his/her knowledge. This spontaneous activity is supported by association of ideas, which is argued as a further aid to the conscious thinking process (Pahl & Beitz, 1996; Schank, 1982).

3.2 The thought structure

Humans have both short- and long-term memory. Short-term memory has been defined as a kind of working storage that has limited capacity and can only retain about seven (Miller, 1956) arguments or facts at the same time (Schank, 1982). Long-term memory probably has unlimited capacity and consists of factual and heuristic knowledge stored in a way that is semantically structured by relationship networks. Memory can therefore be symbolized as a semantic network with nodes (knowledge) and connection (relationship) that can be modified and extended (Schank, 1982; Schön, 1987) via a series of thinking processes. As also proposed by Schank (1982), memory is dynamic. Memory adapts in accordance with its experiences as a learning process of humans. In other words, memories change the way they used to be grouped when they found that the early clustering is inadequate in some way, particularly when one experiences failure from an expectation point of view.

Thinking processes can proceed intuitively and discursively (cognitively). This takes place in the memory of humans and involves changes in memory content. Intuitive thinking is associated with flashes of inspiration which to a large extent occur unconsciously. Insights caused by some trigger or association appear in the conscious mind suddenly. Intuitive thinking can be explained as the primary creativity that is activated by both conscious and unconscious thinking activities. Intuitive thinking occurs when cognitive reasoning fails particularly when one deals with vague concepts, imprecise definitions and episodic memories. A substantial number of writings have occurred in the area of tacit knowledge and intuitive thinking presenting quantitative and physiological proof that intuitive thinking and tacit knowledge are more robust, and more sophisticated than cognitive thinking and explicit knowledge. Reber, one of prolific researchers in this area asserted that "When people were observed making choices and solving problems of interesting complexity, the rational and the logical elements were often missing (Reber, 1993, pp.13). Moreover, people often did not seem to know what they knew nor what information it was that they had based their problem-solving or decision-making on." (Reber,1993, pp.13). Nisbett and Wilson (1977) also asserted "It's often the result of a reasoning process, rather than the reasoning process itself which shows up in conscious thought".

In his seminal discourse, The Tacit Dimension (1983), Michael Polanyi, a philosopher made his argument about tacit knowing (knowing-without-saying) by giving several common sense examples. Tacit knowing is an interchangeable term according to Reber (1993). Polanyi (1983) exemplified that each of us could recognize our spouse's face among a thousand others without being able to explain exactly what features prompted our decision; physicians regularly diagnose rare diseases with very subtle sympomologies without being able to accurately explain the specific cues that led them to their conclusions. Time is, however, needed for the intuitive thinking processes before sudden insights appear. Insights can be stimulated, for instance, by conducting freehand sketches of the solution ideas (Pahl & Beitz, 1996).

On the other hand, discursive thinking or cognitive thinking is a conscious process that can be communicated and influenced. This thinking process is referred by many cognitive psychologists as the secondary creativity where facts, individual ideas or solution attempts are consciously analysed, varied and combined in new ways so that they can be checked, rejected and considered further. Discursive thinking involves checking exact and scientific knowledge and building this into an explicit knowledge structure. In our memory structure, explicit and consciously acquired knowledge cannot be separated precisely from the vaguer tacit knowledge, while they are actually complementing and influencing each other.

A number of different models have been developed to represent the fundamental sequence of the thinking processes, including the TOTE (Test Operate Test Exit) (Miller et al., 1960) model, which demonstrates the basic problem solving iteration loop. A general solution-finding model as illustrated in Figure 3.1, is then proposed by Pahl & Beitz (1996) based on the TOTE. This model is adopted as the guideline for one of the features of the prototype, i.e. the contextual map that is developed for this doctoral research study, and will be explained in the Chapters 5 & 6.

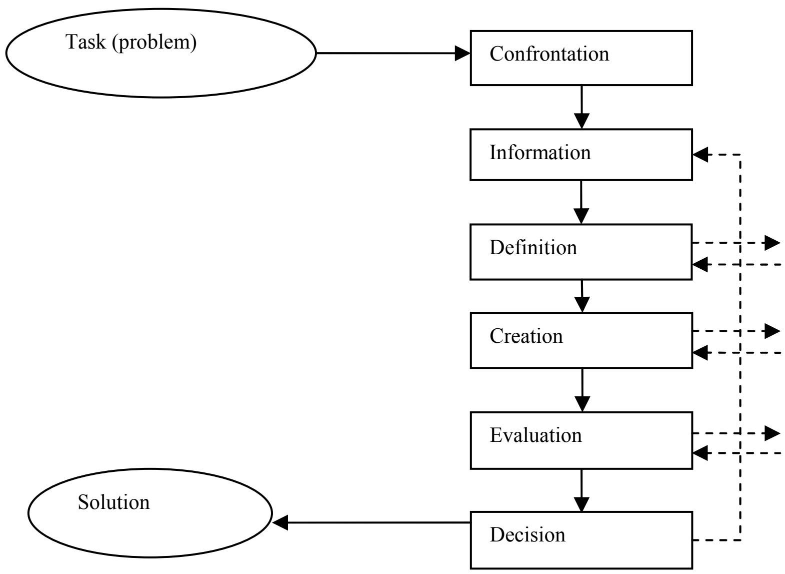


Figure 3.1: The generic solution finding process that reflects the simple decision making loop (Source: Pahl & Beitz (1996)).

3.3 Design Paradigms

What is design? Schön (1983) acknowledges Dewey's view that the heuristics in design activity is that the designer converts indeterminate situations to determinate ones after dealing with many variables of constraints, some initially known and some discovered during the process.

The paradigm of seeing design as a rational problem solving process takes classical sciences as the model for a science of design (Simon, 1969). This approach takes design as a search process, in which the scope of the steps taken towards a solution is limited by the information processing capacity of the designer. A more stable problem definition is therefore needed to allow the designer to define the solution space that has to be surveyed later. This paradigm has been the dominant influence that shapes both the prescriptive and descriptive design methodologies that are still followed. Some designers agree that this paradigm describes more appropriately the later stage of the design process where logical analysis and contemplation of design are the main ways of producing the solutions.

Another paradigm which has equal importance to the one proposed by Simon is to see design as a process of reflection-in-action. Schön (1983) introduced this paradigm specifically to address some of the unexplained blind spots and shortcomings he perceived in the methodology proposed by Simon. Schön argued that any design problem is unique, and it depends solely on the skills of designers to determine how every single problem should be tackled. He terms this with the notion "knowing-in-action":

"Once we put aside the model of Technical Rationality which leads us to think of intelligent practice as an application of knowledge… there is nothing strange about the idea that a kind of knowing is inherent in intelligent action… it does not stretch common sense very much to say that the know-how is in action… There is nothing in common sense to make us say that the know-how consists in rules or plans which we entertain in the mind prior to action." (Schön, 1983: pp 50).

According to Schön, when knowing-in-action breaks down, design is a "reflective conversation with the situation", in which designer actively sets or 'frames' problems followed by taking action to improve the current situation. Instead of evaluating concepts, designers evaluate their own actions in structuring and solving the problem based on the criteria of coherence (am I following a line of reasoning), in accordance with the specifications (am I on the right track), and the problem-solving value (have I made things worse?). The designer's personal view on the design problems and his/her personal goals determine how s/he sets the frames. In other words, the designer frames problems and shapes the situation to match his/her professional understanding and methods, corresponding to his/her personal experiences and background knowledge. The author would therefore suggest that this coincides with the theory of intuitive thinking where insights are generated from dealing with episodic memories, vague concepts and imprecise definitions. These insights are also the so-called inspirations that the designer relies on to frame problems followed by solving them. This suggestion could probably explain why some designers, in particular the architects, are fond of travelling. From the travelling activity, designers believe they will gain new experiences and memories. Some practitioners, therefore, believe that this paradigm works particularly well in the conceptual stage of the design process, where the designer has no standard strategies to follow and is proposing and trying out problem/solution structures.

At the conceptual design stage, designers often seek and discover solutions for difficult problems by intuition, in other words, solutions come to them in a flash after a period of search and reflection.

Under most circumstances, designers believe that the origins of solutions discovered by intuition are tacit and not traceable. Designers are also aware of the danger of relying on the purely intuitive methods (Pahl & Beitz, 1996), which increases with specialization, division of tasks and time pressure. Based on their practical experiences, designers discovered that certain methods are essential to give stimulus to their intuitive thinking. The simplest and most common of these is by associating ideas via discussion with colleagues and/or project team members. Brainstorming, Synectics, Delphi Method and many others are approaches that have been developed and widely implemented for this purpose. A summary of the two basic paradigms conducted by Dorst & Dijkhuis (1995) is shown in Table 3.1 to provide a comprehensive overview with regard to the strategies and implementation under various circumstances.

Table 3.1. The comparison of design paradigms ***(Source: Dorst et al., 1995)***

	Rational Problem Solving	Reflection in Action
Designer	Information processor (in an objective reality)	Person constructing his/her reality
Design problem	Ill defined, unstructured	Essentially unique
Design process	A rational search process	A reflective conversation
Design knowledge	Knowledge of the design procedure and "scientific" laws	Artistry of design: when to apply which procedure/piece of knowledge
Example/model	Optimization theory, the natural sciences	Art/social sciences

3.4 Design Process

It has been common in the A/E/C sector to divide the early project stage into several main phases such as those proposed by RIBA (RIBA, 1973):

Inception and feasibility
Outline proposals
Scheme design
Detailed design

The design process is an iterative collection of steps. Theoretically, the design process starts by composing the client's requirements then proceeds sequentially to the detailed design phase. Compared to the manufacturing industry, the A/E/C industry has relatively less effort in developing a standard design process mainly due to the fragmented nature of the industry (Latham, 1994). Nelson et al. (1999) also reported that the manufacturing industry is used to taking a process view of their operations. Manufacturers usually model both discrete product activities and holistic high level processes for both internal and external activities (Nelson et al., 1999). The fragmented nature of the A/E/C industry typically stems from the short-term basis of the project contract that usually ranges from two to five years, inconsistent players who change from project to project, non-permanent production sites and the existence of the cultural, behavioural, organizational and institutional differences between the project participants. The design process protocol suggested by RIBA was identified as weak because it is insufficiently generic for wide construction works (Fleming et al., 2000), describes design phases in linear sequence (Austin et al., 2001; MacMillan et al.,2002) and sets out only what should be undertaken while neglecting the rationale of why and how it should be performed. In spite of this, the RIBA's design process protocol is still used as the reference in this section of discourse for the reader to grasp a common understanding about the notion of the conceptual design stage.

Conceptual design usually starts with requirement analysis followed by functional specification and finally proceeds to designing the building form. In other words, conceptual design starts from where the business needs are triggered and ends before the detailed design phase starts. Conceptual design is inherently comprised of three iterative activities, i.e. problem analysis, solution synthesis and evaluation (Fruchter, 1996). In the A/E/C sector, a building project is triggered by some ideas concerning the need for a particular kind of building or building works. Thus, the design process is initiated to understand the client's requirements by identifying all the elements of the problem, including the goals to be achieved, and the possible impacts imposed by the potential solutions (Kalay, 2004). *Client* is the term usually used to refer to the initiator of the project. The client may be an individual, or a body of persons legally able to act together as if they are one individual, for instance, a corporation. At the project outset, the project is planned based on the embryonic client's requirements by undertaking analysis from various aspects, including the purpose of the project, its benefits, its risks, any legal, physical and financial constraints and the alternative of procurement methods. Project planning can be carried out by the client either with or without the assistance of an architect. In this planning phase, the rational problem solving approach is implemented at an abstract and preliminary level. A project brief is the outcome after several less formal discussions and idea generation sessions are conducted between the client and his/her commissioning team. The commissioning team may consist of multidisciplinary individuals, each of which has a different interest in the project. Apart from discussions and brainstorming sessions, the rational analytical process also relies on precedents surveys, building codes, economic and physical forecasting and other sources.

After formulating the project brief, the client will approach an architect to further the project to develop the functional requirements. The architect, with assistance from various design professionals, will develop a design brief (or program in US), which incorporates a more thorough exploration of the client's needs. The exploration incorporates different aspects of the building design, including the spatial requirements and their arrangements, the performance of the physical structure, and the requirements with respect to the fittings and services. The client is responsible for selecting alternatives that can best meet his/her own needs amongst those proposals outlined in the design brief. Compromise is unavoidable if conflicts between client's needs and some constraints identified from the legal, practical and economic aspects occur. The selected alternatives are then translated into functional requirements by the architect based on close collaboration with all of the involved parties including the client. The functional requirements are then documented and associated with the identified constraints in the design brief, a type of documents prepared by the design team to facilitate further design exploration in which the design of the building layout is initiated.

The building layout (or the form of the building) is designed after the functional requirements have been well developed. This is the typical design process that reflects the famous axiom "Form follows function" suggested by Louis Sullivan (Sullivan, 1896). "Form follows function" is a design principle widely accepted by many designers. This design principle suggests that the purpose of a building should be the starting point for its design, and functional requirements are developed to provide a better grasp to the client as well as the design team about the purpose of the building from various perspectives including both the spatial and functional needs. In brief, this is the creative phase of the design process, where the designers form ideas and possible solutions based on the functional requirements derived from the earlier feasibility analysis. The solution is created and selected through synthesis that benefits from familiarity with precedents, metaphors, reflective sketching, as well as formal knowledge of rules of composition and style (Kalay, 2004). Several preliminary overall layouts of the building are synthesized in line with technical and economic criteria during this design phase, i.e. scheme design as conformed to the design process protocol suggested by RIBA. These layouts are evaluated thoroughly based on several criteria including function, structural stability, spatial compatibility as well as the financial viability of the project in order to choose one that is to be brought forward to the detailed design phase.

In the detailed design phase, detailed design is developed from the chosen and approved scheme design. Details of design including the arrangement, detailed dimensions, and materials used are required to be specified, types of construction are assessed, costs are estimated and all the detailed drawings and other essential documentation are produced with reference to the particular Building Acts and/or Regulations and other statutory requirements (RIBA, 1973). This is the phase where the rational and systematic problem-solving approach is of particular importance to evaluate and estimate the potential consequences of the decision made.

Nevertheless, in the real world, it is implausible to draw a clear boundary between design phases as suggested in the RIBA's model Plan of Work. For instance, aspects of the layout may have to be addressed during conceptual design, and it may be necessary to determine part of the construction process in detail during the scheme design phase. Within every main phase, there are some important working steps or sub-phases forming the basic decision-making loop. The loop iterates continuously until a satisfactory result is obtained to provide the basis for the subsequent working steps so that the design process can proceed. It is also possible that the result of a decision making step is unsatisfactory. This circumstance may result in certain steps having to be repeated. Collecting information, searching for solution, calculating, drawing and evaluation are the elementary working steps accompanied by indirect activities such as discussing, classifying and preparing. A design process is beyond a linear iterative process has been a concept proposed in several research reports, such as Hickling (1982), Austin (Austin et al., 2001), and MacMillan (MacMillan et al., 2002). Hickling suggested the existence of a whirling process of decision making in design (Hickling, 1982). The suggestion of Hickling (Hickling, 1982) was later asserted by Austin (Austin et al., 2001) and MacMillan (MacMillan et al., 2002) based on the results obtained from their experimental workshop in which the conceptual design activity of fifteen design professionals was tracked and mapped. The design process framework tested and validated in the experimental workshop was reported showing the substantial pattern of the iterative nature of the design phase (Austin et al., 2001; MacMillan et al., 2002). However, structuring individual tests and decision-making steps explicitly for every single action is implausible considering that designers work under the paradigm of reflection-in-action, where more intuitive thinking is involved.

3.5 Collaboration in the A/E/C Sector

Design and construction in the building sector is ultimately project oriented, where a multidisciplinary team of clients (or representative of clients and interest groups), users, architects, engineers, building contractors, regulators and developers is formed to work collaboratively on a particular project, and the team is dissolved after the project is completed. The effectiveness of collaboration amongst the team members, particularly during the design stage of the project has a major influence on the quality of the final product. The need for collaboration arises when the limits of their individual abilities prevent people from completing a given task on their own due to several factors such as lack of knowledge, authority (power), and/or resources. Collaboration also helps people to complete a task more quickly and more effectively based on group work than they could on their own. Properly handling collaboration can be an enabling force for the group, or it will be a restrictive force. The sharing of value that is not only in terms of monetary profits but also experiences and knowledge (Wenger, 1998) is the prominent gain of the positive effect. The negative effect, on the other hand, may result in potential conflicts that may eventually need to reach a compromise.

Kvan (Kvan, 2000) believes that the design process in reality is a continuous loose-coupled process rather than what has usually been semantically interpreted from the word "collaboration" as a close coupled process. During a loose-coupled design process, participants contribute what they can in different domains of expertise at moments when they have the knowledge appropriate to the situation. Dorst (Dorst, 1996) observes that designers often practice "satisficing[2]". It is also explained in (Cross and Cross, 1995) that collaborative designers reach design decisions that are not the best solution, but instead are adequate. The same practice is also mentioned in (Kvan, 2000) as compromising, in which a win-lose situation is created as outlined by Kuhn (Kuhn, 1974). These findings coincide with the study result concerning the cognitive psychology of discussion given in (Senge et al., 1994). The result among other things concludes that participants in a group discussion tend to converge their thinking through sacrificing their own wills to a certain extent for reaching a consensus agreement. Apart from compromising, Kuhn (Kuhn, 1974) acknowledges two more means that are possibly used to mediate conflict, which is a very common incidence during collaboration: persuading one side of the conflict to adopt the position held by the other side and; jointly arriving at a new paradigm in which the parties can attain a win-win situation.

3.6 The Dark Side of Collaborative Design in the A/E/C Sector

It has never been easy to juggle between the positive and negative effects of collaboration. This complex and challenging task has been the subject of study in almost every field, including sociology, psychology, politics, technology, and professional practices such as law, medicine and engineering. Collaboration in the A/E/C sector may be even more complicated than in other fields due to the engagement of the multidisciplinary actors who rarely share a common educational basis. This phenomenon in the A/E/C sector differs from the others such as medicine in perceiving collaboration, particularly with regard to design. The project-oriented nature of the A/E/C sector also plays a hampering role. There is always a possibility that the short-term goals of the project contradict with the long-term ones of the organization from which an individual or a particular team comes. Any issues, financial, legal, ethical as well as professional, can be the source of the disagreements. The dynamic job market may also create a tense situation in collaboration in a way that participants are always required to adjust their working habits, styles and paces in order to keep up with the rate of members changing or replacing.

Communication is fundamental for achieving better collaboration amongst the participating professionals. However, efficient communication amongst these multidisciplinary individuals seems hard to attain. Along the design phase, which begins from conceptual design to bid evaluation and contract negotiations (RIBA, 1973), the architecture and engineering design teams produce project-related documentation including for instance CAD drawings, both function and technical specification, and cost estimations, as a way to convey their design decisions. Interdisciplinary communication particularly that between architects and engineers, usually seems to be the cause of the bottleneck in the design process. It is the author's belief that many of the reasons for the poor interdisciplinary communication stem from the fragmented nature of the industry. This perspective is also asserted by Schön (Schön, 1988) who characterises designing as a social process. He asserts that extra concern is needed to achieve a successful collaborative design because participating multidisciplinary individuals tend to pursue different interests, see things in

[2] "satisficing" is a term coined by Herbert A. Simon in his book The Sciences of the Artificial (Cambridge: MIT Press, 1969), to indicate solutions that are both satisfactory and sufficient to achieve the goals and abide by the constraints of the problem.

different ways and even speak different languages (Schön, 1988). As asserted by many researchers, amongst them for instance Fruchter (Fruchter, 1999) and Kalay (Kalay, 2004), one of the main reasons for the fragmented nature of the industry is the disciplinary specialisation in educational training. Discipline-based education has successfully equipped engineers and architects with increasing amounts of knowledge in a specialised field, but has also increased the difficulty for these two disciplines to communicate, particularly when each of them adheres strictly to their respective specialised worldviews.

In general, architects differ from engineers in the nature of their professional training and working habits. The notion of design is poetic to architects rather than a systematic solutions searching process. To architects, the synthesis of design solutions is not primarily a rational process that involves 'problem-solving', 'information processing', or 'search' (Schon, 1988), but rather involves more intuitive thinking though it also benefits from familiarity with precedents, metaphors, reflective sketching, as well as formal knowledge of rules of composition and style (Kalay, 2004). In most cases, architects claim that they need an appropriate environment in which surroundings can induce them to get better inspirations. On the contrary, engineers were trained to design in a rational and systematic manner in which more discursive thinking is involved. Engineers are used to structuring design problems and tasks in an ordered and stepwise approach so that possible solutions can be sought more quickly and directly.

Furthermore, engineers and architects are used to responding differently to the notion of ambiguity when they approach their work. Engineers tend to expend a great deal of effort to eliminate ambiguity from their terminology and methodology. They believe problems and solutions can be communicated better if there is only one possible interpretation. In this respect, problem statements with unique solutions are preferred over those with multiple solutions. This motivates the development of various problem-solving approaches attempting to deal with design as a predictable problem-solving process. For instance, the structural engineer tends to design by referring to a prescriptive model that was developed conforming to the building codes, and rule-based systems. This approach is still widely used among engineers as an effective approach to find solutions to problems. On the contrary, architecture is as much a form of art as a technical discipline. Architects strive to create spaces and meaning in the built environment that can be interpreted in more than one way. Schön (Schön, 1988) addresses this perspective on designing as "designers discover or construct many different variables. These (variables) interact in multiple ways, never wholly predictable ahead in time." Schön (Schön, 1988) further asserts that in order to formulate a design problem to be solved, the designer frames a problematic (Dewey, 1982) design situation by setting its boundaries, selecting particular things and relations for attentions, and imposing on the situation, a coherence that guides subsequent moves. A further analogy may be drawn between this different nature of practices that dominate the two disciplines and the design paradigms described in Section 3.3.

Clearly, design in the building sector combines efforts of both architects and engineers. Nevertheless, it is also the author's belief that efforts of architects usually lie in the creative phase supported by Schön's reflection-in-action paradigm where abstract results with poetic content may be generated. When the process moves on, the poetic solution needs to be further developed and complemented with the aids of engineers from different professional domains. Design at this stage is more likely to conform to Simon's problem-solving paradigm in which design solutions are sought through an iterative search process.

Based on these fundamental differences between the two disciplines as they interact, many practitioners would say it is almost impossible to reduce architectural objectives to deterministic engineering formulas (Haber, 2000). In order to collaborate better to make a building design project a success, both disciplines recognise the need to share design tools enhanced with data models and structures that can reflect the multi-stage design process. Numerous leading researchers in the area remark that the intrusion of computer technologies into the area has offered hope for the possibility of non-trivial interactions between the disciplines (Fruchter, 1999). Computer-based design tools and the advances in design information management and collaboration support systems have had a positive impact on improving collaboration. In brief, computer technologies have been recognised as playing an important role to improve the inter-disciplinary communication via various mechanisms that share an ultimate goal, which is to enable efficient understanding sharing between the different disciplines so that the optimum state of collaboration particularly in the design phase can be achieved. In light of this, professionals practising in the A/E/C sector have contributed to various research areas in order to seek the most effective approach to improve the performance of collaborative design. Studies undertaken for this purpose are in a wide range, but can be generally categorised as follows:

a) improve collaborative design by changing the habitual product development strategy (see Section 3.7)
b) improve collaborative design through a different educational approach (see Section 3.8), and
c) improve collaborative design by implementing ICT tools support (see Section 3.9).

A brief description with respect to the relevant researches corresponding to each of the above-mentioned category will be given below.

3.7 The correlation of product development strategy and collaborative design

3.7.1 The traditional over-the-wall product development strategy

Communication has been a critical aspect of the multidisciplinary A/E/C sector for achieving better collaboration. Different types of synchronous and asynchronous interactions are used for communication in order to enable intensive information sharing and exchange. It has been a tradition to run a building project based on contractual agreement following a conventional linear product development process. Over-the-wall has been a popular approach used to carry out the linear product development process (e.g., the design process) in which different design departments involved are functioning independently and sequentially. While practising the over-the-wall approach, the responsibility for the design project is transferred from one design professional after completing his tasks to the next professional. Limited interactions are involved between the two professionals while completing their respective tasks. For instance, after finishing his layout design without having many discussions with the structural engineer, the architect “throws” the layout drawings “over” to the structural engineer. The design process continues by passing on the result of every design stage from the responsible professional to another until as-built drawings are produced during the construction stage. The over-the-wall practice is noticeable in the design-build-use procurement method, which has been applied within the building industry for years. The over-the-wall practice is efficient in terms of process in order to get the appointed tasks done, but it also may introduce the feeling of lack of ownership on the product. This pitfall may eventually diminish the overall performance of the product once the involved stakeholders reduce their commitments.

Another side effect of the over-the-wall practice is the generation of a series of discipline-oriented product models, each of which reflects the repeating efforts of interpreting, extracting and entering the relevant design information. Fruchter (1996) also observes that the design team members usually communicate alternative solutions using separate models corresponding to the design of their respective discipline; private and individual engineering notebooks to record background information; disciplinary-centric representational idioms; and diverse media for transferring design information. These practices of the design team create fragmentation of the information flow that worsens the communication of knowledge, including the design rationales and intents, decisions made, and problems across disciplines along with the design process. The fragmentation of information flow may also result in the risk of knowledge loss and miscommunication, in particular, when deterioration in knowledge sharing between the "upstream" (e.g. clients and architects) and "downstream" (e.g. construction managers and facility managers) project stakeholders occurs. In other words, knowledge applied in the earlier design phase may be lost when the responsibilities are transferred because knowledge that resides in "downstream" participants is rarely transferred to the "upstream" participants. Conflicts that arise among the multidisciplinary stakeholders at the early design stage may become critical if the problem of miscommunication remains consistent when the design process progresses into the latter stage.

3.7.2 The contemporary partnering approach

The drawbacks of the traditional method of handling team collaboration as discussed above has resulted in the demand for a new collaboration path to enable proactive interaction between the project stakeholders. A contemporary approach, namely the partnering concept, has started to gain interest from the building industry for implementation in building projects. By implementing this approach, the main stakeholders of a building project, including the client, architect(s), engineers, contractor and sometimes the suppliers and the authorities are invited to contribute jointly with their expertise and experience from the very early stage of the project. Partnering holds the principle to distribute responsibility corresponding to the amount of work and encourages the stakeholders to participate with mutual goals in any part of the project where improvements to their work are applicable (Christiansson et al. 2002).

DIVERCITY (Distributed Virtual Workspace for enhancing Communication within the Construction Industry) was an EC funded project conducted with the partnering concept implemented. As reported by Christiansson (Christianson et al., 2002) this project was conducted to tackle the problem of insufficient technological approach in providing an efficient workspace for special- and temporal-distributed collaboration. This project aimed at developing a "shared virtual construction workspace" that would allow construction companies to conduct client briefing, design reviews, simulate what-if scenarios, test constructability of buildings, and communicate and co-ordinate design activities between teams. The prototype of the project was assessed in a real-life project (Christianson et al., 2002). End-users of the prototype from each stakeholder group (e.g. the architects, engineers, contractors and clients) were actively involved in defining an optimum workspace during the Divercity project development process. The IFC-standard, as well as the ISO Part 42 of STEP (Standard for the Exchange of Product data) were implemented in the Divercity framework to represent building information in a shareable product data model in order to eliminate errors and to improve the accuracy while exchanging information. IFC (Industry Foundation Classes) is developed under the cooperation of the IAI (http://iaiweb.lbl.gov) and some other world leading research institutions as the basis for project information sharing within the building industry, including the sectors of architecture, engineering, construction, and facility-management. A promising success was reported at the end of the project in which a collaborative, explorative and enriching workspace was created and tested based upon the corporation of science and industry (Christiansson et al., 2002). It is also reported that the innovative workspace has successfully diminished the exited discipline-centric barriers by establishing effective collaboration scenarios based on mutual visions.

3.8 Collaborative Design improvement from the educational aspect

Discipline-based education has rooted in the A/E/C sector over the decades and induces professional fragmentation that subsequently results in poor coordination and communication amongst the professionals. Under such discipline-based educational structure, professionals shape their own worldview in a way that is seldom aware of the views, beliefs, and methods of their peer disciplines. Even though emerging technologies promise to provide the means to bridge these fragmentations, technologies alone can hardly achieve their optimum effects without an improved teamwork. To accommodate the rapidly changing needs of the profession, reshaping curricula by focusing on multidisciplinary teamwork improvement has been initiated and tested at some institutions. A learning environment was tested based on a PBL (Project Based Learning) pedagogical approach at Stanford University to investigate how to team up the multidisciplinary, geographical distributed practitioners with cutting-edge information technologies (Fruchter, 1999). At the end of the evaluation, a promising evolution from the state of island of knowledge to a state of understanding of the goals, languages, and representations of different disciplines was noticeable amongst the students who participated in such cross-disciplinary courses.

3.9 Collaborative Design improvement through ICT Support

3.9.1 How does ICT change the practice of the A/E/C domain?

Developing computer-aided building design systems that could be used throughout the design process from briefing to the detailed design stage have gained the attention of research groups in the A/E/C domain since the early 1960's where the first rudimentary CAD (computer-aided design)-systems were developed. After decades of research in the area, the basic consensus achieved for such systems is to have a wide range of capabilities that are not limited to generating plan drawings, but also can assisting in behavioural evaluation as well as producing the respective evaluation reports. In the 1980's, the use of CAD systems in the A/E/C domain as a drafting tool was growing in numbers. In parallel with the CAD systems, a growing interest in new software techniques emerging from artificial intelligence motivated research projects tempted to investigate the potential contribution of expert systems to the A/E/C domain. For example, according to Eastman (1999), much focus was put on developing Prolog-language-based building design systems back then. During this period, relational database systems started to be used for developing integrated building design systems because of the systems' capability in managing large amounts of data. However, prototypes, developed as the results of the various researches, were generally too slow and had poor user interface, causing a lack of interest by commercial software developers (Eastman, 1995).

After conducting numerous exploratory interviews within the sector (for details see Chapter 5), the author finds that the time spent in repetitive works, such as re-inputting information and data that exist in different formats, has been the motivation source for the need of shared and integrated databases. Björk (Björk, 1995) also points out that the concept of shared and integrated databases started to evolve and brought forth the need for standardizing digital building descriptions. The advances in artificial intelligence, database theory and object-oriented programming languages started to show their ability in providing promising data representation methods since the middle of 1980's (Björk, 1995). This contribution has facilitated the A/E/C community to formalize their ambitioned standards of building descriptions after realizing the deficiencies of IGES (Turner, 1988), which was a neutral format developed in the late 1970's to facilitate the exchange of geometrical data between the drafting-based CAD/CAM systems. The inadequacy of IGES (e.g. too large file size) has thus led to the initiation of STEP (Standard for The Exchange of Product model data) standardization process, which is organized under the International Organization for

Standardization (ISO). This ISO STEP and the later IFC initiatives underlie much of the efforts with respect to the development of the product model approach, which will be discussed below.

3.9.2 The Product Model

Björk (1995) derives product model as an information base that describes a particular artefact based on some predefined conceptual schema. A detailed discussion with respect to the definition of product model is available elsewhere (Björk, 1995). According to (Björk, 1995), the product model approach is principally of importance to bring about added values to various aspects of engineering product development. Among these aspects are the coordination and cooperation of teamwork, efficient integration of application tools, improved data exchange and sharing, common model repositories, better navigation in the multi-dimensional project data space, and so forth. In brief, the product model approach is developed to tackle problems arising from data incompatibility among interoperating applications that are very discipline dependent. Product model formalizes the representation of building information in some specific manners in order to form a basis for sharing and exchanging product data in a computer interpretable format between project stakeholders. An ideal product model is not one that caters only geometrical descriptions but also all other project relevant information that covers the whole project lifecycle from briefing to demolition, and is applicable across the multiple disciplines involved in the project. Developing a building product model that can hold different types of building information has thus been an ambition for the A/E/C sector to strive for over the decades. The evolution of the product model approach is comprehensively reviewed by Eastman (1999), and will be briefly discussed below.

The product model approach has gained attention within the A/E/C domain to develop different product data models for both generic and specific purposes. The GARM (General Architecture, Engineering and Construction Reference Model) model was one of the typical generic models developed to organize construction process information at a high level of abstraction regardless of the type of constructed artefact. The GARM is applicable to formalize information of buildings, off-shore platforms, process plants, and ships and so forth. On the contrary, the AEC Building System model was developed specifically to model the functional systems that a building comprises (Turner, 1988). The AEC Building System model was formalized using the NIAM (Nijssen Information Analysis Method) modelling approach, and represents a building through the collections of components of its functional system. The different focus of modelling has distinguished the Building System model from the GARM model whose best known features are the subclasses of functional unit and technical solution (Turner, 1988). Limited success achieved from the attempts of generic product model has resulted in a focus-shift to conceptual schemas that tend to describe specific domains, such as a specific design or construction discipline and/or a specific phase in the construction process. Such a specific purpose product model is termed as an aspect model by Eastman (1999). The COMBINE project exemplifies the effort in the category of the aspect model and produces the Integrated Data Model (IDM) in which data for applications related to the domain of HVAC design are represented (Augenbroe, 1995; http://erg.ucd.ie/combine.html). Other examples in the same category includes the MOB project that was conducted for facilitating data exchange between contractors and engineering companies, the RATAS project (1994) that was to bridge the areas of building design and construction management, and the CIMSTEEL project (SCI, 2000) that contributed its effort in the area of structural design. These different research projects have been conducted with varying degree of success but are all sharing the same objective, i.e. to integrate the project basis information. As pointed out by Eastman (Eastman, 1999), the product models generated from these research projects are generally inadequate in the following aspects: (1) extendibility in parallel with project progress, (2) ability of efficient management of various communication and information exchange across multidisciplinary and distributed design environment, and (3) support to context awareness that plays a role in improving knowledge management, particularly the implicit knowledge such as designer's intents and aims.

To date, a large effort is being undertaken by a non-profit industry consortium, the Industry Alliance for Interoperability (IAI) to develop an integrated building model that is useful in information integration particularly for data exchange. The integrated building model objects are standardised as Industry Foundation Classes (IFC) and is being developed as a neutral A/E/C product modelling support for the building lifecycle, which starts from client briefing to demolition. An IFC model structures project information in the form of class hierarchy to provide a standard data model and a neutral file format that enables efficient share and exchange of information between different types of computer applications. The IFC model covers the core project information such as building elements, the geometry and material properties of building products, project costs, schedules and organisations (IAI, 2000).

It is the ambition of the A/E/C community that by using the IFC model, the need for human intervention to re-interpret and re-format the data to communicate across various computer applications may be reduced, and thus reducing the error-prone data transforming procedure. However, there are researches reporting that the IFC product model (at the time of writing) exhibits a shortcoming in supporting the early design stage where unconventional and creative design activities are involved (Turk, 1998) while communication between design team members is based on weakly structured information, such as hand-written texts, sketches, and so forth (Popova et al., 2002). Ozkaya et al. (2004) also points out that the current IFC model remains incapable of tracing the increasing design information, particularly at the early design stage. Though its development emphasizes on solving issues of data integrity, data sharing and interoperability, the IFC model does not provide a facility for the designers to record their design rationales and intents, which tend to appear as the designers' tacit knowledge. The product model approach assumes that the readers of the data will interpret it using their own professional knowledge. This practice has made communication easier and more efficient, but does not improve understanding sharing, which is fundamental for the collaborators during decision-making. To tackle this shortcoming, pragmatic approaches, such as integrating the ICT with the knowledge management methods, are being tried out in different research project attempts to bridge the gap between users, data models and software applications aiming at providing a common medium for efficient communication between the multidisciplinary collaborators.

3.9.3 The Process Model

Process modelling has been an underlying approach used to explore as well as explaining in detail the process of a particular course of action, be it the process of a whole project (e.g. building project) or merely the process of an iterative decision-making loop (e.g. see Figure 3.1). The main concerns of the exploration are definitely the intention to understand the key activities that take place in the process, the kind of decisions that need to be made, and the information transactions that take place through the process (Bacon, 1998).

For many decades, building processes have been defined and modelled by less formalised methods to serve mainly the internal needs of companies. Process models as such are often prescriptive because they often take the form of checklists of activities published by trade associations for rationalising working methods. These models are useful for clients as the instrument for quality control and budgeting. Professionals in the A/E/C industry characterise the building process as complex and difficult to be formalised compared to other industries such as the manufacturing industry. The complications of the building process may stem from the unique characteristics of a building project including the following:

One-of-a kind of the building project. This characteristic results in the difficulty in modelling reusable knowledge about processes undertaken in a specific building project. The sequences of activities, roles of actors, times schedules are subject to project specific changes.

Short-term/contractual basis organisations. Definition of roles of actors and their corresponding tasks are project oriented. It is time consuming to model a process that is only valid for a temporary organisation.

Multiple perspectives and interests. Conflicts of interests are common phenomena that may occur in a building project because the success of the project would depend on no single actor. Different actors have different views and pursue different interests throughout the whole building process. It is thus difficult to model a process in a way that is adequate to reflect all of the different views from all of the participating actors.

Involvement of site work. The location of building parts, mobile workers, machines, materials and other resources is a key issue that must be taken into account while modelling the process. These issues are very project-specific and thus considered to have least reuse value.

Given the complexities of the building process, the international R& D community within the A/E/C sector has not yet established a standardised process protocol, which can be comparable to the steadily developing product model whose theoretical basis is more solid and well established by worldwide research groups, such as the International Standards Organisation (STEP) and Industry Alliance of Interoperability (IFC). However, the need of a process model is identified to be important to improve the collaboration performance of a building project by many researchers who dive into the area in the past decades, amongst them are Chiu (Chiu, 2002), MacMillan (MacMillan, 2002), Turk et al. (Turk et al., 1998), Hannus et al. (Hannus et al., 1995), Kagiolou et al. (Kagiolou et al., 1998), Björk et al. (Björk, 1999). These studies share a common goal, which is to understand the building process in order to identify the critical problems that are likely to hinder its progress. The common finding of these studies, among other things, is to suggest the important role of process model in improving cross-disciplinary collaboration within the A/E/C sector. Chiu (Chiu, 2002), in his empirical study concerning the organisational view of design communication in design collaboration, suggests that a process model is important to enable the involved project participants to collaborate in such a way that they can understand their respective position in design collaboration in order to complete their design tasks efficiently. This is of particular importance when designers from different professional backgrounds are engaged to proceed with their different habitual working methods to attain the best solution via collaboration.

Since the 1970s, a number of promising process models, both descriptive and prescriptive, either general or specific to a particular project, has been devised at different level of details. Some of these models are established to represent the generic framework of the overall building process. There are also process models with very high level of technical details to describe how to install different types of building components (Björk et al., 1999). A specific process model is often devised to describe workflow of an actual process of a specific construction project. Thus, a specific model functions more like a project planning, which is to describe very unique process occurrences. The level of details of a process model is dependent on the purposes of constructing the model. A model can be generic to describe the typical processes of one of the many different aspects of the building process. Reference model is the term coined in Hannus et al. (1995) to describe a generic process model. The generic design process model developed by MacMillan et al. (MacMillan et al., 2002) is one of the examples in this category. This generic process model is structured to represent the design aspect of buildings projects (MacMillan et al., 2002). The generic framework, to its success, managed to illustrate the iterative behaviour of the design process undertaken at the conceptual design stage.

Studies in regard to the design process have contributed not only to the process models from the architectural and engineering perspectives, but also to the definition of the every individual design phase. Amongst those, for example, Pahl and Beitz, Cross, and Pugh have specified quite clearly the design phases and steps within each phase of the process. For instance, Cross (Cross and Cross, 1995) explains the basics of systematic design; Pugh (Pugh, 1986) devotes himself to developing a methodology encompassing the total development process that generically covers all design processes, namely the Total Design while Pahl and Beitz (Pahl and Beitz, 1996) drafts out a clean process model based on the systematic design approach. These contributions play the key role in laying the foundation for the consistent development of various process models in these recent years.

The most widely used model of building design is the RIBA plan of Work for Design Team Operation (RIBA, 1973). This model depicts the details of work to be conducted by every profession during each stage of the design process. However, the RIBA model does not take the information linkages between activities into account to indicate how particular tasks are related. In view of the inadequacy of RIBA's model, attempts are continued to combine the building design and construction process in the same representation. (Austin et al., 1996) and (Baldwin et al., 1995) combine the level of details given in the RIBA Plan of Work with information linkages by using data flow diagrams to present the different stages of the building design process. (Baldwin et al., 1995) focuses on the concept and scheme design phases of a project, while (Austin et al., 1996) focuses on modelling the civil and structural engineering elements at the detailed design stage. Furthermore, Karhu (Karhu, 2001) develops a generic construction process model (GEPM) with more modeling power. GEPM combines the object-oriented principles with the features such as task, activity and temporal dependency from modelling methods such like the IDEF0 (Integrated computer aided manufacturing Definition) and scheduling. GEPM is flexible in the sense that the conceptual model can be changed to achieve additional special features. This capability is also supported by the database implementation, which enables users to interact with the developed process models through views that represent partial models. The views support the IDEF0, scheduling, and simple flow methods as shown in Figure 3.2.

Virtual Building is a notion suggested by Christiansson (Christiansson, 1993) as an alternative to incorporate the building product model approach in a building process model in an attempt to improve the communication efficiency between the cross-disciplinary project participants at any time throughout the whole building life. Virtual Building is defined as "a formalized digital description of an existing or planned building which can be used to fully simulate and communicate the behaviour of the real building in its expected contexts" (Christiansson, 1993). Virtual Building is envisioned to change the fragmented nature of the building process to a more integrated one. The sequential building process is expected to be changed to be more parallel while the concept of product model can contribute the necessary information to stimulate the parallel building process. The virtual building may be generated at different times during the early project phase, for instance the design phase. It is thus a useful design instrument for simulating the behaviour of the building at different phases of the building life-cycle (i.e. from inception to demolition) when the building is still under design. The virtual building may also allow performance checking of the final virtual (simulated) building against the captured client requirements. Virtual building is required to provide a high degree of realism that the design, construction and use of the virtual building model can be undertaken in a seamless collaborative setting. By integrating the product model approach, virtual building may contain information about the real building on certain levels of detail. The application of the product model approach may facilitate more efficient product information exchange, which subsequently will enable better sharing of the different alternative solutions/versions.

3.10 Concluding Remarks of Chapter 3

Efficient cross-disciplinary collaboration is hard to attain if the fragmented nature of the A/E/C industry is persistent. Numerous approaches have been initiated, examined, experimented, refined and implemented within the A/E/C sector under the corporation of international R& D community and industrialists. These approaches are generally divided into three folds as discussed comprehensively above, which include imposing new strategy to change the habitual teamwork organisation, to restructure the educational program from single-discipline oriented to one that focuses on multidisciplinary teamwork training, and to implement the latest ICT to improve the efficiency of cross-disciplinary communication.

The concurrent ICT has been actively exploited within the A/E/C sector for finding the best approach or alternative to enable efficient cross-disciplinary communication at any time throughout the building life-cycle. At the present stage, the numerous efforts undertaken including the notion of sharing one unanimous product model as well as the wide spectrum of process models developed based on their respective objectives, are found sharing a common basis, which is to facilitate project information exchange. Product model, for instance, is an approach implemented for solving substantial issues of data integrity, sharing and interoperability within the overall building process. Process model is developed in an attempt to allow project participants to conduct proper planning of either the whole building process or only a particular aspect of the building process. For instance, the process model developed for a specific aspect such as the one reported in MacMillan et al. (2002), is envisioned useful to support designers in making decisions at the early design phase. IDEF0 is one of the most ubiquitous process modelling techniques found implemented within the A/E/C research community mainly because of its user-friendliness. This technique has been used in many process modelling researches, ranging from completed to on-going ones, such as the ADePT developing project (Austin et al., 1999), the e-COGNOS project (e-COGNOS, 2001), the PAMPeR project, and the EuroLifeForm project (Eurolifeform, 2002). Process models developed with the IDEF0 technique were found irresponsive to present the reasoning behind the information flow as well as the process flow itself. A reasoning-absent process model, to the author's belief, is inadequate to enable cross-disciplinary sharing of understanding whose kernel is the unformulated reasoning, which has re-use value. In the light of this, a modelling means, particularly one that is more capable in modelling the iterative, vague and highly abstract design process ought to be sought.

The current developed stage of either the product or process model has been undoubtedly successful at varying degrees in attaining the pre-defined objectives, which is to improve communication efficiency within multidisciplinary project teams. However, whether the current achievement is sufficient to better sharing of understanding, which plays a more important role particularly in the iterative, vague and highly abstract design process, remains a question to the author. Is the product model devised to share the tacit design knowledge? How can the design process be modelled so that the design rationale and intent can be captured, shared and reused? These questions have brought forth the next level study of this doctoral thesis, which is to find what contribution knowledge management can offer to improve the performance of cross-disciplinary collaboration at the early design stage.

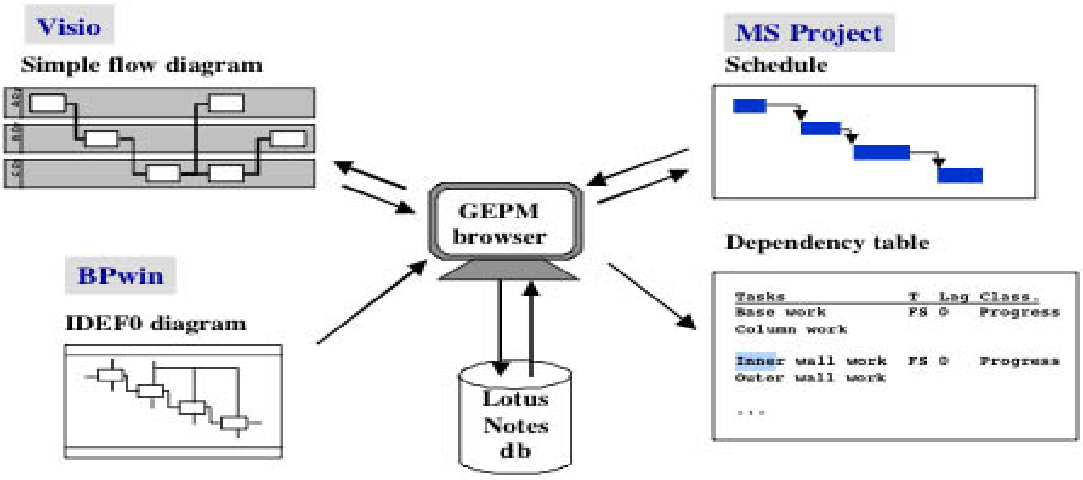


Figure 3.2: The GEPM Process Model enhanced with more modelling power compared with other methods available at one time. (Source: Karhu, 2001)

4 SUPPORTS FOR COLLABORATIVE DESIGN FROM THE KNOWLEDGE MANAGEMENT PERSPECTIVE

Where is the life we have lost in living?
Where is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?
--T.S. Eliot's The Rock (1934)--

4.1 Knowledge Management and the A/E/C Sector

Knowledge is considered a competitive advantage (Quinn, 1992; Reich, 1992; Drucker, 1993) and core competence (Skyrme, 1998; Prahalad & Hamel, 1990) in every organisation of all domains, including the A/E/C domain (Koch, 2002). The A/E/C domain realises that reusing information and knowledge accumulated from previous projects may contribute not only to time and cost reduction, but also to better solution quality throughout the different phases of a building project. Preserving and sharing a corporate memory of decisions, actions, resources, and experiences have thus become an issue for the A/E/C domain.

Project-oriented collaboration between the multidisciplinary actors is the intrinsic characteristic of a building project. The success of a building project is thus highly dependent on the effectiveness of collaboration between these multidisciplinary actors (Kalay, 1985; Kalay, 2004). All actors involved in a specific phase of a building project bring their own unique skills and resources such as knowledge and data to make the project a success. The earlier the multidisciplinary actors can initiate their collaboration in the project, the less negative outcomes the project is likely to have in its later stages. Numerous attempts have been conducted within the sector in order to motivate efficient collaboration, see for example (Fischer et al., 1993). Some of these attempts focus on efficient data sharing between project participants via for example using a shared product and/or process model, while some of them focus on knowledge sharing within the sector. One of the main objectives of researches conducted in the domain has been development of facilities based on a certain degree of ICT support attempting to enable knowledge (e.g. experiences, decision rationales) ingrained in the multidisciplinary professionals to be shared and reused efficiently. With the assistance of such facilities the multidisciplinary professionals may make their decisions at a higher state of knowledge and thus the quality of decisions may be improved (Fischer et al., 1993).

As discussed above, where collaborative design is of interest, the essence of all of the attempts carried out is to improve efficient sharing of design knowledge across the multiple disciplines and design phases. A comprehensive discussion with respect to improving collaborative design is continued hereafter, but will be focused on the perspective of knowledge management as to complement the other approaches mentioned in the previous sections.

4.2 Knowledge and its management

4.2.1 Data-Information-Knowledge Typologies

Data, information and knowledge are words frequently used under the topic of knowledge management. The distinctions between data, information, knowledge, and wisdom continuum are often not very discrete, but the hierarchy that describes this continuum has somehow been pointed out by various researchers from the domains of information science and knowledge management (KM). For instance, Harlan Cleveland (Cleveland, 1982), in the domain of information science, developed an information hierarchy or pyramid to describe the continuum of data, information, knowledge and wisdom in a 1982 *Futurist* article. In the domain of KM, Russell Ackoff (Ackoff,

1989) mentioned the hierarchy of data-information-knowledge-wisdom in his 1989 article "From data to wisdom". In 1995, Nonaka & Takeuchi (Nonaka et al., 1995) offered three observations concerning the relation between knowledge and information.

Data are defined by (Webster, 1961) as something given, granted, or admitted; a premise upon which something can be argued or inferred. Data are representations whose meanings are dependent upon the representation system (i.e. symbols, language, etc.). In brief, data can be defined as raw facts while they themselves are created with facts. Information is defined by (Webster, 1961) as a representation, an outline, sketches, or giving form. Information is transferable and can be communicated in some fashion. The meaning that information is given is determined by the existing knowledge of the receiver. In other words, information has context. Data is turned into information by being presented and organized based on a particular context so that from which conclusions can be easily drawn.

Knowledge is defined by (Webster, 1961) as a clear and certain perception of something; the act, fact, or state of understanding. Davenport and Prusak (Davenport and Prusak, 1998) further define knowledge as, "a fluid mix of framed experience, contextual information, values and expert insight that provides a framework for evaluating and incorporating new experience and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories, but also in organisational routines, processes, practices, and norms." Nonaka & Takeuchi (1995) also affirms that knowledge is about meaning, and it has context and connectedness. In other words, knowledge is the understanding of information and their associated patterns while an individual gains knowledge through context (experiences) and understanding (Cleveland, 1982). According to Cleveland (Cleveland, 1982), understanding is a continuum in which context plays the role to enable an individual to weave the various relationships of his/her past experiences. The greater an individual understands the subject matter, the more he/she is able to weave past experiences (context) into new knowledge by absorbing, doing, interacting, and reflecting (Cleveland, 1982). An overview of the continuum of data-information-knowledge typologies is illustrated in Figure 4.1.

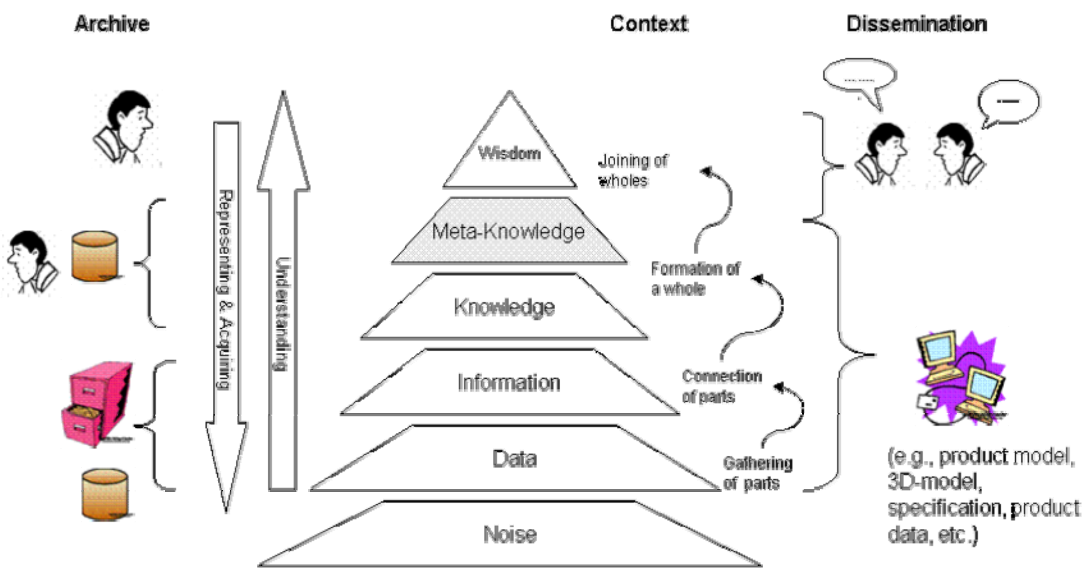


Figure 4.1: The continuum of data-information-knowledge typologies

Knowledge itself can generally be characterised into two different types: explicit and tacit knowledge (Polanyi, 1983; Nonaka & Takeuchi, 1995). Schön (Schön, 1987) defines tacit knowledge as knowledge that is entrained in action and is linked to concrete contexts. Tacit knowledge represents experienced-based knowledge (Woo et al., 2004) resided in the individual's cognitive structures, and therefore it is difficult to formalise and communicate to others as information (Johannessen, 2001; Polanyi, 1983). Polanyi (Polanyi, 1983) expresses the concept of tacit knowledge in the following simple but precise way: "we can know more than we can tell". This expression is somewhat true when the concept of tacit knowledge is further refined into two aspects: 1) know-how (Grant, 1996), which is for example skill and expertise developed after years of experience, and 2) things that are ingrained in each individual and so to be taken for granted (Polanyi, 1983).

Tacit knowledge with respect to the first aspect is also referred to procedural knowledge (Grant, 1996), which consists of examples such as the highly subjective and constitute personal insights, intuitions, hunches and inspirations derived from bodily experience. On the contrary, beliefs, perceptions, ideals, values, emotions and mental models that shape an individual's worldview are the typical examples of tacit knowledge categorised in the second aspect. Since it is difficult to be articulated, in an organisation, tacit knowledge is often lost when the individual possessing it leaves the organisation (Nonaka et al., 1995).

On the contrary, explicit knowledge is knowledge that can be codified and systematically expressed in formal structures compatible with human language (Nonaka et al., 1995). Explicit knowledge, can therefore be put down on paper or be digitalised and entered into a computer-based database. According to Polanyi (Polanyi, 1983), both tacit and explicit knowledge are mutually exclusive but also complementary because tacit knowledge functions as the background knowledge that assists in accomplishing a task which is in focus.

4.2.2 Knowledge Management

The question whether knowledge sharing is beneficial to the participants in a collaboration activity or whether it is causing the loss of personal power has been a widespread speculation (Avison et al., 2003). This viewpoint has contributed to the lack of motivation for knowledge sharing either within or between organisations, and further creates the situation that organisations do not know what knowledge their employees possess. Under the circumstance, in which important knowledge is not being used efficiently though it exists within the organisation, the possibility of knowledge walkouts may happen frequently and eventually create a vacuum in the aspect of missing knowledge.

After being aware that knowledge is the silver bullet for creating competitive advantages (Quinn, 1992; Reich, 1992; Drucker, 1993), knowledge management has thus become as important to organisations of all domains as information management. Knowledge management is about knowledge sharing (Avison et al., 2003), which is the basic requirement for the collaborating parties reaching their consensus. Knowledge management concerns getting information that is in the right context to the appropriate people, when required, helping them to share this information and experience, enabling them to use it to improve organisational performance, and putting all that in action for a specific purpose. Therefore, the author would state that knowledge management is fundamentally an outstanding management strategy that organisations may use to create better opportunities for reusing their existing knowledge as well as gaining new knowledge through different ways of acquisition.

Knowledge Management is defined by Newman (Newman, 1991) as the collection of processes that governs the creation/acquisition, representation, dissemination, and utilization of knowledge.

Newman (Newman, 1991) argues that knowledge management is not merely a "technology thing" but instead, in one form or another, knowledge management has existed for a very long time. Practitioners of knowledge management have covered a broad spectrum of professionals, including the philosophers, priests, teachers, politicians, scribes, librarians, and so on. Knowledge management can generally be interpreted as management of activities that frame and guide knowledge production and use in an organization even though multiple definitions on knowledge, knowledge production and management have become an argument since long ago. As quoted here from (Blaine, 2000), "…knowledge management is a concept in which an enterprise gathers, organises, shares, and analyses the knowledge of individuals and groups across the organisation in ways that directly affects performance. It is about helping people to communicate and share information…" Fischer and Ostwald (Fischer and Ostwald, 2001) gain their insights into knowledge management as a cyclic process involving three related activities: creation, integration, and dissemination.

The different definitions defined by various researchers quoted above share the main principle of knowledge management, which the author would state as in the following:

"Knowledge Management is a set of systematic but dynamic actions or activities that an organisation or an individual takes to obtain the greatest value from the available knowledge with the aids of technologies, in particular computerized technologies. This set of activities is formed of four facets, namely socialization, externalization, combination and internalisation, between and within which (facet) transformation of knowledge from tacit to explicit and vice versa occurs."

Knowledge, like everything else in the world, has a life cycle. Knowledge life cycle involves several stages (see Figure 4.2) that are not only performed sequentially, but also repeatedly until a cycle is formed. It is from these stages the cyclic processes of knowledge management, as mentioned above, are derived. As illustrated in Figure 4.2, one of the prominent stages of knowledge life cycle is knowledge reuse. Fruchter (Fruchter, 2002) applies the concept of knowledge life cycle into the design arena, and argues that knowledge creation occurs when designers collaborate on design projects. A comprehensive discussion with respect to the correlation of knowledge creation with design is available elsewhere (details see Section 4.3). For the purpose of future reuse, the created knowledge needs to be captured, indexed, and stored in an archive, which is suggested by Fruchter (Fruchter, 2002) as a knowledge refinery. When the need of knowledge reuse arises, the stored knowledge can be retrieved from the archive after the searching process has been completed. These processes are repeated to form a loop that is alike the natural learning pattern of human beings (Schank, 1982), where the human's brain functions as an enormous knowledge archive.

Knowledge reuse creates the possibility of knowledge refining (e.g., modification, combination) as well as the potential of more knowledge creation. Various research studies have been started to focus on knowledge reuse because there is evidence of value added to the reused knowledge (Fruchter, 1996). Research studies in this regard can generally be divided into two main aspects, i.e. the cognitive and the computational. On the cognitive aspects, researches have provided some solution in identifying the requirements of designers for contextual information. In the computational aspect (e.g., artificial intelligence), the focus of the researches is on design knowledge representation and reasoning. Each of these researches attempts to devise an efficient tool for knowledge reuse based on the chosen knowledge representation methods, which are generally divided into four types including logic (e.g. First-Order Logic), production rules (e.g. rule-based system), semantic networks and frames (or schemata). Semantic networks is a method of representing knowledge based on the intuition, which reflects the important feature of human memory that relies on the connections or associations between different pieces of information contained in it. Schemata represent deeper knowledge than semantic network. The most frequently used instances of schemata are frames originated from (Minsky, 1975) and scripts originated from (Schank, 1977). Frames consist of a group of slots and fillers to define a stereotypical object while scripts are time-ordered sequences of frames. A case-based reasoning system (Kolodner, 1993) is a typical example developed using the frame-based representation method.

Proper knowledge management has become a necessity in an organization. This point of view is found supported by (Wikstrom & Normann, 1994) that "each organization lies at the center of many inflows of knowledge from customers, suppliers, contractors, … the organization should leverage these inflows of knowledge to create value for itself and its partners". However, the approaches implemented over the years for the purpose of knowledge management are found emphasizing on capturing and disseminating purely explicit knowledge (Nonaka et al., 1995). Approaches as such will be named as the conventional **K**nowledge **M**anagement (KM) approaches in this doctoral thesis. The phenomenon of over-emphasis on the management of merely explicit knowledge is mainly due to the visibility of explicit knowledge, which relatively is easier to handle with less expenditure. The argument with respect to these one-sided approaches is these approaches may eventually result in an ultimate failure in knowledge management. (Nonaka et al., 1995) has raised the awareness to correlate knowledge management to tacit knowledge. As in accordance with Wikstrom & Normann (1994), tacit knowledge is the "know-how", a type of knowledge that adds value to organisations, to the individuals who form the organisations and to the activities performed by the participating individuals. Apart from supporting the important role played by tacit knowledge, Nonaka (Nonaka, 1995) argues that tacit knowledge is synthesised through social effort. He thus concludes that tacit knowledge is not captured, but it is exchanged and transferred from human-human contact through mechanisms such as storytelling, apprenticeship, and conversations. Based on this literature, which indicates the increasing understanding with respect to the equivalently important role played by both the explicit and tacit knowledge, the author suggests that total knowledge management covering the manipulation of both of these types of knowledge will draw more attention in domains other than the knowledge management itself, in particular when getting support of the contemporary ICT is no longer any constraint. David Skyrme (Skyrme, 1998), in his statement, "one of the keys to successful knowledge strategy is a well developed knowledge infrastructure that includes people and information that are readily accessible through your computer and communications network", clearly suggests the fast developing ICT will be useful as a vital tool for developing the currently demanded total knowledge management system.

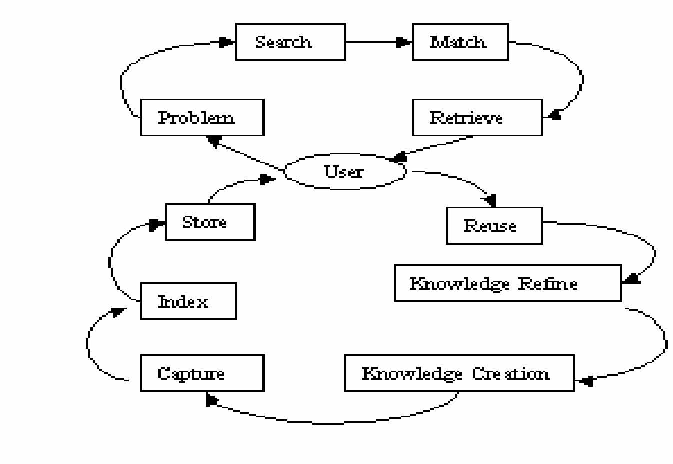


Figure 4.2: Knowledge Life-Cycle

4.3 Designing, an activity of knowledge creation

Design or designing ("designing" is used as a verb hereafter rather than the ambiguous meaning of the word "design", which can be both a verb and a noun) is a complex activity that interconnects three elementary sub-activities: *imaging*, *presenting*, and *testing*, which repeat and iterate forming a spiral metaphor throughout the entire design process (Zeisel, 1981), see Figure 4.3. Imaging, as quoted by Zeisel (Zeisel, 1981) as a word derived from the verb "to image", which is defined by the Oxford English Dictionary as

"to form a mental image of : to conceive (a) something to be executed: to devise a plan, and (b) an object of perception or thought: to imagine, to picture in the mind, to represent to oneself, as in Coleridge, 1818, "Whatever is admitted to be conceivable must be imageable," and in Browning, 1855, "Image the whole, then execute the parts"…"

A mental model of something is formed when a designer conducts the activity of imaging. A mental model is images or the internalized pictures of an individual *(a designer)* that influence the individual *(designer)* to understand the world or a part of the world (Senge, 1990). In design, a mental model provides a designer with a larger framework within which to fit specific pieces of a problem that the designer tempts to solve. These images, in other words, represent the subjective knowledge of the designer (Zeisel, 1981).

A designer is required to externalize and communicate her images in order to continue the designing process. There are many mechanisms that the designer can apply for externalizing her images, including sketch, draw plans, build model, take photographs, and so forth. Zeisel (1981) remarks this designing activity as presenting, where the designer presents ideas to make them visible so that she herself and others can use and develop them. By presuming design as a rational problem-solving process, Simon (1981) describes this activity as "representing it *(a problem)* as to make the solution transparent". Simon (1981) further explains the notion of representation as below:

"…we know problems can be described verbally, in natural language. They often can be described mathematically, using standard formalisms of algebra, geometry, set theory, analysis or topology. If the problems relate to physical objects, they (or their solutions) can be represented by floor plans, engineering drawings, rendering, or three-dimensional models. Problems that have to do with actions can be attacked with flow charts and programs." (Simon, 1981, pp 154-155)

Simon (Simon, 1981) also points out "a deeper understanding of how representations are created and how they contribute to the solution of problems will become an essential component in the future theory of design". This viewpoint of his is proved by the mushrooming researches in the area of knowledge representation, which covers a broad spectrum of studies including the explosion of interest in virtual reality and most recently the ontologies (Brewster & O'Hara, 2004; Gruber, 1993).

Zeisel (Zeisel, 1981: pp. 9) defines testing, the third constituent activity of designing as an activity conducted to "compare tentative presentations against an array of information such like the designer's and the clients' implicit images, explicit information about constraints or objectives, degrees of internal design consistency, and performance criteria - economic, technical, and sociological". Zeisel (Zeisel, 1981) further clarifies the notion of information that the designer uses to progress along the repetitive, iterative and spiral form of design metaphor (see Figure 4.3) in his argument quoted below:

"…Designers use image information heuristically as an empirical source for basic cognitive design decisions…Test information drawn from the same body of knowledge is useful to evaluate specific design alternatives…Using the same information in this twofold way is remarkably efficient and contributes directly to design as a learning process…"

Although Zeisel (1981) does not distinguish the definition of information and knowledge in his above-quoted argument, he describes in a way that the information the designer uses for designing is derived from the mixture of tacit and explicit knowledge, which is in the designer's possession.

In his argument, as quoted here "New [design] options are versions of earlier ones growing out of the thinking that went into the rejection of earlier ones", Schön (Schön, 1983) affirms that design is a learning process through testing. Designers gain knowledge from the spiral metaphor of designing which reflects the learning cycle suggested by various researchers in the field of knowledge management and organisational learning. A broad spectrum of discussion and literature that analyses knowledge creation based on learning theory and strategies has been contributed by a number of researchers from such fields as organisational learning, knowledge management and information science. Just to name a few here amongst them are Bloom (Bloom, 1956), Simon (Simon, 1981), Schank (Schank, 1982), Nonaka & Takeuchi (Nonaka & Takeuchi, 1995), and Schön (Schön, 1987).

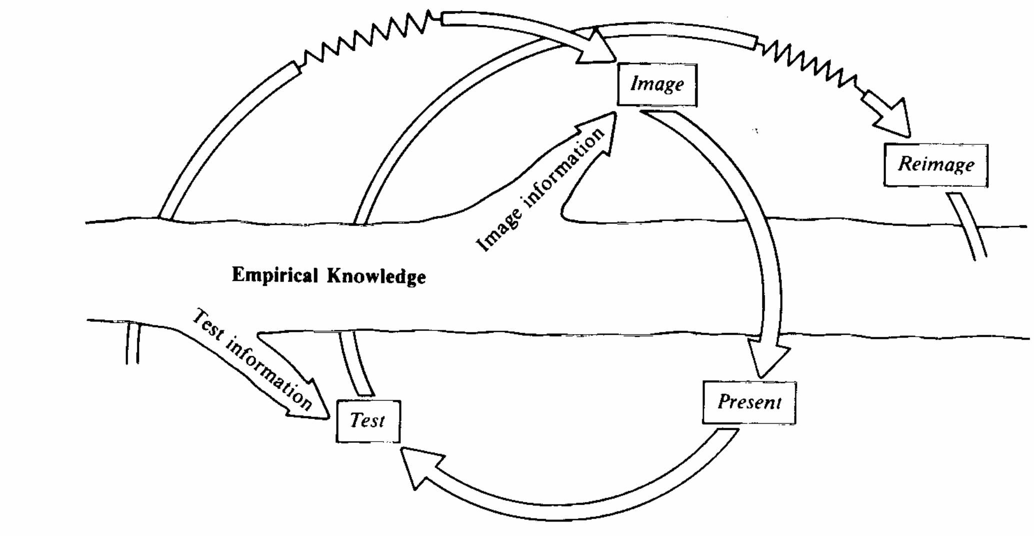


Figure 4.3: The three elementary designing activities (source: Zeisel, 1981: pp. 10)

4.4 Knowledge transfer across the multiple-levels

Collaboration is defined as a team of people working together with shared goals for which the team attempts to find solutions that are satisfying to all concerned (Kvan, 2000). The operation of collaborative design projects is based on the collaboration and coordination of several teams each of which is formed by multidisciplinary professionals from different organisations (see Figure 4.4). The main concern of collaboration with respect to collaborative design, particularly in the early design phase, is to transfer know-how (Chiu, 2002), the tacit knowledge of the designer as described in Section 3.3, as well as sharing understanding. Decisions made in the early phase of a building project, the early design phase, are very vital accounts for their contribution to the evolution and quality of the final product of the project (Fischer et al., 1993), i.e. the building. The quality of any decision made is highly dependent on the effectiveness of understanding sharing, which itself is a function of communication. In other words, communication is the key to the success of design projects, it is therefore always important to have some quality communication means that may allow collaborators to communicate their design information and knowledge quickly and efficiently.

With reference to the spiral metaphor of designing observed by Zeisel (Zeisel, 1981), a designer tends to communicate her understanding about the design problem by externalising them with various presenting/representing mechanisms, such as making sketches, and verbal descriptions or prototypes. However, under the circumstance where communication of verbal descriptions becomes less appropriate due to for example the difference of geographical locations and time zones, the designer tends to choose the asynchronous communication mode. This nature of practice of the designer is also highlighted by Simon (Simon, 1969, pp.109) as below:

"Architecture is a good example of a domain where much of the information a professional requires is stored in reference works, such as catalogues of available building materials, equipment, and components, and official building codes. No architect expects to keep all of this in his head or to design without frequent resort to the information sources. The emerging design is itself incorporated in a set of external memory structures: sketches, floor-plans, drawings of utility systems, and so on."

A typical weakness of a designer while using an asynchronous communication approach is: a designer tends to represent her knowledge/idea in a form of, for instance, sketches or formal design specifications in order to make it visible without giving the reasons behind the design decisions, or in other words, the design rationale. In the case of collaborative design, problems may arise from this type of one-way communication, where the recipient (collaborator) is rarely explained about the reasoning behind decisions made during the design process by the designer (sender). This is because different cognitive processes of different individuals on representations may occur in collaboration (Potts & Catledge, 1996). A richer form of communication is thus necessary for designers who participate in a collaborative design team for efficiently sharing their understanding, which is a continuum of the relevant design data, information and knowledge.

Team learning, the learning process of a team observed by Senge (Senge, 1994), addresses that a team learns and develops its knowledge through discussions and dialogues. Based on the interactions between the team members, including the use of both synchronous and asynchronous communication modes, a better understanding can be achieved so that the same vision is shared. Senge (Senge, 1994) also affirms David Bohm's (Bohm, 1965) assertion that discussion and dialogue are required for the team members to learn together. Though a distinction is given by Bohm (Bohm, 1965) and affirmed by Senge (Senge, 1994), holding discussion and dialogues between team members consistently is suggested as the appropriate approach to enable the individual-level knowledge flows to a collective knowledge pool first at the team-level followed by the organisation-level.

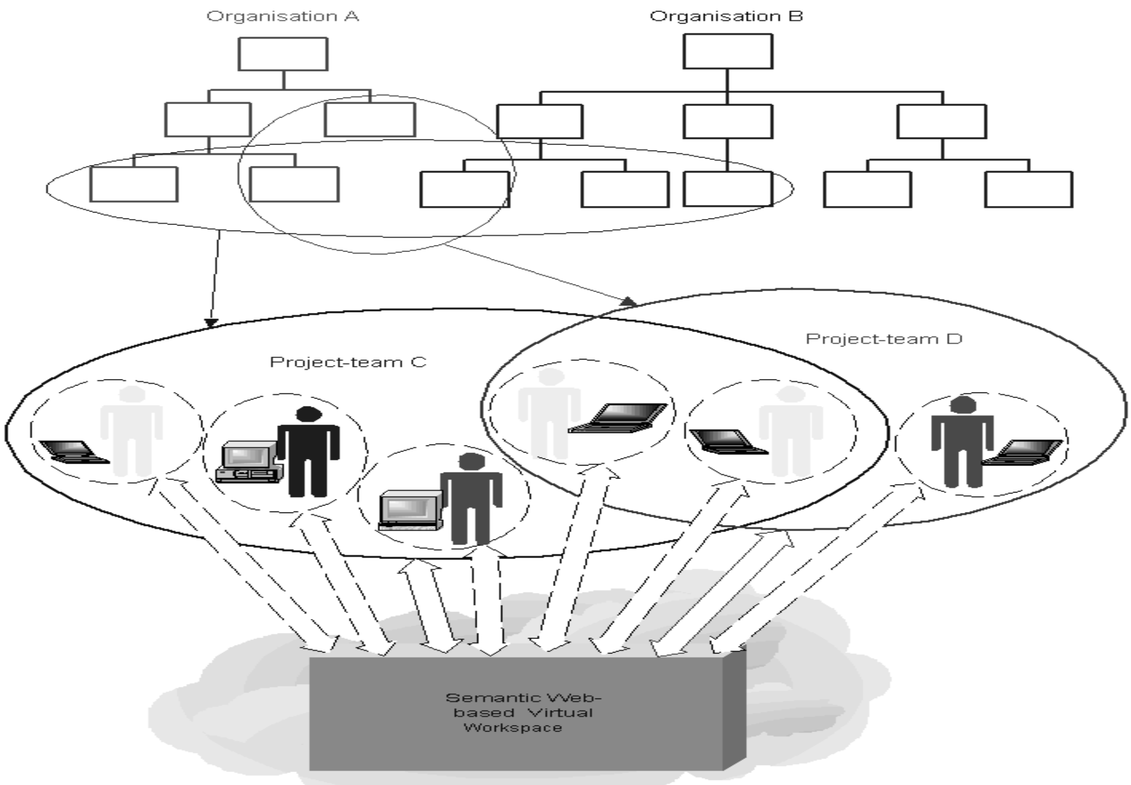


Figure 4.4: The multiple levels (team, organisation, and cross-organisation) of collaboration in design projects

4.5 Design rationale, the tacit design knowledge

Reusing knowledge from past experiences is a natural process of human beings (Schank, 1982), and occurs whether consciously or subconsciously when a particular task, such as designing, is performed. Design knowledge, in its broadest meaning, refers to all information (i.e., object, concept and relationships) assumed to exist in design. The designer tends to search for precedents that best suit the current design problem at hand from either her internal memory or other accessible external sources that consist of the external knowledge repository (e.g., company's best-practice database, library, etc.), and her mentors or professional community in order to access to the existent design knowledge. Apart from her internal memory, knowledge sources on which designer depends most are external knowledge repositories that are accessible without much difficulty, usually through the support of ICT. Precedents that are available in such knowledge sources are represented in the form of codified/formal knowledge (e.g. documents) to which the designer may make reference. However, designer often finds that precedents are insufficient particularly when it is necessary to understand why a particular artefact is designed the way it is. Reasoning behind decisions made in the design process is in fact the essence of the reusable design knowledge that is seldom completely documented. In this section of the thesis (Section 4.5), the author attempts to delineate design rationale as tacit knowledge that a designer uses and gains in the collaborative design process. Design rationale is defined below based on some literature in the corresponding context. Attempts with respect to design rationale management are then analysed as the core discussion subject.

Design rationale is an explanation of why an artefact or some part of an artefact is designed the way it is (Lee et al., 1991). Design rationale includes all the background knowledge such as deliberating, reasoning, trade-off and decision-making in the design process of an artefact, which can be valuable and critical to various people who deal with the artefact (Gruber et al., 1992a; Regli et al., 2000) for particular purpose at any time. With respect to her contribution to the research of design knowledge reuse, Fruchter (Fruchter, 2002) emphasises the notion of knowledge in context, which is defined as design knowledge that is rich, detailed and contextual and occurs in a designer's personal memory. Among other examples, design rationale is used by Fruchter (Fruchter, 2002) to exemplify the notion of knowledge in context. In other words, design rationale is suggested as a representation of the reasoning behind the design of an artefact.

Schön (Schön, 1987) argues that while designing, the designer moves back and forth between two designing states that he named as "*knowing-in-action*" and "*reflection-in-action*". According to Schön, "knowing in action" is tacit and can be described as strategies, understandings of phenomena, and ways of framing a task or problem appropriate to the situation. "Knowing in action" is spontaneously delivered without conscious deliberation and it is difficult to express or convey. Contrarily, Schön describes that "reflection-in-action" is led up by unexpected events and the knowing-in-action. Schön further elaborates "…Reflection-in-action has a critical function, questioning the assumptional structure of knowing-in-action. We think critically about the thinking that got us into this fix or this opportunity; and we may, in the process, restructure strategies of action, understandings of phenomena, or ways of framing problems…The distinction between reflection- and knowing-in-action may be subtle…" The implication that can be observed from Schön's statement is that the notion of design rationale may be associated with Schön's remarks concerning "knowing-in-action" and "reflection-in-action". In other words, the author suggests that design rationale is a constitution of the two notions introduced by Schön, and thus is the tacit design knowledge that can be somewhat articulated with appropriate mechanisms.

Designers who are engaged in collaborative design are aware of sharing understanding as a way to enable them to better perceive each other's work. In accordance with Myers (Myers et. al., 1999), design rationales would enable improved understanding of designs, would simplify the problems of design revision and reuse, and would thus greatly facilitate collaboration among groups of designers. However, designers rarely record their design rationale though realising its contribution for future reuse due to: 1) the difficulty of making tacit knowledge explicit, and 2) the requirement of substantial time and efforts. Thus, design rationale is found as design related information that a designer conventionally records in notebooks, memos, and so on (Fruchter, 1998).

4.5.1 The management of the design rationale

Memory fades over time. More accurately, it becomes more difficult to retrieve memories when cues related to those memories are no longer present and a succession of other events has captured one's attention and been mixed into memory (Schank, 1981; Caroll, 1990). This phenomenon of humans' memory structure generates the demand for mechanisms to manage the design rationale, which is suggested above as a valuable design knowledge that may facilitate collaboration. It is argued that keeping track of design rationale will assist the designers to structure design problems, as well as providing the designers with a basis to explore more design options (Caroll, 1990). On the contrary, without keeping and utilizing the design rationale properly, activities to maintain and redesign an artefact may require much effort when the need to understand the previous work arises. Therefore, various attempts have been conducted to develop an appropriate mechanism for the effective management of this partly tacit design knowledge that the following activities are normally involved: 1) *acquisition* (capture & extract), 2) *representation*, 3) *dissemination*, and 4) *store*.

In a traditional design environment in which CAD drawing tools are heavily relied on as detailed design is the main focus, only data in the physical and functional aspects of an artefact are of interest. Under such circumstances, the design rationale is seldom documented completely, and results in the collaborating work teams often require lots of communication to perceive and understand each other's work. Meanwhile, there is also an argument about the right type of information to be documented as design rationale during a design process. Gruber (Gruber et al., 1992b), in this regard, proposes types of information that is necessary to be captured during the design process, including the information that is used to answer the designers' questions, data that might be used to infer answers to later questions, and the dependency relationship among the data and information. In this respect, (Regli et al., 2000), based on evidence gathered from extensive literature surveys, suggests that the design rationale may be captured during the design process by recording reasoning, decisions, options, trade-offs, and their relevant contexts, followed by constructing a formal or semi-formal structure [of the captured information] so that it is reusable when necessary.

4.5.2 The life-cycle of the design procedural knowledge: Capture-represent-archive-search-retrieve-(use)

The purposes to access design rationale are to answer a user query, show the logical aspects of an important issue (e.g. the causal and conceptual relationships between issues), monitor design process, or obtain a document about the designed artefact (that here refers to the building). As well as the knowledge life-cycle in general, the design rationale life-cycle is comprised of several processes that are essential to transfer the design rationale to a computer processable format so that it is accessible based on some particular needs.

Mechanisms used to *capture design decisions and reasoning* can generally be characterised into two categories:

- The *user-intervention-based capture*, whereby history of designing, including such descriptive details as the decisions made, when and why the decisions were made, who made the decisions, are documented by the designer. Documentation is normally generated by an individual designer as a report after the decision-making process. A typical example of such kind of documentation is meeting minutes, which tends to be produced for recording the summary of the discussion contents of a meeting. One of the many drawbacks of this mechanism is, in most cases, that only the final decision is documented while the thinking and reasoning process that lead to the decision is usually omitted.
- The *automated non-intrusive capture*, whereby the history of designing, including such descriptive details as the decisions made, when and why the decisions were made, who made the decisions, are documented by an automatic monitoring module of the design rationale system. By using such kind of design rationale system, the communications of a design team through CSCW tools (e.g., e-mail, phone conversation, and the archived design meetings) can be captured automatically in the process of team collaboration and communication without much human intrusion. The main drawback of the automatic mechanism is that the recorded rationale is likely to be unstructured, full of digressions and of free form.

In the light of the drawbacks identified from both of the aforementioned mechanisms, some existing tools have been developed to provide a partially automatic acquisition function, whereas substantial efforts or inputs from designers remained necessary. As reported by Myers (Myers, 1999), these tools attempt to capture the rationale information at a specific time, and high-level decisions and requirements. Contrarily, capturing the design rationale during the actual process when design works are carried out to fulfil the designated specifications is still rarely of interest (Myers, 1999). Apart from tackling the difficulty of rationale capture from the technical perspective, Myers (Myers,

1999) also suggests that capture of the design rationale may be motivated by increasing the awareness of its benefits for the designers' current usage, such as modifying, maintaining, and reuse of the existing design. Another way to approach the capture problem is to determine which types of rationale will be the most useful for the proposed use in order to narrow the capture effort down to areas that will provide the most payback.

The design rationale can be represented in different ways, from mathematical and logical formal representation to very informal representations (e.g., designers' notebooks and scribbles on the back of envelopes). Formalising the captured design rationale plays the crucial role to transform this contextual sensitive (tacit) and unstructured essence of reusable knowledge into explicit and computer-transmittable form, which may then be used to facilitate automated reasoning. Gero (Gero, 1990) also remarks that in order to transfer human "know-how" or experiences into machine memory for future reuse, knowledge gained/captured needs to be formalised into generalised concepts or groups of concepts at many different levels of abstraction (Gero, 1999). Various techniques have been developed for this purpose, or the so-called knowledge representation, including semantic nets, frames, scripts, rules, and so forth. Each of these techniques differs from one another by their schemas, methods used for schematizing knowledge, pros and cons, performances, and the typical scenarios that characterize the assigned task. Further discussion in the context of knowledge representation is available in Section 4.6.

The retrieval of the design rationale is determined by the representation schema and the requirements of the domain for which the knowledge is being used (Regli et al., 2000). Different access and retrieval strategies, which can be either pull or push, are needed to help users with different purposes. The retrieval strategies may involve basic retrieval approaches, such as navigating by designers, retrieval by queries, and automatic triggering during the design process.

To date, numerous *design rationale systems* have been developed mostly on a research basis to explore the different possibilities to support design rationale management for the different phases of the design process, by which different designing characteristics can be identified. For example, there is an argument about whether the choice of system used relies on the nature of the designing situation. Under designing circumstances, in which well-defined domain models are unavailable, a system with a non-intrusive monitoring scheme such as one that acquires design rationale knowledge through informal means (e.g., videotaping of meetings) is more preferable (Ramesh, 1995). These situations often occur during the early design phase where the emphasis of designing is on identifying and resolving high-level abstractions of functionalities and requirements (Myers et al., 1999) when definite design rules are rarely available. Meanwhile, the feasibility of either formal or informal representations, with their respective pros and cons, is another criterion of concern for the development of an appropriate design rationale system. As Anderson (Anderson et al., 1991) points out, the attempts to represent informal knowledge as design rationale through formal tools and notations can result in thin descriptions. Ramesh et al. (1995) also asserts that the meaning embedded in the informal knowledge could be lost when formal tools and notations are used in an attempt to represent the knowledge. In brief, such factors as labour-intensiveness, the level of granularity of the representation to describe the captured knowledge (e.g., too coarse or overly fine-grained), social significance to the design deliberations, the size and the complexity of the design rationale knowledge, are criteria for selecting the most appropriate capturing and representing mechanism.

CRACK, an acronym for **CR**itiquing **A**pproach to **C**ooperative **K**itchen Design (Fischer et al., 1989), is an example of systems developed to support handling of the design rationale at the detailed design stage, at which the design process is more constrained by rules with respect to the domain knowledge. In general, systems as CRACK are developed as an additional function to the main design system for designers to store the design rationale in a computer processable format to which designers can refer when the needs to resolve conflicts and evaluate decisions arise. Such kind of system is usually developed in a task specific context using an empirical study (Regli et al., 2000), and therefore may contain domain knowledge bases that can be used to support automated reasoning. The limitation identified from CRACK is its over-emphasis on *how* the artefact (e.g. building) is designed to satisfy the requirements while neglecting to deal with options exploration, negotiations and other history descriptive information for contextual questions such as who, when, and why. JANUS_ARGUMENTATION (Fischer et al., 1995; McCall et al., 1998) is a design rationale system augmented to a kitchen design system. An issue-base (archive) was pre-established from various knowledge acquisition activities (e.g., protocol studies, extraction from books) to gather such information as precedents, decisions, intents, and arguments for the user to navigate when the needs to validate a design decision against a design rule arise. JANUS_ARGUMENTATION was developed to support the detailed design stage of kitchen design. However, only the use of the design rationale was in focus while the capture of the design rationale was beyond the development of this system. This is because the capturing process as well as the efforts involved to translate the captured information into a usable format was considered difficult and expensive at the time when the system was developed.

4.6 Knowledge Representation

Knowledge representation is one of the essential elements of knowledge management. It is easy to explain knowledge representation in plain language by posing the following questions:

- "How can x (be it the data, thought or idea that an individual possesses) be presented?", and
- "What can we state about x in symbolic terms?"

Knowledge representation is a central issue of Artificial Intelligence (AI), a branch of computer science, which among other things focuses on developing knowledge-based systems in order to facilitate the human's efforts in managing domain knowledge, in this case the design knowledge. AI in design is no longer a new subject within the A/E/C sector. The pros and cons of using knowledge-based systems in design have long been explored and discussed within the sector. Among other professionals in the domain, Kalay (Kalay, 2004) points out that the knowledge-based systems will be capable of assisting designers at a much higher level of the design process than the traditional CAD system do. Zreik (Zreik, 1991), however contributes his conflicting viewpoint by arguing that integrating plenty of knowledge within a system is not necessary to produce "satisficing" solutions to the problems.

Approaches to knowledge representation can generally be classified into two main fundamental principles, the top-down and the bottom-up, respectively. The top-down approach is applicable when more information correlated to the data in question is obtainable. Contrarily, the bottom-up approach is applied under the circumstance when there is only limited prior information available to the data in question. Top-down has been the dominant approach to knowledge representation. While implementing this approach, the scope of a knowledge base is decided before constructing a general knowledge framework in which the specific declarative facts are filled. Under this circumstance, the extensibility of the resulting knowledge bases may thus be restrained due to the rigid structure. This constraint may break down the knowledge management system by limiting its growth in parallel with its ever-increasing data/information/knowledge input need. The bottom-up approach is found useful in some particular domains (e.g., systems biology) that study basic components and integrate data to detect relevant patterns (e.g., subatomic particles form the nucleus). Data overload has created a dilemma to the bottom-up approach while the difficulty to convert data into information and further into knowledge has worsened the situation. Lots of efforts are required to spend on data mining and keeping data coherency as well as interpreting the data in the right context in order to produce the meaningful information.

The drawbacks identified from both the top-down and bottom-up approaches have encouraged the use of *hybrid knowledge-management strategies* in which both approaches are implemented and complementary to one another. Based on its inherent characteristics: extensibility and flexibility, ontology, has become an alternative which itself can be designed top-down and bottom-up simultaneously. Developing a KM system whose skeletal framework is a cluster of multiple ontologies is now drawing the attention of researchers, including those of the A/E/C domain, who have realised the shortcoming of the current WWW (World Wide Web) technologies in tackling the exponentially increasing information while the WWW has been relied as a medium for knowledge dissemination. Simoff and Maher (Simoff and Maher, 1998) suggest that a comprehensive conceptual framework, or "ontology" is needed in order to represent the deep knowledge of design rationale while Ndumu and Tah (Ndumu and Tah, 1998) reported that the product model is incapable of representing the design rationale. A brief review of the related research contributed in the area of knowledge representation within the A/E/C domain based on the AI techniques is given below.

4.7 Knowledge-based Systems

Knowledge-based systems can be classified into three types (Rosenman et al., 1994): rule-based systems, case-based systems, and prototype systems, based on the design knowledge classification that consists of two categories: the compiled knowledge and the case knowledge. Rosenman (Rosenman, 1994) refers compiled knowledge to general knowledge that is represented in a computer environment either in the form of rules (as those found in rule-based systems), or schemas. Schemas that are formulated to represent the general knowledge may be exemplified by a product model, which remains a popular research topic in these recent years. A brief review of researches correlated to product models is given in Section 3.9.2. Case knowledge is knowledge wherein actual experiences are stored (Rosenman, 1994). Case knowledge is retrieved to deal with a situation at hand that shows similarity to experiences. Case knowledge, to the author's opinion, stems from the concept of the theory of dynamic memory, which is defined by Schank (Schank, 1982) based on his findings that humans often rely on past experience to solve new problems. The basic premise of dynamic memory is that remembering, understanding, experiencing and learning cannot be separated from each other. According to Schank (Schank, 1982), we understand by attempting to integrate new things that we face, with what we already know. Understanding is thus argued by Schank and supported by many other researchers such as Kolodner (Kolodner, 1993), Rosenman (Rosenman, 1994) and Lawson (Lawson, 1997) relies on finding relevant old experience in the memory, and uses this experience in the current situation. This process is called case-based reasoning, and is derived as a methodology used to model the way of human reasoning and thinking so that an intelligent computer system can be established to solve problems based on previous experiences (Kolodner, 1993; Moore, 1999). This AI technique aims at solving new problems by adapting solutions stored in library of past cases. Users will then modify this adaptable solution with or without some predefined adaptation rules to fit the current problem in order to create a new solution. The new solution will then be stored into the same case library for future retrieval when similar problems arise.

Some examples of the case-based reasoning systems are ARCHIE and CASECAD, and SEED. ARCHIE is a case-based reasoning tool that is applicable by the architects during the conceptual design phase (Domeshek & Kolodner, 1993), and when it is incorporated with CASECAD the designers are able to retrieve previous design cases based on the formal specifications of new design problems (Maher, 1997). SEED is another case based system that supports the reuse of solutions in building design throughout all phases, from programming to detailed design (Fenves, 2000). SEED is somehow different from ARCHIE in terms of its motivation, which is to provide the designers quickly with an initial solution that can be edited and modified immediately under the system and/or the designer control (Flemming et al., 1997.).

4.8 The Proliferation of ICT in the A/E/C Sector

Coleman's law (Coleman, 1997) states that "People resist change and organisations resist change to an exponentially greater degree" and "the larger the organisation, the greater the resistance to change, or the more complex the project the greater the exponent for the resistance to change". The Coleman law is somewhat applicable to the A/E/C industry as evidenced by Fischer et al. (Fischer et al., 1993) that the A/E/C industry is like other project-based industries in terms of being slower in adopting new management, production and competition philosophies. Fischer et al. (Fischer et al., 1993) further explain this situation by correlating the nature of the project-based industry, in which the fragmented organisational structure outlines the main discouraging cause for active investment and exploitation of technology. As asserted by many researchers, amongst them for instances are van Leeuwen and Fridqvist (van Leeuwen et al., 2002), a requirement for collaborative design is the ability to identify and share design knowledge. Sharing design knowledge has been a common practice, but it is often conducted in an informal way (van Leeuwen et al., 2002), in which design knowledge is described implicitly with ambiguous interpretation (Peng, 2001; Ramesh et al., 1995; Klein, 1993) at a higher abstraction level. More accurately it is the efficiency of the sharing process of understanding (i.e. a continuum of data, information and knowledge) that underlies the efficiency of collaborative design (Cleveland, 1982). Researchers in the area have tried out various mechanisms tempting to formalise design knowledge in a way that the knowledge can be shared at an optimum state while creativity in design is not impeded. Design rationale, as mentioned above, is among other types of design knowledge, the one that is most of interest to be formalised. This is because the formalised design rationale can be managed (stored, searched, accessed) and efficiently shared between designers for different purposes, including mediating conflicts of interests, achieving consensus during the decision-making process, as well as facilitating designers to learn from either their own or others' past experiences.

The design knowledge is kept at four different levels of organisation: the *individual*-, *team*-, *project*- and *company*-level. Apart from keeping knowledge in her internal memory, the designer tends to externalise her design knowledge, for instance through verbal communication (e.g., dialogue, discussion) for being understood. Verbal language alone is not enough for making knowledge explicit (Polanyi, 1983), the externalised knowledge is most commonly documented into different documentation types, such as notes, reports, images (drawings, sketches), specifications, and so forth. As a consequence, a substantial quantity of design information is produced via the various available representation approaches. The mass quantity of design information is archived in the repositories at the aforementioned four different levels of organisation. These repositories are often named knowledge sources and/or knowledge bases. Nonaka & Takeuchi (Nonaka & Takeuchi, 1995: pp. 63-69) whose research focus is on organisational learning, attempt to explain the different states of knowledge transformation from explicit to tacit, and vice versa, through analysing the interactions between individuals within an organisation. An organisation to which is referred here as a team of two people or more who engage in the same business unit of the company in order to complete the assigned tasks. Nonaka et al. (Nonaka et al., 1995) elaborate on four modes of knowledge *creation* or *conversion* that are derived from the concepts of tacit and explicit knowledge. Nonaka et al. (Nonaka et al., 1995) remark that knowledge in organisations goes through a constant process of transformation between tacit and explicit knowledge by formulating the matrices tabulated in Table 4.1. (Nonaka et al., 1995) also succeed in providing an elegant expression of the dynamics of knowledge creation and transformation in a 2-dimensional space, as illustrated in Figure 4.5.

Table 4.1. The knowledge-creating company (Source: Nonaka & Takeuchi, 1995)

Transfer	Movement	Method
Explicit to explicit	From knowledge sources to knowledge bases. Intranet and portal publishing	Publishing and internet/intranet access. Collect, store and disseminate
Explicit to tacit	Knowledge bases to people	Knowledge acquisition and e-learning
Tacit to explicit	People to knowledge bases	Captured expertise to knowledge base or learning programme
Tacit to tacit	People to people	Collaboration, communication of practice, storytelling, e-mail.

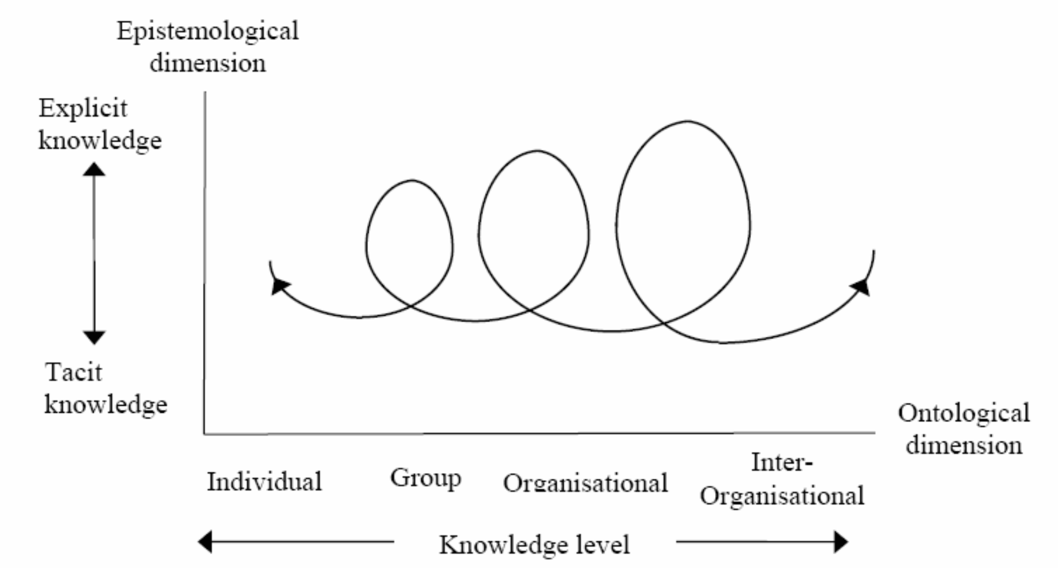


Figure 4.5: The Spiral of Organisational Knowledge Creation (Source: Nonaka & Takeuchi, 1995)

When tackling design as a problem solving process, as introduced by Simon (Simon, 1981), project actors who are involved tend to solve problems based on easily accessible knowledge. It is important to ensure that appropriate knowledge is available at the correct time in the process (Lawson, 1990). Most designers are likely to generate local rather than global design environment (Lawson, 1990; Chira et al., 2004) when knowledge sharing becomes impractical to them. In this respect, knowledge dissemination followed by search and retrieval is crucial, in particular with the contribution of ICT to provide an efficient knowledge sharing environment (Kazi & Hannus, 2002). Although ICT gains positive viewpoints for knowledge management, Nonaka (Nonaka et al., 1995) claims that ICT implemented in organisations has, however, traditionally focused on the management of explicit knowledge. This remark raised the concern of the A/E/C sector where both unstructured and explicitly well structured knowledge is scattered in a complex blend. Developing ways of converting tacit knowledge into explicit knowledge based on the advancing ICT has outlined the research trend in the aspect of knowledge management of the A/E/C sector (Kazi & Hannus, 2002).

For large-scale building (design and construction) projects where effective collaboration between multidisciplinary professionals is crucial, *project information management systems* are established to facilitate managing the enormous quantity of the project related information. The literature suggests that the current project information management systems are acknowledged to have several limitations for efficient information delivery (Futcher & Thorpe, 1998; Amor et al., 1996; Kelly et al., 1997; Björk & Turk, 2000). The argument is that a project information management system merely functions as a document management system that is incapable of assisting the project participants to interpret the meaning of the contents of documents even though efficient documents dissemination is achieved. Systems that implement the product model approach, which takes up the issues of data classification and information exchange standards for communication through data modelling (please see Section 3.9.2), exhibit limitations of inflexibility for the conceptual design use. Some studies (van Leeuwen, 2002; Froese, 1996; Eastman, 1999) attribute this main shortcoming of the product model approach to its functional purpose, which is to structure the product data based on a class-centred modelling schema. The class-centred schema is criticised restraining the designer from designing freely in his own pace and style. On the contrary, by using the class-centred schema, the designer is required to frame the design problem in a way that the answers to the questions are required to be found fast enough to set all the parameters required for the designed object at the early design stage. This rigid way of first defining followed by structuring design information is less practical in the conceptual design phase where the designer favours to design in a fuzzy manner to sustain ambiguity, uncertainty and parallel lines of thought (Lawson, 1997).

Given the aforementioned shortcoming of the product model, developing a more flexible but less complex approach that may assist the designer to design with enhanced information sharing capability at the conceptual design stage has become the next level of research focus within the A/E/C research community. For instance, the feature-based modelling (FBM) approach, which has been familiar in mechanical engineering, has been adopted for developing a property-oriented prototype system (van Leeuwen et al., 2002). This prototype system aims at modelling architectural design information by integrating the modelling techniques in FBM with the concurrent peer-to-peer internet technologies. Van Leeuwen et al. (van Leeuwen et al., 2002) remarks based on their findings with respect to the prototype system that FBM is an approach that supports the dynamic nature of design by fulfilling the requirements of extensibility and flexibility of the conceptual information model in order to allow evolution of the model during the course of design.

Despite all these years of efforts in applying ICT in an attempt to improve the efficiency of information exchange in the A/E/C industry, it remains an argument how much positive influence ICT has had in this context. In light of this, Anderson & Thorpe (Anderson et al., 2004) conducted a survey study to investigate the effect of information flow in project teams within the A/E/C industry at national level. They report that the implementation of ICT in the A/E/C sector has increased the information flow which may potentially result in the negative impact of information overload that will eventually affect the decision quality. *Information overload*, has no universal definition, but implies the negative impact caused by the overwhelmingly excessive information. Edmunds (Edmunds, 2000) states that information acts like noise when it is in a large excessive quantity that reaching overload. Information overload may cause stress, distraction and interpretation errors to its user (Edmunds, 2000). Under the circumstance when there is too much information, it is no longer possible to use the information effectively (Feather, cited in Edmunds, 2000). A very typical example of this phenomenon is the excessive information in the form of electronic messaging. Electronic messaging (e-mail) is a widely used ICT within the A/E/C industry to communicate and disseminate data/information. However, receiving for example 50 e-mails during a working day, can severely disrupt normal working procedures, and can distract the user's attention from more important tasks.

The advancing ICT plays a crucial role in enhancing the collaboration amongst project participants who are geographically apart by providing the facilities to establish a *virtual common workspace*, for example the so-called groupware. Collaboration builds on sharing of data, information and knowledge through shared environments (Chaffey, 1998). In real life that might be for example a meeting room, a black board or a notice board, and so forth. In groupware it typically means a shared folder, a shared database, or a discussion group on a web page. Groupware should, however, be carefully designed to eliminate the restraints of time and place while minimising the impact of information overload.

A web-based project information management system is a typical example of groupware that has been practised in the A/E/C sector. This electronic project-management system is conducted via an extranet using Internet protocols to transmit information. These systems generally provide a centralised, commonly accessible, reliable means of transmitting and storing project information (Nitithamyong & Skibniewski, 2004). The basic concept of the system is to store project information on a server while a standard web browser is used by team members to access the information regardless of geographical locations and hardware platforms. However, it remains questionable to the A/E/C research community if the web-based application is an ultimate solution for knowledge management. One of the many factors to this context, in the author's opinion, is that the web-based applications implemented at the present stage are mainly document-centric. This factor was also reported by Amor et al. (Amor et al., 2002) as one of the findings drawn from the extensive literature review, which was conducted attempting to outline the ICT vision in the future construction industry. In a document-centric web-based system, building project related information is captured in various types of documents before being disseminated via the web-based system for sharing in between the geographically dispersed team members. The problem arises when the volume of documents and their versions increase. In other words, the document centric web-based application has apparently facilitated sharing of project data and information, but also increased drastically the flow of information that is weakly structured in documents whose likely consequence will be the situation of information overload.

Apart from the technical factor, Björk (Björk, 2002) in his study of how the web-based information system influences construction information management suggests that behavioural, cost and sociological are other prominent factors, which also influence the implementation of success/failure of the system in the A/E/C industry. The psychology involved in getting all participants in projects to change their way of work is not simple. Some project participants have been used to the conventional communication channels such as paper mail and fax. The findings from several case studies reported in (Sellen & Harper, 2002) indicate that the reluctant feeling to change may be difficult to overcome though both the development and running costs for the system are sometimes not a critical concern. Some project participants may feel constrained from organising freely the project related information as what they used to do in their personal archives by the obligation of using the centralised web-based system. A thorough user's requirements investigation and analysis shall be the pre-requisite for the development of a web-based information management system. It is a fact that the users of a system in a project cannot be treated as one uniform group, but rather consists of several groups with different attitudes and skills. This sociological context can expand to other aspects concerning for instance the discipline of producing information, the control of accessing information as well as the ownership of the information.

Blaine suggests that knowledge management shall be a strategy, through which the right information in the right context can be disseminated to the right person, at the right time, for the right business purpose (Blaine, 2000). Many practitioners have acknowledged that the web-based project information system is somewhat insufficient for being an efficient tool of knowledge management because of its incompetence (Wetherill et al., 2002) to accomplish such tasks as summarised below:

- Externalise the tacit domain knowledge of an individual. Experience learnt is not externalised and organised to a tangible form that is accessible by others in the future, but is instead buried in details and/or remains residing in the mind of an individual, who has career mobility.
- Document decision rationales that are important, but always scattered in the unstructured forms (e.g., ad-hoc messages, phone calls, memos, and verbal conversations).
- Solve the documentation problem, which commonly occurs when the process of creating documentation is decoupled from the process of creating the subject of the document. For example, the process of design has the problem of capturing design rationale. Not only is documentation viewed as a different task than design, it is done with a different set of tools and skills, and often by different people. Under such circumstances, people who are

responsible for documentation may not necessarily understand the usefulness of the documents to other actors.

- Contextualise data/information to increase its reuse value. Data/information is usually not organised in accordance with the right context while being captured and archived. The reuse value of the data/information reduces or even diminishes when people who have knowledge about the project have left for other projects. It is therefore necessary to include a rich representation of data creation and usage contexts to minimise any consultation necessity.

4.9 Concluding Remarks of Chapter 4

Improving cross-disciplinary collaboration throughout the building life-cycle, particularly at the design stage, has been in focus in the A/E/C discipline for decades. In light of this, the research community and industry in this discipline have cooperated at different levels: internationally, nationally and institutionally, plunging into various different areas in an attempt to achieve varying degrees of success in improving the collaboration efficiency. Knowledge management is one of concerned areas on which the A/E/C discipline has focused in these recent years in an attempt to put the notion of multi-level of knowledge sharing, i.e. cross- disciplinary, phases and project, into practice.

At the design stage, the design process itself is as important as any of the artefacts produced in the process. This is because it is the process through which the valuable design knowledge is generated. Sharing of design knowledge has been a common practice within and between the collaborating designers and other involved project participants for reaching constructive consensuses. Besides, design knowledge is also valuable for its reuse value on other projects. As outlined in the above, design knowledge is generally divided into two main groups, tacit and explicit. Managing explicit design knowledge has been practiced in the industry for years by using various mechanisms enhanced with the ad hoc ICT. However, the author believes that managing explicit design knowledge is insufficient to achieve the goal of improving collaboration efficiency as the essence of the design knowledge, the design rationale, which is difficult to formalise and thus remains tacit, has been left behind. The need of a total knowledge management system is thus addressed above based on the research findings suggested by other researchers.

Different research themes have been conducted over the decades for managing the overwhelming design information, to which the author refers as explicit design knowledge, through various means supported by the advancing ICT. Building product and process models, knowledge-based systems as well as groupware are the examples of outcomes of these different research themes. Literature (Futcher et al., 1998; Woo et al., 2004; Johannessen et al., 2001; Gruber, 1992a) finds that the use of ICT solutions in these research outcomes merely influences the communication of explicit information. As a consequence, sharing and retrieving tacit knowledge are suggested in these references to have achieved limited success only.

The web-based information management system is the example of groupware given above, which has been implemented with varying degrees of success for improving project oriented collaboration and co-ordinations. The intrinsic characteristics of the World Wide Web (WWW) technologies (e.g. the use of HTML that incorporates data and presentations in one piece), on which the web-based groupware applications are built, has somehow been successful to improve communication of project information, but exhibits weaknesses in the aspects of information overload. As a consequence of information overload, human's burden has thus not been reduced to process information before the right information can be retrieved through the web-based groupware. Apart from facilitating disseminating project information, a web-based information management system has the least contribution to total knowledge management where managing the tacit knowledge is also in focus. A notion of the next generation web, which aims at machine-processable information, was thus introduced by Berners-Lee (Berners-Lee, 1999) as a new hope to increase the competence of the web in information as well as knowledge management.

5 CASE STUDIES

There are only two ways to live your life. One is as though nothing is a miracle.

The other is as though everything is a miracle.

--Albert Einstein--

5.1 Introduction

This chapter reports the strategies that were used to collect and analyse data in order to identify, in general, the communication mechanisms implemented for sharing understanding including data, information and knowledge in the multidisciplinary collaborative design environment. The collected data were then analysed with specific approaches that would also be delineated hereafter, attempting to investigate in depth into the following contexts:

- Interaction amongst the multidisciplinary practitioners (designers) to achieve consensus during decision-making;
- Management of the design information at project level;
- The practices of sharing understanding (incl. data, information and knowledge) across disciplines and organisations.

A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 1994). Multiple case studies were implemented as the data gathering strategy for investigating the multidisciplinary collaboration pattern of design teams. The design process of three different building projects was studied in order to comply with this data gathering strategy. All identifying information of these three projects was removed in order to preserve anonymity as per the requests of the practitioners participated the case studies. All data collected from these studies was aggregated, analysed by means of Contextual Design methodologies proposed by Beyer et al (Beyer et al., 1998). An analysis of the collected data from the socio-cultural perspective was also conducted. Part of the collected data and the corresponding analysis are presented in this chapter.

5.2 Case studies, the overview

The case studies focused on the investigation upon the decision-making process, and how the design team members communicate amongst themselves effectively, at the early design stage of a building project. Contextual inquiry (Beyer et al., 1998), including both the *observation* and *interview*, was implemented as the methodology for gathering data/information attempting to identify the requirements for the design teams to achieve the optimum efficiency of understanding (design data, information and knowledge) sharing. A reference was also made to (Preece et al., 2002) while planning the data gathering methodology for this research study to familiarise with the notion of contextual inquiry. A demonstrator whose hypothetical user was the designer was developed as the outcome of this doctoral research study. An extensive discussion with respect to the demonstrator is reported in Chapter 8 of this thesis. The design teams of the case studies were therefore taken as the targeted user groups of the demonstrator, from whom information was gathered and elicited via observations and interviews.

5.3 The rationale of data collection for the case studies

A completed building project was adopted as the retrospective case study before direct observations on collaborative design were conducted. The retrospective case study provided the foundation for drafting the scenario-based questions that guided the author to establish focus for both the observations and interviews. The excerpt of these scenario-based questions is collected in Annex

5.A. In accordance with Beyer et al. (Beyer et al., 1998), focus is important because it draws a framework of the aspects on which attention is required during the observation study. Findings from the retrospective case study revealed that progress meetings were one of the important collaboration activities conducted regularly amongst the designers throughout the entire design process. *Design progress meetings* were therefore the targeted cases to be investigated into the three above-mentioned main contexts.

The three chosen cases for observation were all construction projects that were then at different stages of the design phase, ranging from the beginning of the conceptual design stage, the middle of the conceptual design stage and the end of the conceptual design stage. Conducting observations on a project whose project life lasts for several years, such as the building design projects, may be problematic. This is because the two to three hours of observation may be insufficient to represent the entire project life. It was also implausible for the observer, i.e. the author, to follow along the whole design process of one single building project due to the limited time frame available for the research study. Under such circumstances, the strategies suggested by Beyer et al. (Beyer et al., 1998), which is to cope with the long-term projects using the contextual inquiry methods were customised in this research study. In general, the customised strategies were two-folds:

Firstly, the author *observed multiple cases* each of which was at different stages of the design process under the assumption that work strategy repeated itself, and thus common patterns would emerge even though the cases were different. The main objective of undergoing observation was to understand the nature of the work of the practitioners, including exploring their workplaces and examining the key activities that entailed intrinsically the iterative behaviour of design. By observing, the author could gain better insights into the real working conditions of the practitioners, i.e. the design teams. In other words, observation was a good way to figure out how design and its relevant tasks were carried out and what were the corresponding problems while carrying out the tasks.

Secondly, the author conducted *interviews* after the observations. Generally, an interview could range from structured to unstructured and all stages in between. If the interviewer had little idea about what were the real concerns of the interviewee, an unstructured interview with a series of open-ended questions would be more appropriate. By undergoing such type of interview, the interviewee would steer the interview in the direction of issues that the interviewee perceived as important. Contrarily, a highly structured interview could be equivalent to interviewer-administered questionnaires. In the case of the design progress meetings, the author was not supposed to interfere with the ordinary workflow to prevent from being obtrusive, and therefore interviews with key practitioners were arranged after the observations. Semi-structured questions probing into the details of the observed meetings were directed to the interviewees for eliciting the work walkthrough by grounding the inquiry through exploiting the relevant project artefacts, such as plans, reports, work schedules, e-mails, and so forth.

5.4 Data Analysis of the Case Studies

In this paragraph, an overview of the mechanisms applied to analyse the data collected from the case studies is given. With reference to the methodology of contextual design, five different types of work models were substantial for interpreting the huge amount of the collected qualitative data. These work models were to portray graphically the observed working conditions based on a coherent way of structuring the data. The work models were to reveal the underlying framework of the collected data from the socio-cultural perspective because they were constructed to study the relationships between actors, artefacts and activities. Each of the five types of work models (i.e. the flow model, sequence model, artefact model, cultural model, and physical model) had its own concepts and symbols representing one of the key aspects of work that the observer needed to account for in the case studies. See Beyer et al. (Beyer et al., 1998) for the detailed explanations of these different types of work models. The data collected from each of the three case studies were represented by the five different types of work models before being interpreted. The work models of one of the case studies followed by the corresponding findings are presented in the following section to exemplify the data analysis method used in the entire research study. The work models of the other two case studies are included in Annex 5.B and Annex 5.C of this thesis while the corresponding findings are summarised and discussed in this chapter.

5.4.1 Case Study 1

Background

The case study was to observe a design meeting that was undertaken amongst a design consultant and his sub-consultants engaged in designing a station building of a big-scale civil engineering project, the across-nation high-speed rail project in a city in China. The project formed several contract basis multidisciplinary design teams that were responsible for the design of the different aspects of the project. The contract of the station building design consisted of four principal stages, i.e. the concept and preliminary design, detailed design, tender document preparation, and tender award. The observation was undertaken at a design progress meeting whose objective was to review the preliminary design for preparing onwards to the detailed design stage.

Methodology

The direct observation of the design meeting was recorded by means of hand-written notes. Voice recording was not permitted because discussions in the meeting at such an early design stage were considered highly confidential. Every meeting participant was given a nick-name (i.e. Nic, John and Andy) to facilitate the recording work. The hand-written notes were transcribed into several *sequence models* in order to depict the sequence of activities that each meeting participant carried out to achieve a particular intent. Thus, three sequence models were developed with reference to the observations of the three key meeting participants (see Table 5.1). These three sequence models were then merged into a consolidated model (see Table 5.2), which served as the framework that reflected the intents of the meeting participants, the corresponding actions taken to achieve the intents, as well as the reasoning behind the actions taken.

Interaction and communication flows between the meeting participants were also observed and transcribed into a flow model (see Figure 5.1). A *Flow model* was used as a tool to assist interpreting the coordination between people, the implicit strategy used to organise roles, as well as the roles that every individual played in the meeting.

A *cultural model* was generated (see Figure 5.2) to make the working culture of every individual in the meeting tangible. The main aim of the cultural model was to represent how the working culture of each individual influenced the working culture of the others during the meeting.

A *physical model* was roughly generated to show the physical environment of the meeting room (see Figure 5.3). The physical model together with the flow models could be useful for the analysis of the supportive workspace for the collaborative design meeting.

During the observation, different artefacts were noticed to be used and also created in a collaborative environment. The artefacts used in the meeting were noticed in a wide varieties ranging from paper-based meeting notes, reports, magazines, digital data stored in CD-ROM and computer, and to the full-size sample physical object (a sign post). The artefacts generated on the spot were mainly hand sketches and handwritten notes. In accordance with the interviewees, some of the handwritten notes would be converted to meeting minutes after the meeting was finished. Meeting minutes were thus the artefacts that were both used and created in a meeting. In view of this, meeting minutes were chosen as the *artefact model* for complementing the contextual inquiry methodology. There was, however, no meeting minutes available from case study 1 because all written records in the meeting were obliged to be treated confidentially. Artefact models acquired from case studies 2 and 3 are presented in Figure 5.B.4 (Annex 5.B) and Figure 5.C.4 (Annex 5.C) of this thesis, respectively.

Observations

Table 5.1 Sequence Model

The Sequence model of Nic

Intent: coordinate assignments.	Trigger: Started meeting at 09:50. Introduced meeting participants. Review telephone conversation from his paper-based notebook.
	Trigger: Discussion on time schedule and physical layout. Used a pen to sketch on a piece of paper put in front of him. Elaborated discussion while pointing at the sketch. Continued sketching on paper while discussing.
	Trigger: Secretary walked in with 4 copies of documentation, which were irrelevant to the meeting. Looked at the cover of the documentation and signed on each copy Left meeting room together with the documentation
Intent: to monitor & coordinate the meeting. Intent: to find document related to the discussion content. Intent: to show the document for collaboration purpose.	Trigger: Walked into the meeting room. Requested to know the discussion content between the other participants. Read a document relevant to the project's budget, which is put in front of him while listening to the discussion. Found a graph from the document after reading for a while. Put the document in the middle of the meeting table. Leaned forward to point at the graph found from the document.
Intent: to enable project participants to get known of each other.	Trigger: Mark walked in to join the meeting. Introduced Mark to the rest.
Intent: to have a quick glance of and "feel" the report. Intent: to show the real object to support the perception with respect to the discussion. Intent: use scenarios to create better understanding of the conversation context	Trigger: A report (IMS) was shown by Andy by passing it (only one copy) around. Flipped the report. Discussed about assignment context (about passenger flow & fixture of station ceiling). Stood up and walked to the window side. Took out a sample sign post. Walked back to seat. Continued discussion complemented with scenarios description. Mentioned to Andy about checking existing drawings of previous projects. Pointed at CD-ROM pile that was put beside Andy.

(design of signs and stations). To prepare for next meeting. To create consensus on the conversation context.	Read fax while listening to discussion. Lifted up a folder from the documentation pile in front. Listened to John's request.
Intent: To end the meeting.	Trigger: Secretary walked in with 4 copies of documentation Looked at the documentation & wrote something (signature?) on it. Quick review on assignments before next meeting by reading some lines from his paper-based notebook.

Sequence model of John

Intent: To brief the meeting scope. To create a common goal. Note: no agenda was prepared for the meeting.	Trigger: Meeting was started. Listened when Nic was reviewing the context of a telephone conversation. Checked the updated news from Andy. Listened to explanations from Andy. Raised doubts. Listened to clarification from the other two.
Intent: To use sketch as a communication media.	Trigger: Nic sketched on paper. Leaned forward. Looked at the sketch. Elaborate discussion based on what could be understood from the sketch.
Intent: To acquire clarification.	Trigger: Nic's secretary came in with documentation. Continued discussion with Andy while Nic reading the documentation. Raised question to Andy to acquire clarification on his doubts. Listened while Andy summarised the discussion contents to Nic when he was back to his seat.
Intent: visual aids were used to create better understanding in a discussion.	Trigger: Nic pointed to a graph (figure) found from one of his documentation that was beside him. Leaned forward to look closer at the pointed figure. Continued discussion based on the figure. Listened and watched Nic's gestures when he was describing the size of a ceiling structure/substructure.
Intent: records for future referral.	Trigger: A report was shown by Andy. Jot down notes on a F4 size notebook (paper) while listening to the discussion.
Intent: communicate thoughts to share understanding.	Trigger: Nic showed a sign post (about 1 m high) at the meeting. Listened when Nic was talking. Spoke with gestures.
Intent: checked for information that was unclear.	Trigger: Raised questions about the appropriate tool/software to prepare drawings. Asked if softcopy drawings are acceptable in accordance with the interface policies. Pointed at a folder that Nic was holding.

	Wanted to have a copy of the policies. Asked if design criteria are available. Looked at Andy when he was talking. Wanted a copy of the design criteria.
Intent: to cross-check the assigned tasks.	Trigger: Nic's secretary came in with 4 copies of documents. Jot down notes on a F4 paper size notebook (same as before). Reviewed assignments to be complete before next meeting. Trigger: meeting finished. Kept notebook in briefcase. Stood up from the chair. Left the meeting table and walked out from the meeting room.

Sequence Model of Andy

Intent: to review what had been done to John.	Trigger: Meeting was started at 09:45. Read on a paper-based notebook. Reviewed telephone conversation with Nic. Answered to John's questions.
Intent: to share thoughts.	Trigger: Nic sketched on paper. Leaned forward to have a closer look. Discussed based on the sketches.
Intent: to start discussion.	Trigger: Nic's secretary came in with documentation. Discussed with John. Summarised the discussion contents to Nic when he was back to his seat.
Intent: to articulate mental image with different methods.	Trigger: Nic pointed to a graph (figure) found from one of his documentation that was beside him. Leaned forward to look at the figure. Talked using body language to clarify ideas.
	Trigger: Mark walked into the meeting room at 10:03. Moved chair to adjust spaces around the meeting table. Continued discussion with signs and gestures. Listened while Nic was introducing Mark to the group.
Intent: to show alternatives to team mates.	Trigger: picked up a document from the table to show a report to the group. Talked about the report.
Intent: to comprehend discussion contents.	Trigger: Nic showed a sign post (about 1 m high) at the meeting. Looked at Nic while he was showing the sign post. Listened and talked. Made notes with pen on paper-based notebook when Nic mentioned about looking for old drawings. Touched and flipped a pile of CD-ROMs that was put between Nic when Nic mentioned about the availability of information with respect to ceiling substructures.
Intent: to record discussion contents.	Trigger: questions about the appropriate tool/software to prepare drawings. Listened while John was questioning. Spoke out own opinions to answer the question. Made some notes. Promised to check the request about design criteria. Made notes in notebook (paper).

Intent: to check if he had the assigned tasks written down.	Trigger: Nic's secretary came in with 4 copies of documents. Listened and read on notebook (paper) to review assignments. Agreed with Nic when he informed the rest about a regular meeting with other project team.
	Trigger: meeting finished at 10:40. Read on notebook (paper) while John prepared to leave the room. Remained seated for the next meeting. Talked with Mark.

Table 5.2. The Consolidated Sequence Model

The Consolidated Sequence Model

Main Activity	Intent	Abstract Step
Review tasks assigned in previous meeting.	Disclose meeting history. Provide quick introduction of the meeting scope. Coordinate assignments.	Trigger: Start the meeting. Refer to the meeting minutes of previous meeting as the current meeting agenda. Someone speaks out the review.
Report tasks that have been achieved before meeting.	Allow meeting participants to familiarise themselves with the responsibility of other team members. Coordinate the progress of a particular assignment. Estimate the project progress.	Refer to the decision made in previous meeting on certain task. Refer to a common project schedule. Report problems/barriers faced orally.

Start discussion session.	Keep team member notified with the updated information. Define problem, if any. Generate the alternative solutions for the problem. Compare the alternatives.	Trigger: Interpret the problem. Describe the problem orally. Use tools/aids to describe the problem to help other participants to get a grip on the problem. Decide what are the main areas of choice. Find what are the different solutions in the area (consult experienced supervisor, use social connection, access to relevant archive, etc) Assess solution feasibility (based on experience, advices or use special tool). Compare the alternative solutions by assessing their respective nature. Make comparison from multiple perspectives (based on experience and relevant knowledge with and/or without using a special tool). Decide a set of comparisons and preferences as a basis for a choice (based on compromise and collaboration between the affected parties).
End discussion session.	Choose one alternative as solution. Make a decision about action and policy.	Estimate the impact of the decision made. Decide if the decision can be made now. Decide the next following step that either directly or indirectly correlates to the action taken.
Summarise meeting contents.	To check if the meeting follows the agenda (if any). Decide if any additional topic should be covered. Allow the meeting participants to know their respective duties.	Check the meeting agenda to ensure that all topics have been covered (e.g. read the circulated agendas that is either paper-based or softcopy). Conclude the meeting.

Record assignments/tasks to be achieved before next meeting.	To refresh memory when it is necessary.	Record the reasoning behind decision made on a certain action (e.g. someone shall prepare meeting minutes during or after the meeting).

The Flow Model

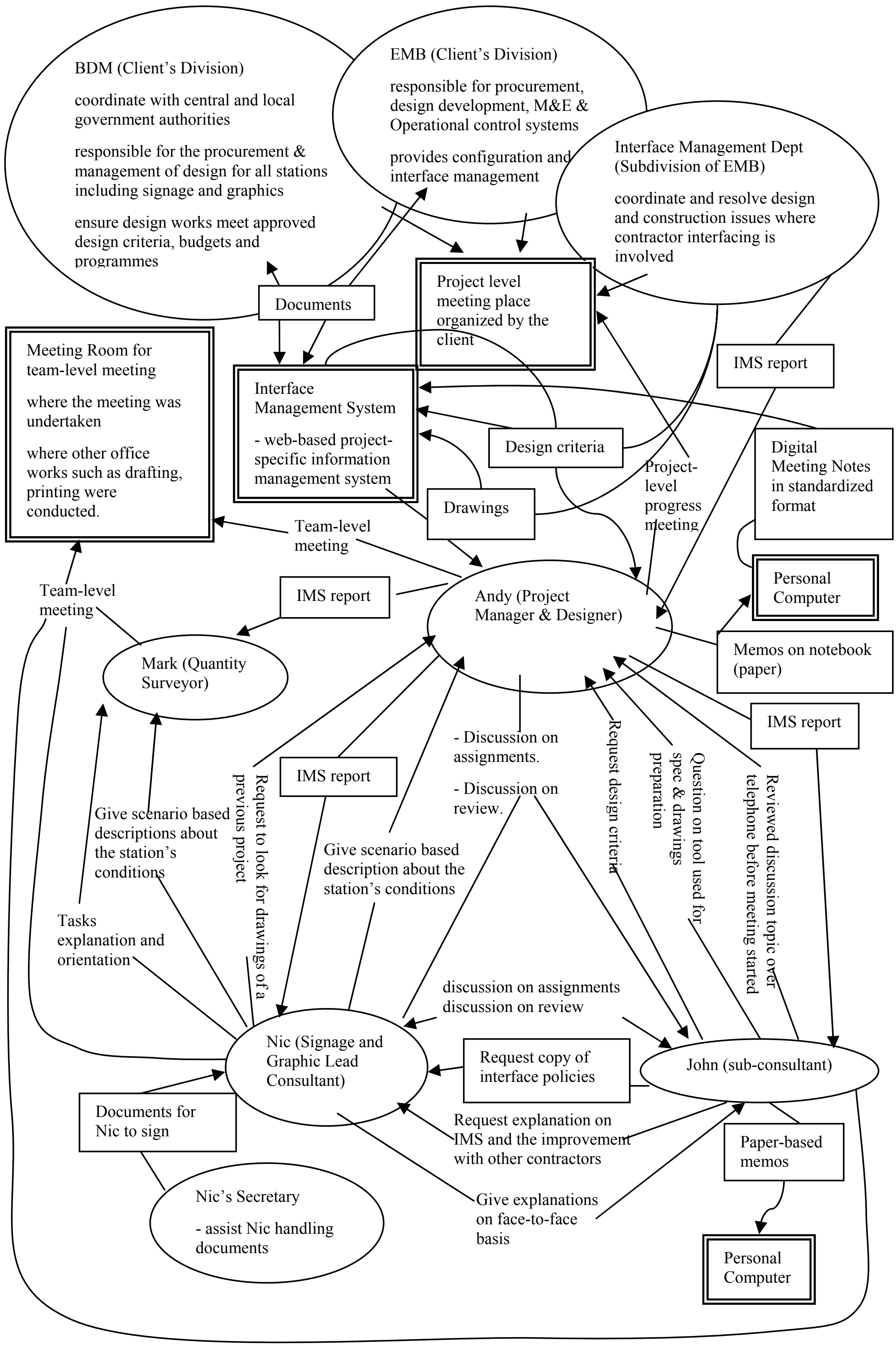


Figure 5.1: Flow model between meeting participants.

Figure 5.1 shows the flow model of case study 1. In this figure, every meeting participant is represented by a bubble with nickname as identifier. The role played by a particular participant is written in a bracket after the nickname while the responsibilities with respect to the role are listed underneath. Small rectangular boxes represent the artefact used or produced in the communication between participants. Arrow is used to represent the communication flow between people to get work done. The communication flow may consist of informal talk and coordination. The communication topic or action is written in the middle of the arrow. A double-lined box is used to represent the place, either real or virtual, where meeting participants go in and out of in order to get their work done, which in this case for instance are the physical meeting rooms and the digital information management groupware prepared by the client.

The Culture Model

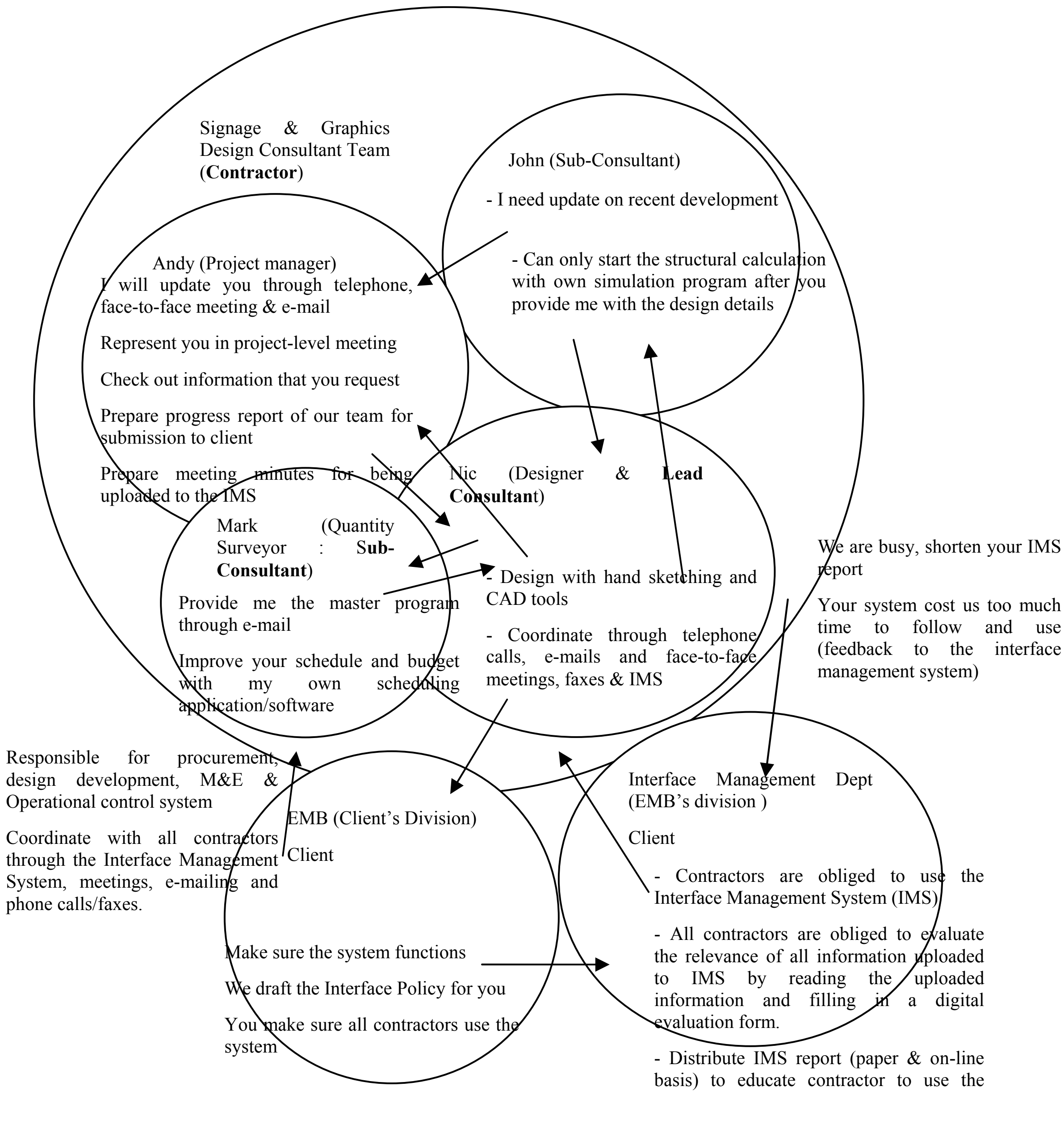


Figure 5.2: Culture model.

Figure 5.2 shows the culture model of case study 1. The bubbles sit on one another to illustrate how one organisation/person forced another to take or not to take actions. Influences are represented by arrows that are labelled with phrases representing the experiences of people/organisation doing the work.

The Physical Model

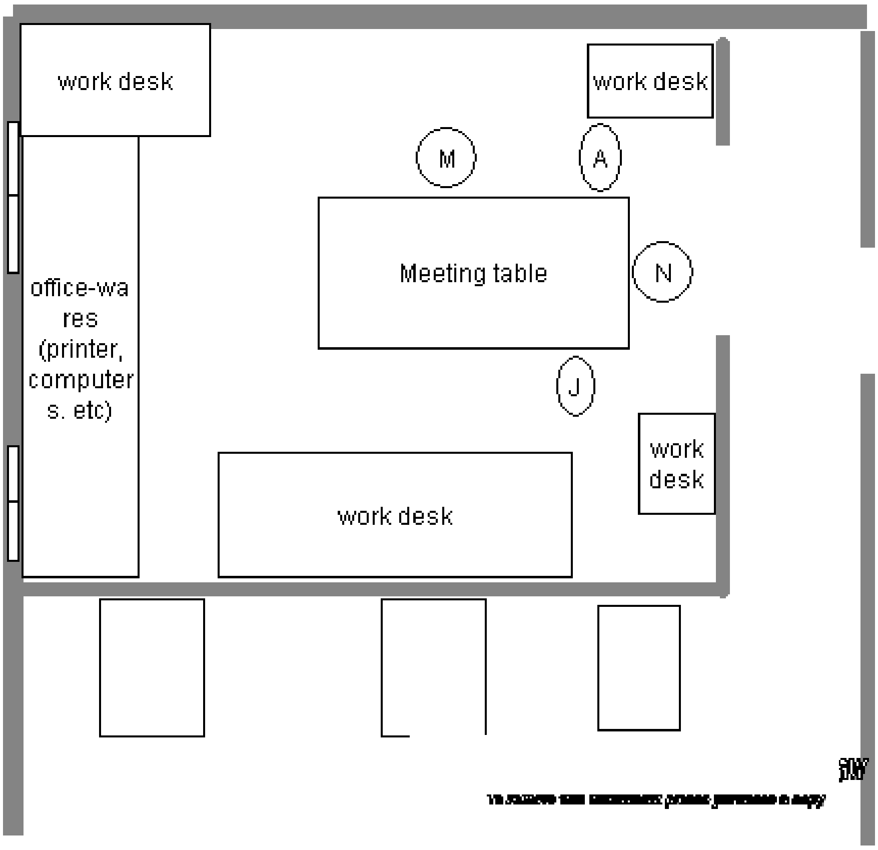


Figure 5.3: Physical model that illustrates the physical environment of the meeting room

Figure 5.3 shows the physical model of case study 1. The small bubbles are used to represent the meeting participants with their respective initials of nicknames written in the middle. The author was notified by the interviewees that internet connections were available in all of the computers used at the office. The internet connections are, however, not illustrated in Figure 5.3.

Work Model Analysis from the Socio-Cultural Aspect

The work models were constructed to study the human activities in a collaborative environment. The dynamic relationships between the actors, artefacts and activities are the core aspects of the study. A brief analysis of the models is presented hereafter.

The sequence model outlined a general picture of the dynamic relationships of actor-actor, actor-artefact, actor-activity, artefact-artefact, and activity-activity. Four concerns, upon which the effective collaborative design was dependent, could be generalised as follows from the sequence model:

- Spatial barrier, referred to the collaboration barrier due to the different physical locations.
- Temporal barrier, referred to the barrier caused by communication difficulty across time
- Conceptual barrier, which could easily occur in cross-disciplinary collaboration where the striving for a common ground and shared understanding would be one of the project goals.
- Technological barrier, which occurred when different artefacts were used by the different actors.

The four barriers mentioned above were then further analysed using the flow and culture models, respectively. In the flow model, the interactions of actor-actor, actor-activity, and actor-artefact were represented. The actors interacted with one another to achieve the objective/s of a particular action. For instance, John interacted with Nic in an attempt to acquire the operation details of the project-specific Interface Management System (IMS). As noted in the model, artefacts were involved in the operations of certain actions. For instance, John, in his interaction with Nic, expected to receive a copy of the interface policies from Nic. The copy of the interface policies was an artefact involved in one of the John-Nic interactions. IMS report, memos on notebook, drawings, documents, were a few of the artefact examples. The interactions of actor-actor and actor-artefact represented in the flow model also shaped clearer three of the four collaboration barriers generalised from the sequence model, namely the barriers of spatial, temporal and technological. Since face-to-face meeting was the preferred collaborative method, the actors faced the spatial barrier. The actors used, for instance, the IMS, in an attempt to bridge the temporal and technological gaps between each other. A digital medium as IMS was developed attempting to create a common socio-technical environment where all participants could create a common ground for shared understanding establishment throughout the project.

The conceptual difference between the multidisciplinary project actors was examined by constructing the culture model shown in Figure 5.2. The culture model presents how an actor thinks, acts and reasons with respect to his/her professional role and company values in order to complete the assigned tasks. The model showed that interactions between actors were conducted with specific motives or objectives. It was noted in the culture model that actors collaborated first through hypothesis defining followed by action taking. For instance, as Andy collaborated with Nic, Andy set-out the hypothesis on how he would update Nic using different options to reduce the spatial, temporal and technological collaboration barriers. Andy was required to carry out many actions (or activities) to complete the corresponding tasks as a project manager. Every action conducted by Andy would influence, to a certain extent, the action of the relevant collaborator, which would eventually affect the final results of the collaborated tasks. A domino effect would be most likely to happen if the operation of one of the actions failed due to lack of a shared understanding of the task-at-hand. The action taken by every collaborator was thus tending to establish a shared understanding, which was essential for the success of a collaborated task.

As also noted in the culture model, the project collaborators attempted to reduce the conceptual differences through interpersonal interactions. The interpersonal interactions were noticed being conducted with various communication means, including those supported by computer technologies and the face-to-face verbal conversations. Through interpersonal interactions, actors were noticed attempting to obtain work-related information in order to build a common ground for efficient collaboration purposes. Each actor served as the non-technological information source to his/her collaborator. The actors also served as the mediators for their collaborators to access to the technical information source, the IMS, as in this case study. For instance, Andy, was both the non-technical information source and mediator to one of his collaborators, Nic. Artefacts, either technical or spatial, were used to facilitate interpersonal networks within which interaction occurs. Some of the artefacts were produced as the outcome of the interpersonal interactions. For instance, the meeting room was the spatial artefact that the actors used for conducting interpersonal interactions; the telephone was, on the other hand, the technical artefacts that the actors used to interact. In addition, the drawings were the artefacts produced as the outcome of interactions while being used to facilitate the interactions process.

The culture model also indicated that division of labour was undertaken on a collective basis. Every individual actor (or group of actors) performed specific actions corresponding to his/her professional role, but these actions were required to be reported back to the other actors (or other groups of actors). This collectivistic individualism (Engeström, 1987) collaboration pattern was again the approach used to strive for reducing the four collaboration barriers mentioned above. For instance, the interaction between Mark and Nic indicated that works were divided between them to strive to use the same artefacts in an attempt to minimise the technological and conceptual barriers.

The complementary interviews

Several interviews were conducted with the key meeting participants within a reasonable timeframe after the observation to cross-check some of the uncertain information, such as the responsibilities of the meeting participants in the project, the sources of information used in the project, and so forth. The transcripts accumulated from the interviews were summarised hereafter.

Table 5.3. The role and responsibility of the meeting participant

Participant	Role	Responsibilities
Nic	Lead consultant	Designing and leading the team.
Mark	Sub-consultant (quantity surveyor)	Does detailed program -10 pages The program will be used to monitor the cross-reference activities
John	Sub-consultant	Provides the Structural engineering and M&E engineering advices
Andy	Project Manager	Produces both weekly and monthly activities report. Represents the design team at project-level meetings.

Table 5.3 tabulates the roles that the key meeting participants played in the project and their respective responsibilities, which were not specified clearly in the culture and the flow models attempting to present the diagrams with better readability. With reference to Table 5.3, Nic, who played the leading role of the design team, was responsible for coordinating the design process. Progress meetings were the important occasions in which collaboration activities such as discussions and dialogue between project team members were encouraged to enable efficient decision making.

Progress meetings could be categorised into two levels, the team level and the project level. The team level progress meeting was also referred to as the internal progress meeting by the interviewees. The participants of the project level progress meetings comprised the representative(s) of each team that was responsible for a particular aspect of the project, such as structural design, land surveying, and so forth. The design team formed by Nic, Andy, Mark and John, had assigned Andy as the project manager, i.e. the team representative to attend the project level meetings hosted by the project client. One of the situations of holding project level meetings when the needs arose was to involve all of the relevant project stakeholders, including the architects, consultants, contractors and sub-contractors in the same physical meeting space. This was because most of these project stakeholders involved themselves simultaneously in several different projects whose physical site locations were geographically dispersed across the different time zones. It had been a quite common situation for the project stakeholders where two meetings for two different projects could occur at the same time, but at two different locations that were thousands of miles apart. Under such circumstance, the project client provided a web-based project information management system to facilitate project information dissemination and monitoring in order to encourage consistent communications between the project stakeholders. The workflow including how the interviewees communicate and coordinate amongst themselves as described above was represented by the flow model depicted in Figure 5.1.

Apart from the regular progress reports, meeting minutes of formal meetings at both the team and project levels were obliged to be uploaded to the web-based project information management system on a regular basis. This web-based information management system was called the Interface Management System (IMS) and was developed to ensure that the essential project-related information would be circulated amongst the different project teams. The client used monitoring of meeting minutes strategy to be kept informed about the project progress. The reasoning for using this strategy was that meeting minutes were the documents produced either formally or informally for recording the discussion contents of meetings. During meetings, discussion contents were usually summarised and written down on paper by one of the meeting participants. Such paper-based notes were referred as informal meeting minutes by the interviewees. These informal records were required to be superseded by the formal documentation whose formats were standardised by the client before being submitted to the web-based IMS. Comments given by the interviewees based on this documentation handling formality imposed by the client were extra work loads that cost extensive labour forces and time.

Apart from handling meeting minutes, the IMS was also applied for the management of other project relevant documentation, such as the design sketches, design drawings of floor plans and building envelopes, project programmes and so forth. However, the IMS was commented to be inefficient to disseminate documentation to the right person at the right time. The IMS was not established to sort the uploaded information to the right receiver based on its relevance for the receiver. The interviewees were under contractual obligations to read and evaluate every piece of information that was uploaded to the IMS. Such formality was seriously criticised by the interviewees for occupying too much of their time. As indicated by the interviewees, a chaotic state of excessive communication was driven by the IMS and inappropriate use of technology. The interviewees envisioned a new Information and Communication Technology (ICT) system that would emphasise on disseminating information to the right person at the right time instead of one that often bombarded them with excessive irrelevant information.

The interviewees were dissatisfied with the capability of information retrieval provided by the IMS. *Historical precedents* for designs and decisions made in previous projects were unavailable in the IMS. Historical precedents were commented to be very useful for designers to carry the design process through either as the means to improve the client's understanding of the design ideas or as the reusable knowledge that could reduce the design time. The IMS functioned merely as a client information source for the current project without synchronisation with the other information sources of the interviewees (designers), such as books, previous projects, magazines and so forth that they used to rely on while designing. Interviewees envisaged a system that could provide efficient information search, high information integrity from different but relevant professional fields to enable efficient tracking of updated information, as well as efficient and sufficient (but not excessive) communication with other project stakeholder groups. The interviewees also reported that no product model approach was implemented in the project. Apart from the IMS, design information was shared via telephone conversation and face-to-face meetings. Paper-based design information, such as hand sketches and handwritten notes, were transformed into digital forms on selective basis with the use of document scanners. Judging by the interviewees, only information that might interest the client or that was about the final decision made for a particular discussion topic would be selected for being digitally stored. Under such circumstances, reasoning behind decisions made during the design process might be absent in those selected representations.

5.4.2 Case Study 2

A *multidisciplinary project-level progress meeting* was observed in this case study. The project was to build privately owned premises used for educational purposes at both primary and secondary levels. According to the client requirements, this school was to have numerous facilities including indoor swimming pool, several auditoriums, sports hall, library, music room, etc. The project had been started approximately 2 years before the observation was conducted. The project was at the transition stage between the late scheme design and the beginning of detailed design when the observation was conducted. At that transition stage, the designers were to produce working drawings based on the ketches and decisions made beforehand.

A specific computerised drafting platform (Micro-station) was used by the contracted architectural firm to produce graphic building representations (i.e. drawings). Other designers in the same project used various different drafting tools. However, the interviewees suggested that the problem of data exchange was not critical in this project because the two dominant drafting tools (i.e. MicroStation and AutoCAD) used in that geographical region could provide sufficient flexibility in the aspects of data interoperability. Conversion of drawing files from the format supported by AutoCAD (DWG) to that supported by MicroStation (presumably version 8) (DGN) was remarked problem free. Slide shows made in Microsoft Office PowerPoint were the dominant tool used to present ideas to improve the horizontal communication in cross-disciplinary progress meetings. In this project, some of the design information had been well maintained in digital form rather than being printed out on paper. 2D drawings (sectional drawings, plan drawings, elevation drawings), scaled physical presentation model and 3D computer images, and paper-based hand sketches were used to communicate design information. Paper-based hand sketches were mainly used at the preliminary design stage. Meeting minutes were made after every meeting by the assigned project manager. A meeting agenda was made only for the first meeting. Meeting minutes of one meeting were used as an agenda to guide the discussion topics of the subsequent meeting. A progress report of each project team was made and submitted to the Project Manager once a month.

A web-based information management system was set up by the client for coordinating information generated throughout the project. A progress meeting at project level, i.e. one that involved all stakeholders was conducted on a regular basis, approximately twice-monthly. A progress meeting at team level was usually conducted more frequently than the project level meeting. Apart from face-to-face meetings, faxes and telephone conversations were among others the most prevalent communication channels used. Telephone conversations were not recorded thoroughly, but only the decision made during the conversation was recorded. Both digital and paper-based archive systems were used in the project.

Information management was conducted at two separate levels, company level and project level. At company level, the project specific information was stored in the company owned digital database and/or paper-based archives. Information was disseminated to colleagues of the same project through e-mail, telephone and face-to-face conversation or handing-in in person. Different filing structures were used between the company level and the project level information management systems for categorising the project specific information. This was the situation that caused the problem of mapping the same information in between the two different levels of information management systems. Manual efforts in regard to file searching, identifying, retrieving, disseminating and storing were implemented extensively for synchronising the contents of these two separate information management systems.

The interviewees revealed another situation with regard to the handling of the paper-based company level information. Limited office space was the main constraint of managing the increasing paper-based documentation. The paper-based documentation was only kept in the company offices for a particular timeframe, say about 5 years. After the specified timeframe, the paper-based documentation would be archived to warehouses located at a remote countryside whose rent was much cheaper than offices that were sited in the city. Space constraint was one of the reasons that motivated the initiative of digitalising documentation. However, the A/E/C professionals around the geographical region where the observations were conducted remained sceptical of the reliability and durability of digitalised documentation. The production of paper-based documentation had thus never been reduced though various means of generating and storing digitalised information were used. As a consequence, the financial expenses for information management had increased drastically.

5.4.3 Case Study 3

This case study was to observe a *cross-disciplinary design meeting conducted at a noted architectural firm*, which was assigned by a worldwide famous real estate company to design a cluster of commercial premises in a city in China. The traditional procurement system, design-bid-build, was implemented in this project, and the architectural firm was assigned to play the leading role to coordinate the design team. The members of the design team were composed of the client appointed design consultants, the client, the architects and the quantity surveyors. The basic client requirements of this project were to design the premises based on the concept of green building and to complete the project in year 2006. The project was at the preliminary submission stage whilst the observation was undertaken. At the preliminary submission stage, the designs were required to be evaluated by the client and/or the appointed design consultants. Thus, the designs were kept sufficiently flexible for any potential changes that might be requested by the client.

Presentations were performed regularly to the client and his/her design consultants for approval to proceed with the project to the next level. In-house design team meetings within the architectural firm were usually held on a weekly basis since the project started. Meeting minutes recorded from the preceding meeting was usually used as the agenda for the succeeding one. Graphic representations in regard to building design such as hand sketches and the printed copy of computer drafted drawings were used in the meeting, where the observation was carried out, as the main way to communicate design ideas amongst the meeting participants. Hand sketches remained the most favourite choice of the architects to externalise their intangible conceptual models rapidly (see Figure 5.4). When presenting design ideas, designers tended to put up their hand sketches on the partition walls of the meeting room (physical meeting space) in order to help their audiences visualising the ideas. The interviewees suggested that this was the best approach to promote effective communication for reaching mutual understanding. Apart from the physical face-to-face meetings, telephone conversations and faxes, a web-based information management system was also available for the project participants to communicate their project relevant information. Extra efforts were also spent by interviewees of this project to digitalise the paper-based documentation. This repetition of workload was criticised as tedious and a waste of resources in terms of labour, time and money.

5.5 The Interpretations of Findings

The data collected from the other case studies 2 and 3 were analysed with methodologies corresponding to the first case study. A brief report of the findings of each of the two cases was given above. Apart from using the contextual design methodology for data analysis, the contents of the conversations observed in the case studies were also analysed attempting to explore the decision making process undertaken by the multidisciplinary design teams (see Table 5.B.1 (in Annex 5.B) and Table 5.C.1 (in Annex 5.C)). Exploring the decision making process was taken into account because the process itself was important to reflect the reasoning behind decision, and appeared to be a valuable source to study the interdisciplinary communication. Studying the decision making process undertaken in the collaborative design meetings is thus an alternative to probing into how the multidisciplinary design team members interact to achieve mutual understanding. In brief, the data analyses accumulated from all of the case studies laid the foundation to formulate findings whose interpretations would be discussed below.

5.5.1 The essence of collaboration in the early design phase

The main concern of collaboration in the context of collaborative design, particularly the design that is carried out in the early design phase, is to share and transfer understanding including know-how (Chiu, 2002). Activities involved in the early design phase comprise client briefing, data collection, architectural program formulation, conceptual design and scheme design. This is also the phase where critical decisions that could influence the evolution and quality of the final product are made. *Collaboration* was *defined* as a team of people working together with shared goals for which the team attempts to find solutions that were satisfying to all concerned (Kvan, 2000). While engaging in collaborative design meetings, as those observed in the case studies, the design team that comprises multidisciplinary project stakeholders will search design solutions through an iterative rational problem-solving process (Simon, 1969). For instance, in case study 3, it was the responsibility of the key project stakeholders, the architects and the design consultants, to assist the project client to formulate the functional requirements. As evident in the collaborative design meeting, the architects synthesised the design solutions in compliance with the plain client briefing through close collaborations with the design consultants. As noticed in all of the case studies, interviewees collaborated to strive for a consensus on critical design issues accompanied by activities such as discussion and information enquiry. This work routine was iterated in a way that conformed to the problem-solving model, which was illustrated in Figure 3.1. In other words, the key project stakeholders functioned as problem solvers who were to confront the inherently ill-defined design tasks (Thomas & Carrol, 1979) until the adequate solutions (Cross and Cross, 1995) were found.

The interactions between the design team members including their verbal conversations were examined in the case studies in order to perceive the *problem solving behaviour* that the team members possessed when practising collaborative design. As conforming to one of the Simon's arguments concerning the problem-solving behaviour of a designer (Simon, 1973), the interviewees remarked that they *required a large base of relevant knowledge/information* throughout the problem-solving process in order to confront the design tasks effectively. The efficiency of problem solving was further delineated as to depend on the efficiency of information processing during their interactions. Information of various kinds, including inferential, hypothetical, recollected, and evaluative, was noticed to undergo various information processing procedures that were composed of a series of collaboration activities including review, planning, analysis, synthesis, negotiation, consultation and evaluation. These collaboration activities supported by verbal conversations and gestures were the cornerstones from which the cognitive processes of the interviewees in information processing and knowledge exploiting could be reflected (see Table 5.B.1 (in Annex 5.B) and Table 5.C.1 (in Annex 5.C)). As tabulated in Table 5.B.1 and 5.C.1, a coding scheme in compliance with the Protocol Analysis methodology was used to analyse the conversation contents. The finding of the analysis indicated that interviewees carried out a series of actions to identify problems, to synthesize alternatives, and to choose the best alternative based on reasoning explained orally to other meeting participants.

5.5.2 Communication Channels and Artefacts

As noticeable in the case studies, the interviewees shared knowledge and information between each other through both synchronous and asynchronous communication. For instance, progress meetings, as revealed by the interviewees, were conducted on a regular basis at two levels, team- and project-level, respectively. Evidently, face-to-face meeting was the synchronous communication means that the interviewees preferred particularly when oral explanations were needed along with visual presentations. Physical face-to-face meeting provided the meeting participants a setting in which discussions and dialogues could be held and supported by various presenting mechanisms including verbal descriptions, hand sketches and gestures so that the optimum state of collaboration could be achieved. The interviewees were noticed to have extensive explanations and discussions over issues that were in connection with the reasoning behind any decisions made and decisions to be made.

In general, the interviewees regarded face-to-face interaction as an efficient communication channel to convey the abstract mental model. Other communication channels used apart from face-to-face meeting were faxes, telephone and e-mails. The use of e-mails has been increasing after the Internet-based communication has been widely adopted within the A/E/C sector. E-mail was remarked by the interviewees as a very convenient and economical tool to share and exchange information particularly under the circumstance where communication of verbal descriptions becomes less appropriate due to for example the difference of geographical locations and time zones.

Meeting minutes were the most regular artefacts generated to capture the decision rationale as well as the dominant discussion contents in the collaborative design meetings under study. Decision rationale with respect to designing in the early collaborative design phase could also be regarded as the tacit design knowledge. This is because the decision rationale contains all sorts of routines, intuitions, norms, beliefs and hunches that are hard to formalise, but are exploited extensively throughout the design process. As observed in the case studies, meeting minutes were usually prepared by a responsible person in a 3+1 procedure:

- summarised the discussion contents first on papers, then
- input the summary to the computers, followed by
- uploading the digitalised meeting minutes to an electronic project basis information management system (e.g. project web) and/or circulating it as an attachment of an e-mail.

The 3+1 procedure implemented to disseminate meeting minutes as mentioned above was considered by the author as repetition of workload. The conventional notes-taking approach also tended to structure the meeting summaries in a tree-like hierarchy with *design rationales implicitly contained* in written plain text. The implicit design rationales could only be interpreted rapidly by those who attended the meeting and actively joined the discussion. For those who did not participate in all of the meetings, but were interested in following the design progress, extra time was needed to collate and review the series of time marked meeting minutes. The conventional meeting minutes were also unable to integrate the vast quantity of design information produced throughout the early design process. Meeting minutes were generated as the written record to summarise discussion contents of a meeting, but were not devised as a mechanism to integrate design information. Gathering the relevant, but scattered design information was a burden that was left on the shoulders of the project stakeholders. An extensive explanation in regard to the demerit of this inherent characteristic of the conventional meeting minutes is given in Chapter 7 of the thesis.

5.5.3 Application of ICT in Design Information Management

All sorts of information (objects, concepts and relationships) in relation to the design process are in its broadest sense regarded as design information. Design information was communicated amongst meeting participants via various types of representations including 2D drawings (sectional drawings, plan drawings, elevation drawings), scaled physical presentation model (scaled mock-up), 3D computer images, hand sketches, and text-based descriptions. Most of the design information was maintained in both digital and paper forms, and therefore both digital and paper-based archive systems were noticed to be used in the case studies. Hand sketches were the prevalent representations used and generated in the collaborative design meetings, particularly for communicating design ideas at the conceptual stage when a verbal description was insufficient to visualise the ideas. Computer 3D images were used when the design process began to move forth to the scheme design stage. Apart from graphical drafting tools, designers preferred simple computer tools that they could use for the purpose of managing design information without special training. Designers commonly used different varieties of personal tools such as word processor, spreadsheet tool, calendar, e-mail facilities and simple electronic filing system.

The basic need of a project information management system is to enable support of traditional project management tasks in planning, monitoring, reporting and control of baseline scope, cost, time and quality (Archer et al., 1997). Such a system is also expected to incorporate the mechanisms of trend forecasting and change control, and to be able to manage documents in a manner that would track issues, provide fast retrieval of relevant documents and support the time limited process for the resolution of disputes (Archer et al., 1997). Several attempts have been conducted within the A/E/C industry including the concept of a project web as discussed below, attempting to apply the fast developing information and communication technologies (ICT) to manage the ever expanding information base. Information that was accessible through the support of ICT was regarded by the interviewees as codified knowledge, which could be in the form of texts and/or graphics. Codified design knowledge was remarked by the interviewees as insufficient to impart the procedural knowledge of designing that is composed of routines, intuitions, norms, beliefs and hunches implemented during designing as well as in the problem-solving process of designing. The un-codified procedural knowledge was reflected and traceable from the verbal discussions and dialogues undertaken in collaboration activities. However, the verbal discussions and dialogues were seldom completely documented but summarised in a way that the procedural knowledge was not formalised sufficiently explicit.

A web-based groupware was found implemented in each of the case studies as the digital portal and source of project relevant information. This groupware would be recognised as *project web* in this thesis because it was devised to facilitate the management of project relevant information. It was devised to function as a centralised repository for project stakeholders to share the digitalised project-related information, such as design drawings, progress reports and meeting minutes that were generated throughout the project life. This electronic project information management system was conducted via an extranet using Internet protocols to transmit information. Project related information was stored on a centralised server while a standard web browser was used by the team members to access information regardless of the geographical locations and hardware platforms. The project web was remarked by the interviewees to be an increasingly widespread used digital container within the A/E/C sector in these recent years. However, the author would argue that the efficiency of project web in sharing both the tacit of explicit design knowledge remains a question that needs further investigation.

The interviewees remarked that the project web was insufficiently efficient to eliminate the problem with respect to fragmentary information flow that would further cause negative impact on the motivation of stakeholders to share information. The limitation of the project web as employed in the building design projects observed in the case studies, was found having correlation with the inherent weakness in the design of the information system framework. The project web was not devised to coordinate the management of all types of digitalised information produced in the project. Weakly structured information such as briefing note, design rationale, and e-mail message was not stored in the project web. E-mail messages were collected in another project-level digital information source that was responsible for collecting all project related electronic correspondences. Paper-based information was kept in the company-level paper-based archives such as the physical filing cabinets, which were arranged specifically for the project. Drawings were generated at every stage with respect to the advance of design, but only the final version was uploaded to the project web. In brief, the situation of fragmentary information flow was not improved after introducing the project web concept.

The project web supported the basic information access mechanisms such as simple keyword search and manual navigation of the archived contents. It also supported the basic information control mechanism in which information was first categorized based on some sort of relations before being archived in different electronic file folders corresponding to the information categories. For instance, all information correlated to structural design would be put into the same electronic file folder. These electronic file folders were arranged based on a tree-structure index in alphabetical order. Information stored in the project web under such arrangement was only searchable through the basic information access mechanisms supported by the project web. Also, the project web provided no assistance to its users to shorten the timeframe needed to comprehend the *context* of information accessible from the project web. As remarked by the interviewees, this facility was of interest particularly when digesting a stack of documents that were needed either shortly before a meeting or even during a meeting.

5.5.4 Capture of design Knowledge

Approaches that the interviewees implemented including the project web were noticed developed for disseminating the different types of documents in which the project relevant information was stored. The different types of documents such as progress reports, meeting minutes and CAD drawings, either paper-based or digitalised, were the media for information sharing. Documents generated, disseminated, stored and retrieved in the case studies, however, indicated a general weakness, concealing the tacit design knowledge. Information was stored statically conforming to the framework that was designated for a specific document type, for example the dimensional description of a building layout was represented on a 2-D plan drawing whose properties such as size were pre-defined and agreed upon by the project participants. The tacit design knowledge (as part of the design rationale) carried in this graphical representation was not necessarily explicit to its receiver when such graphical representation was used as the medium for knowledge sharing. Under such circumstances, additional explanations would be required to assist the receiver to interpret the embedded tacit meaning. The additional explanations were usually given orally in a face-to-face meeting or telephone conversations. In most circumstances these informal explanations were not incorporated in the formal documents such as the 2-D plan drawings, which were to present the results of discussion, negotiation and compromise. The informal explanations were sometimes captured in handwritten notes on a personal notebook (logbook), the backside of an envelope, post-it note, a scrap of paper found on the desk, and also as annotations on the document of concern itself. The importance of these informal scribbles was usually disregarded. Thus, the informal explanations whether in written form or in verbal descriptions were not archived properly for any possibility of future reference. Loss of tacit knowledge including design rationale and reasoning behind decisions was in consequence of this documenting practice.

5.5.5 Integration of design knowledge

The mass amount of information produced at the project outset has a big *variety of formats*, including the well structured data stored in a database, the semi-structured HTML and/or XML files, and also the weakly structured texts/graphics/multimedia files (Maher & Simoff, 1998). The designer usually creates design information in a tangible form for externalising his/her thoughts so that they could be communicated (Zeisel, 1981). At the other communication end, this information is transformed to knowledge of an individual (the receiver) after it had been well perceived in the appropriate context (Cleveland, 1982; Davenport & Prusak, 1998). Design knowledge including the design precedent is accumulated in the internal memory of a designer and the external knowledge sources. There are a wide range of external sources the designer could access including for instance the state library, company's database, as well as the experienced personnel and professional community. All interviewees remarked that designers relied on precedents to design. *Experienced designers possessed a large base of precedents in their internal memory*. The interviewees revealed that it was a common practice for designers to seek precedents, which were best suited to trail the design problem at hand, from their internal memory. This work habit described by the interviewees was found complying with the argument of Schank (Schank, 1982) in regard to human reused knowledge from the past experience. The trail of information was of importance to assist the interviewees to track the potentially reusable information with regard to the content and storage location.

Integrating design knowledge had drawn the attention of the A/E/C professionals after realising that collating the vast varieties of design knowledge was not an easy task. Both technical and managerial approaches have been investigated within the A/E/C industry (Fischer & Kunz, 1995) attempting to improve the efficiency of information monitoring. These approaches involved the use of a centralized project model that adopted data standards ranging from the maturely developed ISO-STEP to the recently fast developing IFC, in which structured data integration was the primary concern. However, the application of a centralised project model was not evident in any of the case studies.

5.5.6 Externalising the Cognitive Processes of Problem Solving

Decision making based on group discussion is one of the core activities of collaboration, from which the design problem solving behaviour was reflected. The decision making process involves several cyclic activities which repeat themselves until the satisfactory solution is found (see Figure 3.1). Reasoning behind decisions was noticed to be influenced by the interactions that the interviewees underwent while compromising their own wills. Before any decision could be made, as many ideas as possible concerning the same issues would be brainstormed in order to create several different alternatives. Assessment of these different alternatives would be undertaken based on particular criteria through analogy of ideas. A decision that would cause either change of the existing design or creation of a new design would be made based on the assessment results.

By presuming that the analogy of ideas was traceable when their representations were tangible to be presented and documented, the trail of reasoning behind decisions could then be plotted. For example, a proposition of a design alternative would be rejected based on several reasons given by for instance different individuals of the design team. The reasons were founded on sensible verbal explanations corresponding to factors such as time constraint, limited budget, lack of the appropriate technological skills and so forth. Formulating the verbal explanations in texts and/or graphics was considered an alternative to capturing the decision rationale in a reusable form. The reasoning trail on which the explanations were founded would need to be established with the relevant knowledge sources clearly identified in order to facilitate future access. The correlated knowledge sources could be the responsible personnel or the location where the information was stored. This assumption was of vital importance for the purpose of keeping track of the discussion contents in the design meeting, in which the meeting participants used different approaches to communicate their thoughts, or in other words to verbalise their cognitions through conversations. Finding a mechanism to structure the verbalised cognitions would be crucial to enable the reasoning behind decisions including the design rationale be captured and stored for future reference.

Cognitive processes were difficult to explain, but they were important to imply the tacit knowledge that an individual possessed for problem solving. Exploring the cognitive processes of project stakeholders engaged in collaborative design in which interactions were the core activities for completing a design task was thus hypothesised as the first step needed to examine the applicable mechanism for documenting design rationales, the valuable design tacit knowledge.

Protocol Analysis, a research methodology based on the psychological theory of information processing, had been attested by several researchers including Akin (Akin, 1984) and Simon (Simon, 1984) in their studies as an effective approach to assess cognitive processes in design. For example, Akin implemented this methodology attempting to make explicit the intuitive problem-solving behaviour of a designer engaged in a complex design problem (Akin, 1984). The carefully structured coding scheme of the Protocol Analysis was also proven able to portray the different kinds of mental events that the members of design team experienced as well as the collaboration activities they practiced in the problem-solving process (Caroll et al., 1990). In view of this, the principle concept on which the coding scheme of Protocol Analysis was built was adopted for structuring the collaboration activities that were observed in the case studies, aiming at identifying how the team members shared their understanding. Table 5.4 below exemplifies the coding scheme of Protocol Analysis that corresponded to the problem-solving process generalised from the case studies.

Table 5.4. The example of the coding scheme of Protocol Analysis vs the problem solving process

The Generic Sequence of Problem-Solving	Coding Scheme of Protocol Analysis
Trigger: A question (problem) arose	
Set the goal	Goal definition
Identify the problem	Problem structuring
Initial facts/information retrieval (mostly from short term memory)	Enquiry
Define problem	Problem structuring
Search/collect the existing/new solutions strategies	Enquiry
Identify and describe the needed competence and knowledge	Inference (=justification generated by the problem-solver or higher order conclusions, assertions, propositions, negotiations)

Choose methods and tools needed to solve the problem	Decision
More facts (probably from long-term memory)	Enquiry
Solve the problem	Decision
Look at the result, capture interpretations and critique	Evaluation
Analyse & evaluate the result	Evaluation
Formulate support for decisions	Inference

5.5.7 The Procurement Method

The procurement methods decided for a building project by the client influences its project team organisation. The interviewees remarked that the organisation structure of the design project influenced the efficiency of design communication. As noticed in the case studies, the larger the scale of the project, the more complex and hierarchical the organisational structure would be. A project with complex organisation structure, but without a properly developed knowledge management system might face higher risk of failing to transmit the right information to the right person at the right time. Under such circumstances, situations such as loss of information, delay of information, and excessive information as encountered by some of the interviewees might occur.

The procurement methods commonly used in building projects are available in a wide range, including the traditional design-bid-build, the design and build, and the management contracting alternative. The selection of procurement method is dependent on numerous factors including the client preferences, the project scale, the financial adequacy of the client, the regulations enacted by the local building authorities, and so forth. Different procurement methods use different managerial strategies, but indicate a common project progressing trend, which is the so-called *over-the-wall* situation as described in Chapter 3. The over-the-wall practice was noticeable in all of the three case studies. This practice was, however, remarked by some of the interviewees as unavoidable though they were fully aware of the complications that might occur, involving restructuring the organisation of the project team as the project proceeded to a later stage and new functional needs arise. This circumstance further increased the difficulty to trace the status of some specific design information such as the design reviews and feedbacks, in particular when design tasks started to be overlapping. Overlapping of design tasks was no news in practice, but might create the complication to trace the design information trail based on the specified task, in particular after the organisational structure was restructured. Organisational structure of a building project team was unstable because it involved too many different players that were bound under a temporary basis contract. Conflict of interests might occur between these different players and in some worst case scenarios would further result in break of contract. Change of players halfway during the project life could mean delay of progress because redo of the affected project-related activities, for instance redesigning, was necessary. Overlapping of design tasks would thus be the consequence of change of players, who would walk away from the project together with design information (e.g. design reviews and feedbacks) that was usually not archived in the project-basis information management system.

The interviewees claimed that the managerial approach called partnering applied in the retrospective case study as a success in improving collaboration through better communication between the project stakeholders. This approach got all the key stakeholders involved in all discussions and decision-making processes from the very beginning of the project. Specific evaluation was conducted by a research group to investigate the result of the partnering approach applied in the retrospective case study. The evaluation result was available at www.projectweb.com. However, the details of this approach as well as its evaluation study were beyond the scope of this doctoral research.

5.6 Summary and Discussion

The findings of the case studies presented in this chapter were sufficient to suggest the state-of-the-art in the aspects of working practices and techniques employed by the interviewees to undertake their tasks in collaborative design environments. The analysis of the findings as discussed in the last part of this chapter was the essential input to the formulation of user (project stakeholder) requirements in regard to the improved collaboration efficiency. In a collaborative design environment, different types of collaboration activities were undertaken by the interviewees who were to share their information and knowledge of a particular domain of interest. These collaboration activities were ideas synthesis, analysis, simulation, evaluation and negotiation, which were cyclic in nature to shape the decision making structure.

There were various interaction forms that the interviewees could choose to communicate their ideas/thoughts during a meeting. However, the selection criteria were dependent on a number of parameters including the type of workspace, the feasibility of accessing technological facilities, the complexity of ideas that they wanted to share, and the stage of cognitive processes corresponding to problem solving and decision-making. For instance, more brainstorming sessions were noticed in case studies 1 and 3 whose discussions focused on issues at the conceptual design stage. This was because brainstorming was used as an effective mechanism to collect a wide range of different ideas, which was helpful in ideas synthesis. Informal speech and gestures were the most prevalently used interaction method when interviewees were gathered face-to-face in one physical workspace. Representations on papers were frequently used to assist the presenter to present/externalise ideas of high complexity where formalisms in words as speeches were found difficult to understand. There were two types of paper-based graphics representations frequently used in the case studies, CAD drawings printed on papers and hand sketches. Paper-based hand sketches were the most preferable method amongst the designers when rapid prototyping of mental models was needed.

Several generalisations as listed below were drawn from the analysis of findings presented in this chapter:

- The quality of the outcome with respect to collaborative design relied on the *collaboration efficiency* between the collaborators.
- The optimum state of collaboration could be reached through efficient *sharing of understanding* (i.e. data, information and knowledge).
- Efficient understanding sharing could be achieved by using the *appropriate communication techniques* and tools as discussed above, which could support either synchronous or asynchronous communications, or even both.
- *Asynchronous communication usually focused on sharing codified knowledge.* The prevalent asynchronous communication channels used for sharing codified knowledge were e-mails, faxes, and the project web (a type of web-based groupware). Codified knowledge that took forms of graphics and text could be disseminated as attachments to an e-mail while the e-mail itself was also perceived as codified knowledge. The project web was the virtual workspace where codified knowledge could be stored for being accessible and thus shared.

- *Sharing codified knowledge required competence in knowledge management*, which involves several cyclic activities including acquisition, representation, store, and dissemination of knowledge. Knowledge management was usually accompanied by several complications, including:

    a. *What sort of knowledge that existed* (data, information, explicit or tacit knowledge)? Managing well structured data that could be processed automatically by computer was relatively less complicated than managing weakly structured information written in natural language plain texts. A more detailed discussion about the complication of acquiring knowledge from weakly structured information is given later in Chapters 6 & 7 of this thesis.

    b. *Where were the knowledge containers*? Knowledge is a dynamic resource that flows from one knowledge container to another. A knowledge container can be a physical container such as book or paper-based file cabinet, digital repository such as computer-based database, and the human's mind. Having the capability to identify the location of the knowledge container is important for an individual to access the required knowledge. If the different knowledge containers are inter-connected in some way, the efforts needed to locate and access these containers could be conducted more efficiently.

    c. *When was the knowledge produced and accessed* (or at what project stage when the knowledge was produced)? Knowledge that was produced at the early project stage could be more intangible and hard to formalise. Extra efforts may thus be needed to formalise knowledge produced at this stage before it could be further transferred and stored for future access.

    d. *Why was the knowledge generated*? The line of reasoning that led to the creation of new knowledge was prevalently not structured as codified knowledge in a way that was sufficiently explicit for both human and machine comprehensible.

    e. *How to translate knowledge to representation comprehensible to other collaborators*? There are several different ways applicable for representing mental pictures and cognitive processes to a form that is transferable between and comprehensible to other collaborators. Oral expression, written text description and graphics illustration (both paper- and computer-based) are among the selectable choices based on criteria such as working methods, the capability of the available tools for information representation and communication, and the value system of the targeted knowledge receiver. Graphics and texts are widely used to transfer knowledge, but sometimes indicating the difficulty to make reasoning behind decisions adequately explicit to the knowledge receiver.

The generalisations listed above were essential to formulate a vision that could improve the quality of collaborative design within the A/E/C sector through implementing ICT to a relatively higher extent compared to those applied in the case studies. Exploration of numerous aspects was required for shaping the framework of the vision. The interpretations discussed above have outlined some of the underlying aspects as depicted in Figure 5.5. Figure 5.5 is a self-explained rich picture diagram for drafting the scope of a hypothetical infrastructure, named IT-CODE, whose principal objective is to improve the effectiveness and efficiency of collaborative design via improving the competence of the project stakeholders in the aspect of knowledge management. As shown in the diagram, *IT-CODE is devised to integrate and manage design information and knowledge*. The hypothetical system focuses on exploiting meeting minutes, a type of design information that commonly exists in collaborative design, from a new dimension by means of ontology. Ontology has been a popular discussion topic within the ICT area in these recent years. A thorough discussion in regard to ontology and its application in this doctoral research study is given in Chapters 6, 7 & 8.

Figure 5.5 also indicates that the procurement method selected in a building project could also play a substantial role in improving the efficiency of collaborative design because it could be a factor that influences the organisational structure of the project. The information flow within the organisational structure is naturally influenced by the organisational structure itself. Identifying the information and knowledge sources based on the organisational structure will be an important step before the network of knowledge sources can be established. A knowledge management system that can handle efficiently a network of knowledge sources may benefit its users in coordinating design tasks as well as distributing design information more efficiently to the targeted receivers. Constructing information trails based on causal (e.g. client's dissatisfaction leads to redesign) and conceptual (e.g. architect is a project stakeholder) relations is also illustrated in Figure 5.5 as one of the underlying aspects of which the IT-CODE is to consist. An extensive discussion about the concept of IT-CODE from which its design is derived is given in Chapter 7.

A consolidated flow model (see Figure 5.6) was constructed focusing on the workflow of how the summary of the discussion contents of a formal meeting was handled. The summary of discussion contents of a formal meeting is also known as meeting minutes. The consolidated flow model (Figure 5.6) depicts that two levels of information management systems are implemented to handle information generated at the company- and project-level, respectively. Repetitions of workload as described above are also shown in the model. A vision for IT-CODE is formulated to simplify the workflow of meeting minutes handling in an attempt to improve the efficiency of design information and knowledge sharing. Higher efficiency in information and knowledge sharing is the key aspect taken into account if efficient collaboration amongst cross-disciplinary stakeholders is a key element to make a project a success. In the vision (see Figure 5.7), IT-CODE would support the management of design information generated at both company level and project level. The vision would reduce repetition of workloads by employing the concurrent semantic web technologies in order to support design knowledge management by making explicit the reasoning behind decisions made in a meeting. This vision shapes the basic framework, whose comprehensive discussion is given in Chapter 7, for the design of IT-CODE.

Figure 5.4: Hand sketches, the rapid conceptual modelling techniques

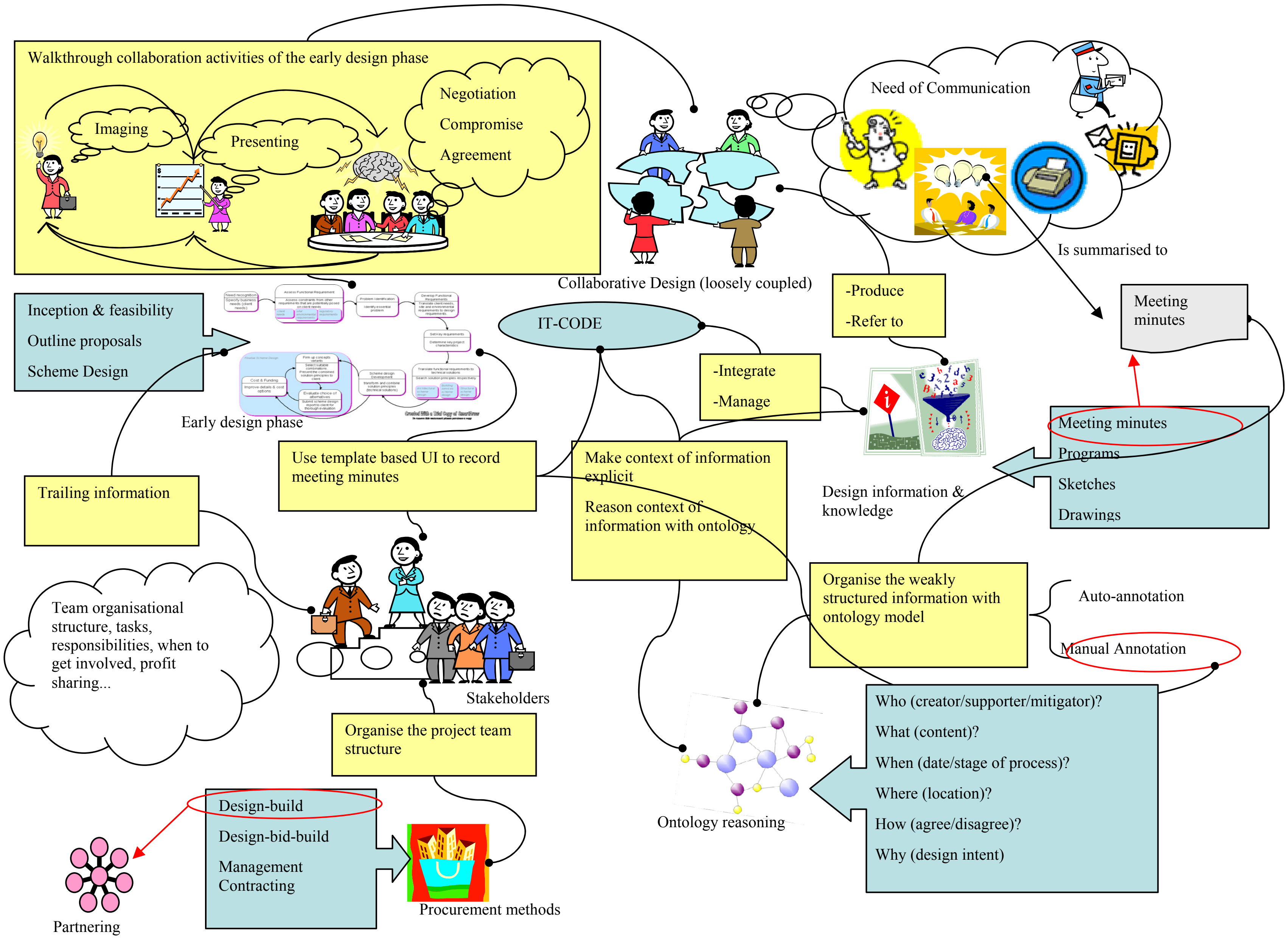
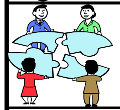
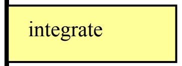
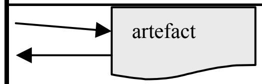
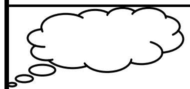
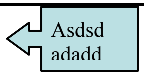


Figure 5.5: The Conceptual Framework of the Vision

Table 5.5. Notations of the Rich Picture Diagram

Sign	Description
	Role/community/actor/system that performs an assigned activity/task; or Object that community/actor/system manipulates through interactions.
	Activity/task conducted through interaction between roles/communities/actors/systems.
	Interaction between roles/communities/actors/system that are depicted at both ends.
	Artefact that is produced by an activity or is referred to in an activity.
	Concerns of an actor to perform his/her tasks.
	Further explanation of role/community/actor/system/object.
	Selection of the doctoral research study.

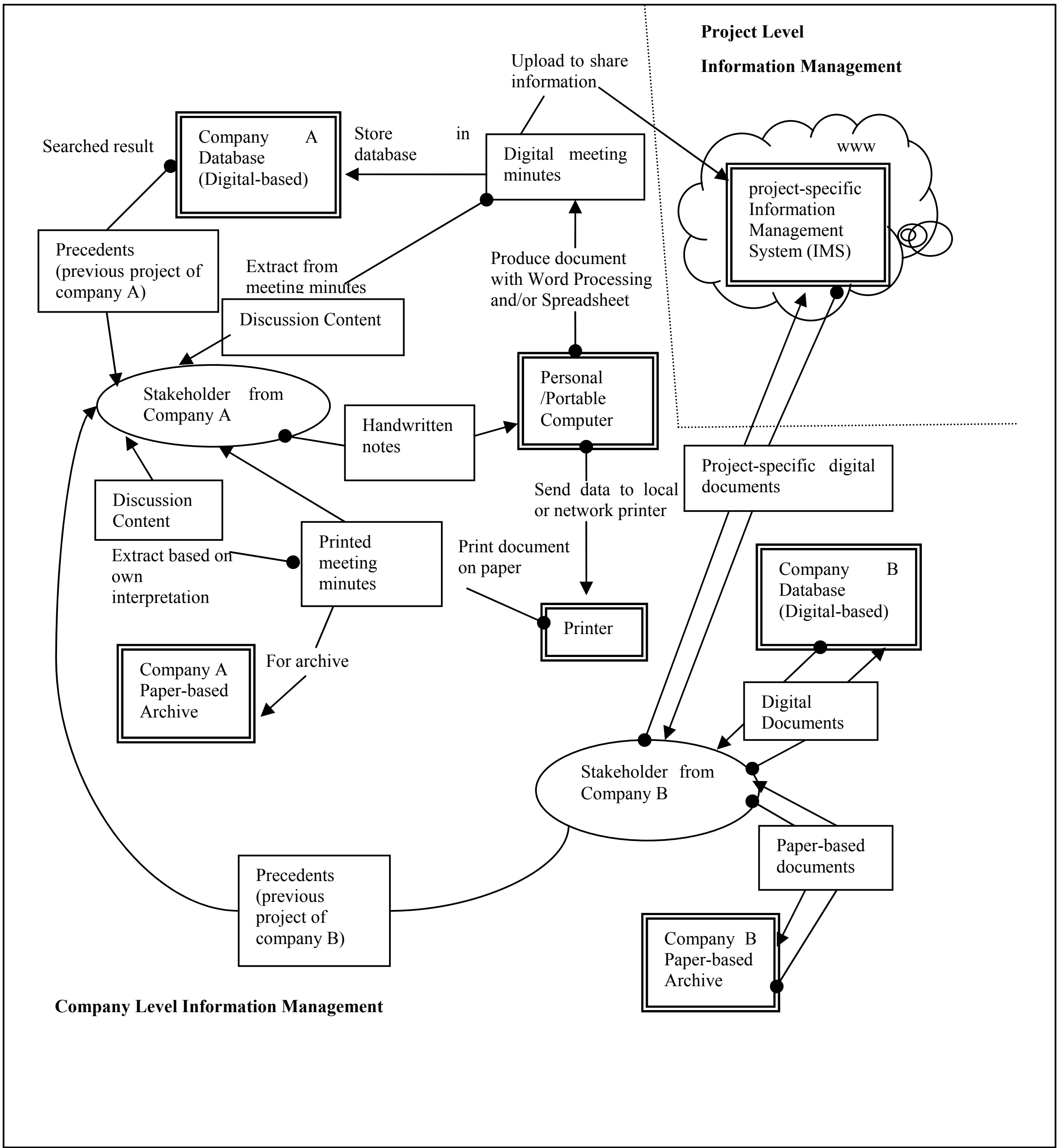


Figure 5.6[3]: The consolidated flow model based on data from case studies with emphasis on meeting minutes handling.

[3] The legend of the symbols used in Figure 5.6: a bubble represents a meeting participant; a rectangular box represents the artefacts used or produced by a meeting participant; an arrow represents the communication flow between people and/or work places to get work done; communication topic or action is written in the middle of/above/under an arrow; a double-line box represents a (work, storage, etc.) place.

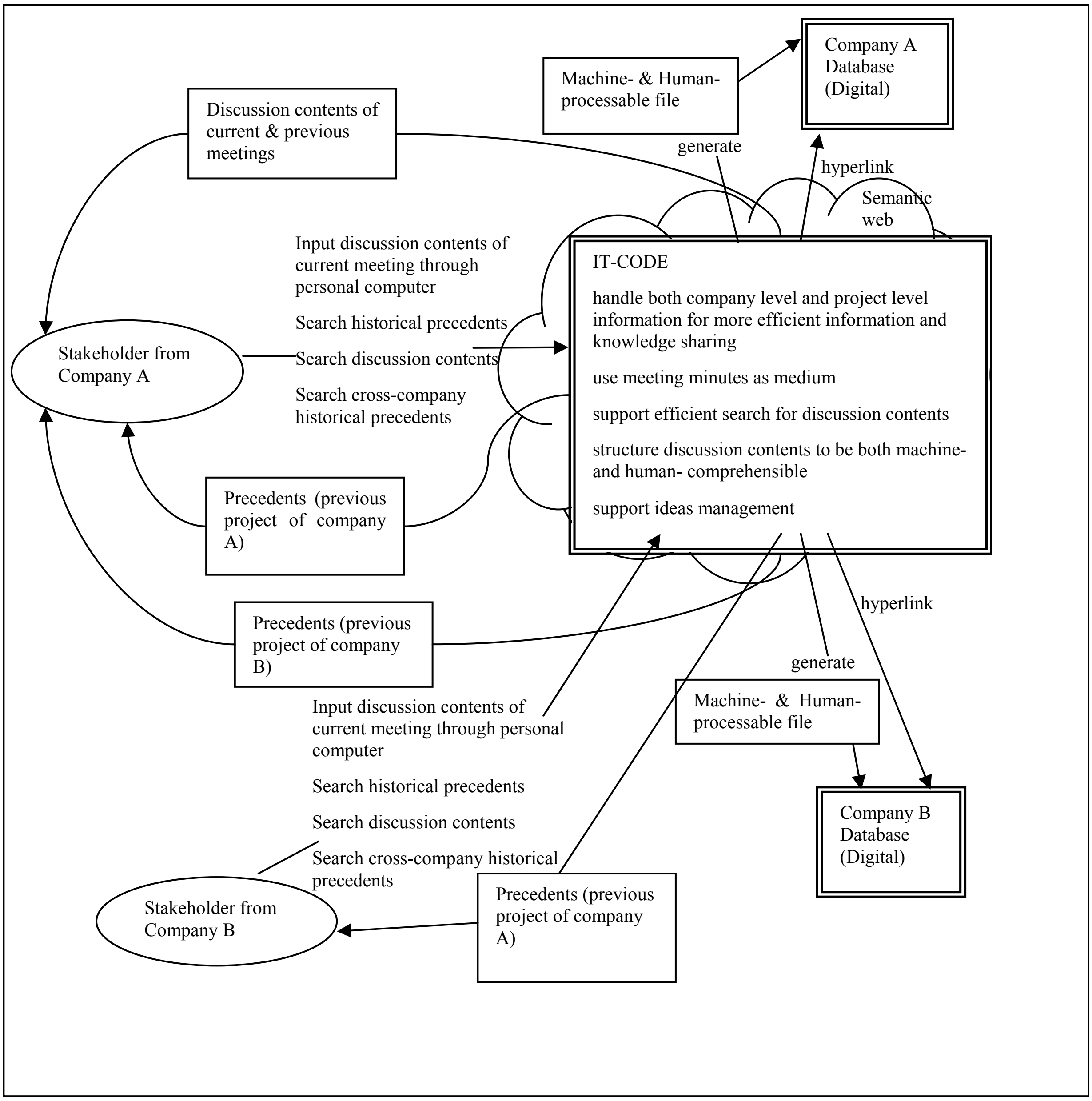


Figure 5.7[4]: A vision for IT-CODE, the hypothetical system.

[4] The legend of the symbols used in Figure 5.7: refer to Figure 5.6.

6 ONTOLOGY AND COLLABORATIVE DESIGN MEETING

While you are experimenting, do not remain content with the surface of things.

Don't become a mere recorder of facts, but try to penetrate the mystery of their origin.

--Ivan Pavlov--

6.1 Introduction

Sharing design information effectively may improve collaboration quality. As defined in Chapter 5, design information in its broadest sense can be referred as all sorts of information that exists in design regardless of its form of existence (e.g. objects, concepts and relationships). Apart from its core role in stimulating better collaboration, design information also has its reuse (for Operation & Management, new projects input) value, which is no less important than organisational and project memory. In view of this, organising design information for better searching and retrieving purposes has not been a new issue within the A/E/C industry.

In this chapter, meeting minutes are proposed as one of the important document types wherein conceptual contents could be found implicitly written in plain texts. Conceptual contents are contents of the discourse conducted in a meeting, contents which in most cases remain at a conceptual level of which documentation is neglected. Some typical examples of conceptual content are ideas, rationale, activity histories and lessons learned. The contributions of conceptual contents contained implicitly in meeting minutes such as design knowledge that has value to be articulated, captured and stored in a collective memory system are usually overlooked. Therefore, no extra attention has been paid to seek a better method for generating meeting minutes whose function could be promoted to an organisational memory system rather than what it has usually been used for.

The approach implemented for structuring conceptual contents in one of the prevalent information management systems used within the A/E/C community, the project web, is exemplified and analysed in this chapter. Such approach is designated as indexing approach, which is crucial for supporting efficient information search and retrieval. The prevalent indexing approaches share a common principle, which is to focus on encoding the primary content attributes, which are partly composed of the keywords of the contents. These attributes may be codified based on a metadata scheme or controlled vocabulary, or be extracted automatically. Support for personal interpretations remains, however, limited to make the meaning of an artefact or idea explicit though some common metadata are available to present the substantial content attributes such as date, author, topic, and so forth. Using computational support for constructing explicit, interpretive levels of indexing approach is the motive for devising a hypothetical knowledge base from which semantic-centric meeting minutes could be generated.

The concept with respect to correlating the vision of the hypothetical knowledge base with the concurrent Semantic Web technologies is delineated in this chapter. The discourse starts with the discussion about managing knowledge on the basis of documents followed by projecting a paradigm shift to the futuristic semantic-centric approach. The underlying component of the semantic-centric knowledge management approach is specification of ontologies. How ontologies contribute for integrating information distributed in heterogeneous sources is also discussed comprehensively to overlay its application in the design of the hypothetical knowledge base. The chapter ends with outlining the fundamental concept that the hypothetical infrastructure implements for contextualising the discussion trails, which the author argues are useful to reflect the valuable tacit design knowledge.

6.2 The Document-Centric Knowledge Management Approach

Before a document centric knowledge management can be defined, it is necessary to define what a document is. A document is defined as information on a data medium treated as a unit (ISO/TC10/SC1 WG5). A data medium is defined by IEC (IEC 62355:1997) as material on which data can be recorded and from which they can be retrieved, for instance, paper, microfilm, magnetic or optical disk. Examples of document content types are policies and procedures, product specifications, catalogs, corporate historical documents such as minutes of meetings, corporate records, and important correspondence. A document-centric knowledge management system is developed to help its user retrieve documents in which the non-machine-interpretive structured information is contained. A document-centric knowledge management system integrates a variety of storage and processing technologies to provide complete document retrieval, presentation and analysis. The system is required to provide access to document databases containing documents that are generated during product development processes. The document is itself an information repository or container in which information appears as chunks of natural language and most often represented in a human-readable form. Natural language chunks are seldom structured in a machine understandable manner. Information that is organised in a human-readable manner only is referred to as *unstructured information* in this thesis. Likewise, information that is organised in a human-readable manner and with some bits that are machine understandable is referred to as *semi-structured information*.

"Document" is an obsolete term whose meaning is too ambiguous, particularly from the ICT perspective. In the A/E/C industry, "document" remains the valid term applicable to all sorts of documentation produced during a building project. Practitioners within the A/E/C industry have also been used to implementing the term "document" for both the data and information produced, used, and/or referred to during a project lifespan. There are several different ways that could be used to divide the categories of documents. One of them was delineated by the researchers Anderson and Thorpe (2004), who categorise the documents associated with the A/E/C industry into four main groups: the project documents, the office management documents, the communication documents, and the reference documents.

The European Standard (EN) 82945-1defines the document concept covering not only traditional paper-based documents, but also, more generally, computer-based information that is identified, structured, processed, controlled and interchanged/communicated as a unit (a closed container of information) (IEC, 2001). A document is a fixed and structured amount of information that can be managed and interchanged as a unit between users and systems while this unit may not necessarily be human perceptible. Documents are generally classified into several groups as listed below with reference to EN 82945-1:

a) text documents, for example textual description or message;
b) graphical document, for example drawing, picture, diagram, chart;
c) lists, for example parts lists;
d) hypertext documents, for example linked documents built on HTML, XML, etc;
e) multimedia documents, for example composition of text, picture, video, sound;
f) electronic information package, such as query message, automatic log message, e-mail messages;
g) CAx models, such like CAE, CAD, CAM, etc.

Documents may be considered as a result of a process activity during the product life cycle, carrying information to one or more subsequent activities. The document itself is a representation of a part of the information about the product as well as the associated development process. In other words, a document represents information, which is an important resource factor within a company. However, document provides no explicit formal semantics to its human users. It is the user who needs to interpret the contents of the document, which is a procedure that involves lots of personal interpretations. The ICT supported information sources such as the electronic document management system and digital library still face the challenge in supporting text interpretation computationally.

A document centric knowledge management (KM) system is a knowledge management system whose main entities consist of different types of work-in-process documents that are generated while project teams collaborate to complete their tasks. The focus of knowledge management is on understanding how to capture, share, and reuse knowledge and how tools and technologies can help. The project web systems implemented in the case studies described in Chapter 5 merely functioned merely as a *document-centric database* based on the following argument:

The main focus of the described project web systems was to share and reuse information that was captured in documents within a single project and/or across different projects through the use of web technologies, mainly WWW-servers/clients and HTML-documents. Information is contained in documents of various types with the assumption that its main consumers are humans. The major concern of a knowledge management system, which is to convert information into knowledge, was not achieved by the document-centric project web system. The difference between information and knowledge though has been defined by different researchers (Section 3.2.1) in their typologies about data-information-knowledge-wisdom; it is, however, difficult to distinguish these two notions from one to another in reality because both of them are pervasive. These two terms are often used interchangeably and as a result we often have different perceptions of – and honest disagreements about—whether a particular chunk of recorded information is actually knowledge. However, in reverse recorded knowledge obviously contains lots of information. Recorded information is often necessary because it contains the details one needs to execute a particular task successfully. Recorded knowledge helps one make the connection between his/her objective in performing a task and the supporting information that is available to him/her. One of the most important characteristics of knowledge is abstraction, which is to minimise by generalisation the increasingly excessive information. Effective knowledge helps one eliminate or filter the unwanted information. Knowledge is often associated with “why” and “how” but not just “what”. Knowledge is therefore neither a list of facts nor compilation of data. It is also not only a description of products or services (or the so-called metadata describing the primary content attributes) such as what is available in the document-centric database system.

Relationships between information, such as what does one need to know before using a specific piece of information, what are the consequences of a particular action, and so forth, are crucial to facilitate the process of abstraction in relevant contexts. In other words, a person gains knowledge through context and understanding based on a series of reasoning that may also be conducted tacitly. This series of reasoning is seldom made explicit in the document-centric database system although available as textual description in documents stored in the database. Document-centric databases lack the ability to handle the semantics underlying these documents. This is because a document confines its own boundary and thus reduces the connectedness/coherence between the relevant chunks of information stored in the heterogeneous sources. This intrinsic shortcoming of documents was specified by Vannevar Bush in 1945 in his publication about a visionary device called Memex. In Memex, all information ever available to mankind would be richly interconnected (Bush, 1945).

Users would be able to find relevant information and organise it into a thread, or a trail for their own use.

6.3 Indexing, an Approach to Organise Information

6.3.1 The Hierarchy Approach vs. the Associative Approach

The indexing approach is an approach used to make an index of data/information so that the data/information can be located when needs arise. The index needs not contain the data and thus it needs not be a database. The indexing approach plays a vital role in determining the efficiency and effectivity of any information management system, be it a paper-based or digital-based system. Vannevar Bush (Bush, 1945) argues that before knowledge could be used it had to be selected and retrieved, and knowledge that cannot be selected was lost. Bush also argues that the act of selection was the most problematic. In any information/knowledge management system, indexing approach plays a role that influences the efficiency and effectivity of information selection and retrieval. Different types of the indexing approach may be used to organise data of any sort that are stored. The most basic and conventional approach used for indexing data/information is to organise the data/information based on alphabetical or numerical order.

Apart from the alphabetical or numerical orders approach, information and data are also organized on a hierarchy basis. Before the time that information and data could be digitalised and stored in a computer, information and data were stored in the mechanical world with mechanical-based storage systems, such as file cabinet and bookshelf. In a file cabinet, for example, the paper-based information/data are arranged in different folders based on some common characteristics. Each of the file folders is labelled based on a particular subject that describes the common characteristics. The paper-based information and data are arranged in alphabetical order in the folder whose label matches the main subject that the information/data represent. Each of these folders is also organised in an alphabetical order inside a file drawer of the file cabinet for facilitating future retrieval. In brief, paper-based information is nested in a hierarchy that rarely exceeds two levels because it is impractical to have folders (paper-based) inside folders or file drawers (of a cabinet) inside file drawers.

Computer science introduced the hierarchical structures as tools to solve the problems of managing massive quantities of data and information. In the current computer desktop metaphor, information and/or data can be stored in folders nested in a hierarchy of infinite levels. For example, a user of a computer desktop may tend to put documents of Project A inside a folder named “Project A”, which, in turn, is stored inside the “Active Projects” folder that itself is stored inside the “Project” folder. A hierarchical structure is developed to facilitate both the human and the machine to locate information by tracing it from subclass to subclass, but somehow conflicts with the human’s mental model of storage system. The hierarchical structure of storage paradigm violates the natural mental process of human being, which operates by *association* (Bush, 1945). It is common that we, the human users, encounter a situation where we shall recall where a particular chunk of information is stored, whether it is in Document A or Document B and from which repository the document can be accessible. Quoted from Cooper (Cooper et al., 2003), “Most humans are familiar with hierarchies in their business and family relationships, but hierarchies are not natural concepts for most people when it comes to storing and retrieving arbitrary information. Most mechanical storage systems are simple, composing either of a single sequence of stored objects (like a book-shelf) or a series of sequences, one level deep (like a file cabinet). This method of organising things into a single layer of groups is extremely common and can be found everywhere in home and office. Because it never exceeds a single level of nesting, we call this storage paradigm monocline grouping.”

6.3.2 The Aids to the Human Mental Processes

Technologies that would aid the mental processes of classification and knowledge representation have been of interest since the last few decades. These technologies are to support and extend the powers of human memory. In the hypothetical Memex machine of Bush (Bush, 1945), any two items could be permanently coded for associative selection. Bush called this coded association “a trail”, analogous to the trail of mental association in the user’s mind. Trails in Memex have an advantage compared to the mental association, i.e. trails in Memex once recorded would not fade over time. The principle of trail could be followed at any time without the need for going up and down the hierarchies of conventional indexing. Bush saw trails as an alternative to the traditional indexed, hierarchically structured information.

Douglas Engelbart, an early believer in Bush’s idea of a machine that could aid human cognition, developed the idea that would form the basis of today’s computer interfaces. Engelbart (Engelbart et al., 1988) was particularity concerned with the notion in regard to “asynchronous collaboration among teams distributed geographically”. He developed a hypermedia-groupware system called NLS (oNLine System), which was an integrated environment for natural idea processing. In his paper “Augmenting Human Intellect: A Conceptual Framework”, Englebart wrote:

“By augmenting human intellect we mean increasing the capability of a man to approach a complex problem situation, to gain comprehension to suit his particular needs, and to derive solutions to problems. Increased capability in this respect is taken to mean a mixture of the following: more rapid comprehension, better comprehension, the possibility of gaining a useful degree of comprehension in a situation that previously was too complex…We do not speak of isolated clever tricks that help in a particular situation. We refer to a way of life in an integrated domain where hunches, cut-and-try, intangibles, and the human ‘feel for a situation’ usefully co-exist with powerful concepts, streamlined terminology and notation, sophisticated methods, and high-powered electronic aids.”

Hypertext is a term coined by Ted Nelson (Nelson, 1965) to the conception of non-sequential writing. Hypertext is the presentation of information as a linked network of nodes which readers are free to navigate in a non-linear fashion. The hypertext facility embodies certain features of Bush’s trail notion. Ted Nelson used Bush’s Memex and Douglas Engelbart’s NLS (oNLine System) (Engelbart, 1962) as jumping off points for a discussion of his own Xanadu’s (Nelson, 1974) hypertext design with the goal to support communication and collaboration in an envisioned future online scientific community. Xanadu has many interesting concepts: for example, Nelson has tackled the problem of generating unique names for new documents so that they can be found. This is the concept from which the principle of Universal Resource Identifier (URI) stemmed. Ted Nelson elaborated his conception of hypertext to hyperbook, which links different works and grand systems:

“[These consist] of ‘everything’ written about the subject, or vaguely relevant to it, tied together by editors, in which you may read in all directions you wish to pursue. There can be alternate pathways for people who think in different ways (Nelson, 1974).”

Hypertext is a concept, an organisational form. It is not inherently tied to technology, content, or storage/access medium. Hypertext, at its most basic level, is a database system that lets one (the user) connect chunks of information using associative links.

Hypertext would allow any document in the information space to be linked to any other document via Internet, which is a technology that links computer networks. Tim Berners-Lee applied the concept of hypertext in conjunction with the internet technology when he wrote the Hypertext

Transfer Protocol (HTTP) in 1990. HTTP is the language a computer would use to communicate hypertext documents over the Internet. The World Wide Web (WWW) was then developed to retrieve and view hypertext documents that were stored on Internet computers. The principle behind the development of the WWW (Berners-Lee, 1990) is to allow easy sharing of information through a simple decentralized system with simple rules that would be acceptable to all. The notion of the Web attracts lots of interest from a wide spectrum of communities, including the industrialists, academics, scientists, government agencies, and so forth. The WWW has thus become the source of unstructured, heterogeneous and distributed information. The WWW as has been envisioned back in the year of 2001 would interweave one billion people and penetrate not just computers, but also other devices, including cars, refrigerators, coffee machines, and even clothes (Fensel et al., 2001).

However, the identified significant impediment of the current web technology for further growth is its lack of efficiency in managing the overwhelming amounts of information. The current web technology offers limited support for a computer to interpret the actual contents of information that are shared and exchanged within the web. The main burden of extracting and interpreting information remains on the human user. In order to mediate these bottlenecks, Tim Berners-Lee (Berners-Lee et al, 2001) envisioned an extended version of the current web, the *Semantic Web*, in which information is given well-defined meaning so that automated information access could be achieved more effectively.

6.4 A paradigm shift from document centric to semantic centric

The notions of trails, NLS, hypertext, and the most recent semantic web have indicated the tendency of a paradigm change in information handling from the conventional static information container (document) to a *dynamic* one in which *non-sequential writing* is necessary.

Semantic web is envisioned to be a global database in which information is structured to be both machine- and *human-understandable* in contrast to the current web with mostly unstructured information. However, the concept of *machine-understandable* documents does not imply some magical artificial intelligence that allows machines to comprehend human mumblings (Berners-Lee, 1999). Contrarily, it only indicates a machine's ability to solve a well-defined problem by performing well-defined operations on existing well-defined data. In order to achieve this vision, human users are required to make an extra effort (Berners-Lee, 1999) to formalise and classify information before it is stored.

6.5 Ontology and The Semantic Web

In response to the shortcoming of the web, the *Semantic Web* is envisioned to enable automated information access and use based on machine-processable semantics of data. In a Scientific American article, Berners-Lee, Hendler and Lassila described the semantic web as an extension of the current Web in which information is given a well-defined meaning, better enabling computers and people to work in cooperation (Berners-Lee et al., 2001). A series of activities has been undertaken leading by the W3C (World Wide Web Consortium) with participants from a large number of researchers and industrial partners to provide a common framework that allows data to be shared and reused across application, enterprise, and community boundaries. These collaborative efforts have produced different standards/frameworks (see Figure 6.1) and supporting materials to facilitate the goal of the Semantic Web to be achieved. Ontologies are referred to as the kernel technology for the Semantic Web by researchers who pay attention to this area (Fensel, 2001; Ding et al., 2003; Berners-Lee et al., 2001). With the implementation of ontologies, the Semantic Web may allow computers to better categorize, retrieve, query and deduce information via the Internet. (Ding et al., 2003; Fensel, 2001). Ontologies are to be developed based on the Resource

Description Framework (RDF), which integrates a variety of application using XML for syntax and URIs for naming.

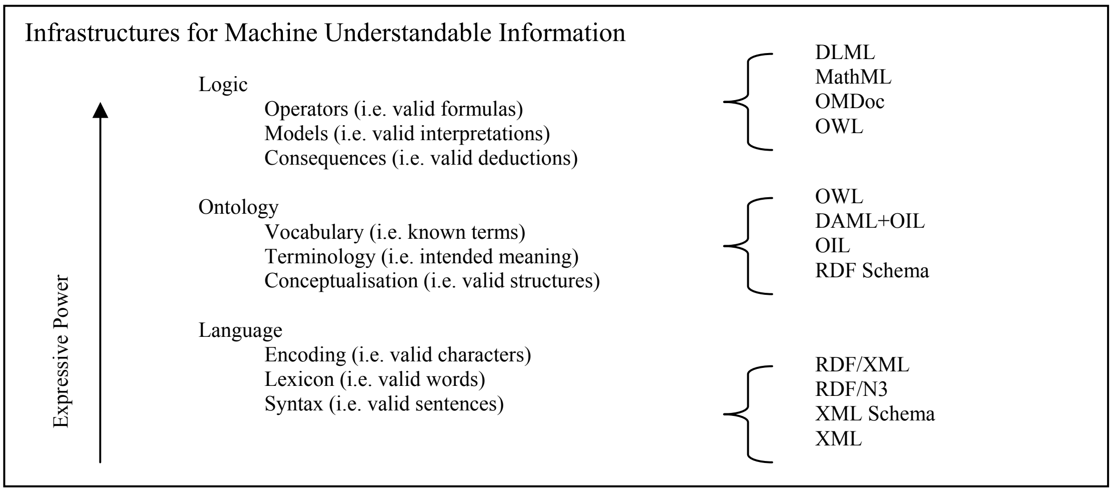


Figure 6.1: The existing standards/frameworks with which machine-understandable information can be created to facilitate the web evolution to the Semantic Web.

Ontology is not something new, but exists as the science or study of being. The Oxford English Dictionary, OED, defines it as a branch of metaphysics which relates to the being or essence of things, or to being in the abstract (OED, 1989). The concept of ontology has been used in different areas including the area of philosophy, computer science and artificial intelligence. In the area of philosophy, ontology is the study of different ways thinking about what different kinds of things there are, and how they relate, as what is defined by the OED. It is contrasted by epistemology, which concerns what we know about the world and how we know it with reference to its limits and validity. Since the 1960's ontology has been used by computer scientists to represent a particular idea about the different kinds of things that exist in the world and how they relate. Ontology is sometimes mistaken as the synonym of taxonomy. An ontology is, however, more than a *taxonomy* because an ontology makes a claim to cover a domain of discourse while a taxonomy only functions as a system that classifies things. For example, a taxonomy of plants might not contain the words "climate_factor", whereas an ontology would have to, as it is required to offer a conceptualisation of an entire domain of discourse (i.e. plant, in this case) while obviously climate factor has something to do with plant. An ontology is also different from a *thesaurus* because an ontology usually does not comprise multiple terms for the same meaning, and an ontology contains many other relations apart from those found in a thesaurus that are mainly composed of terms such like "type-of", "is_a" and "same-as".

In the 1990's, ontology was defined by Gruber as a formal explicit specification of a shared conceptualisation (Gruber, 1993). Gruber's insight into ontology as a designed artefact built for a purpose has made his definition popular amongst the Artificial Intelligence community. His concept of ontology has flourished the use of ontologies in areas with respect to knowledge sharing and reuse. Gruber further delineates ontologies that they are always a mix of formal and informal parts. The informal parts of ontologies help explaining something to humans while the formal parts allow some automated analysis. A *dictionary*, which is a set of terms classified to allow one (human user) to deduce meanings, was given by Gruber to exemplify that the mixture of both the formal and informal parts in a specification has long been in use. The textual definitions in dictionaries are informal because they are in free form natural language and are thus vague, ambiguous and *context dependent*. The informal textual definitions play the role of explaining something (meaning) to the humans. The term of Semiformal Ontology was coined by Gruber (Gruber, 2004) to refer to an ontology which has a few bits of formality, but is largely informal. With this unique characteristic, the formal parts of ontology should enable it to be machine-readable (Ding et al., 2003; Fensel, 2001). Thus, ontology is envisioned as the silver bullet to facilitate knowledge sharing and reuse (Fensel, 2001) by providing a shared and common understanding of a domain so that people and various application systems can communicate across the widely spread heterogeneous knowledge sources.

In general, ontology is a graph whose nodes represent concepts (e.g. processes, concepts of resource, actors) or individual objects while arcs represent relationships or associations among concepts (see Figure 6.3a). The ontology network takes account of properties and attributes, constraints, functions, and rules that govern the behavior of the concepts (Fensel, 2001). As mentioned above, an ontology is more than a taxonomy and thesaurus because it is a specification that describes a particular conceptualisation. This argumentation can be exemplified by illustrating a simple concept of project that relates to another concept, the stakeholder. These two different concepts, the project and the stakeholder, are not in any case found coexisting in the same taxonomy because they tend to be classified into different groups. These two concepts are also unlikely to be connected in a thesaurus because of the limited choice of relations available in a thesaurus. These two concepts can, however, be related in an ontology by a self-defined relation, for instance, "*participates_in*" so that the conceptualisation of the entire domain of discourse, in this case a project, can be specified. The ontology may thus be written as the statement below, via which part of the conceptualisation of a project is described by implying that a project is run by stakeholders:

"Stakeholder *participates_in* project".

An ontology network may be perceived as a modular network that comprises a number of different modules, each of which is, respectively, an ontology. The ontology network has unlimited expansion capacity in that the different modules can be connected with self-defined relations, which in this case are also referred to as cross-ontology-relations. The graphical presentation of the concept of an ontology network is illustrated in Figure 6.2 to show the modular characteristics of the network. A network as such is sometimes referred as ontologies by some people to imply its plurality. As in accordance with Gruber (Gruber, 1993), a network of ontologies is developed as a specification for a shared conceptualisation. Based on this argumentation, ontologies are to be developed in a way that is able to capture knowledge of a particular domain of discourse, which has the value of share and reuse. Ontologies are likely to be applicable for capturing not only the explicit knowledge, but also the tacit knowledge of a domain.

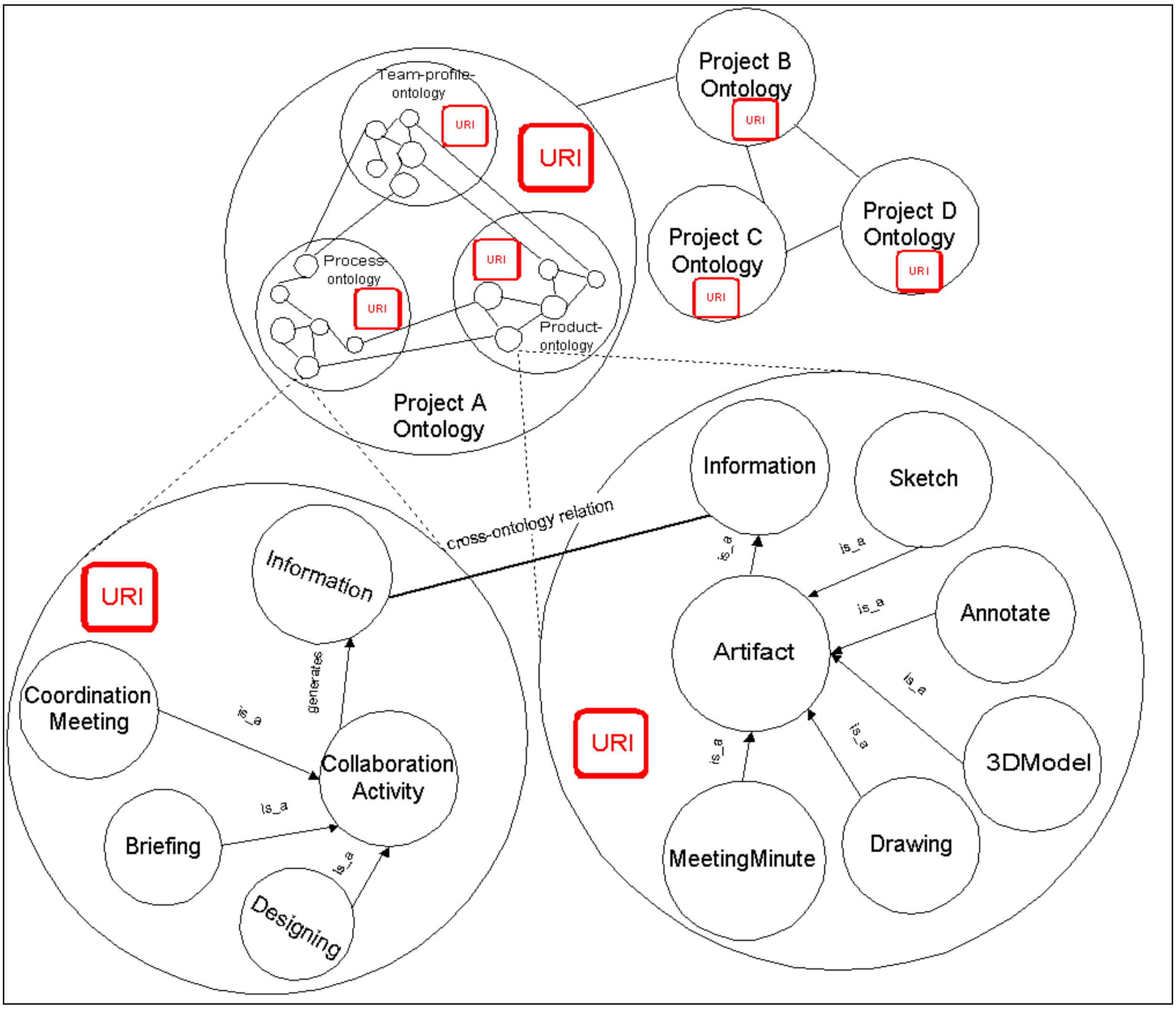


Figure 6.2: The modular characteristic of an ontology network augments its expandable capability.

6.6 Information Integration, the contribution of ontology

The practical use of ontology in the daily life has already existed for long without our awareness. For example, any personal information management software that we use daily more or less explicitly specifies an ontology that comprises various concepts and/or objects, ranging from people (with contact details such as postal addresses, email addresses, and so forth), email messages, calendar entries, and so on. Naturally, different software or information management tool provides different levels of ontological commitment, which is one of the factors that influences the ability of software to integrate information.

Ontologies are increasingly important in their use in organising information and knowledge that is desired to be shared amongst a particular community, such as a design team. AI researchers have used ontologies for sharing domain-specific information because ontology is an explicit specification of the concepts in a domain and the relations among them, which provides a formal vocabulary for information exchange. In other words, ontologies have been used as decentralized vocabularies of concepts and their relations to which any resources, whether it is the digital source such as the existing web content or the paper-based source, can refer.

The incompatibility of domain models is in many cases the cause of conflicts of communication between these models, one of the core functions of ICT tools and database management systems.

By specifying formal ontologies, the interoperability between heterogeneous software applications including tools and databases, and reuse and sharing of knowledge may be improved.

6.7 Ontology Languages for Semantic Web

Specific instances of the concepts defined in the ontologies are referred to as instance data. With reference to the ontology statement specified above ("Stakeholder *participates_in* project".), the following instance data may be asserted:

"John *is_a* stakeholder"

"Project A *is_a* project"

"John *participates_in* Project A"

The above statement *"*John *participates_in* Project A*"* indicates that instance data can be paired with ontologies (see also Figure 6.3a) and thus contribute to building a Semantic Web. Various languages have been created by different communities with different backgrounds and goals to represent ontologies and instance data on the Web, such as SHOE (Hefflin, 2001), Topic Maps (ISO/IEC 13250, 1999), RDF(S) (W3C, 2004a; W3C, 2004b), and DAML+OIL (Dean, 2001; DARPA, 2000-2006). These different ontology languages generally share the similar notions of some of their fundamental constructs. A Semantic Web language for describing ontologies and instance data contains a hierarchical description of important concepts in a domain, which are named *classes* in some of these languages. Individuals in the domain are instances of these classes, and properties (named slots in some languages) of each class describe various features and attributes of the concept. Logical statements can then be developed by describing relations among concepts based on the specified properties. Take the above ontology statements as an example; consider developing an ontology describing project, stakeholders, and the professional role a stakeholder plays in a project. Some of the classes describing this domain may be *Project*, *Stakeholder*, and different types of professional roles such as *Client*, *Engineer*, *Architect*, and so forth. Some properties of the *Project* class include the project's *start_date*, *end_date*, *procurement_method* and the *owner* of the project. For some Semantic Web languages, properties describe attributes of a resource and/or a relation of a resource to another resource, in which resource can be an instance of class and the class itself.

The SHOE (Simple HTML Ontology Extensions) language, developed at the University of Maryland, uses constructs to define ontology and instance data on Web pages (Hefflin, 2001). Classes are called categories, and constitute a simple is-a hierarchy. Properties are called slots and are binary relations. Besides binary relations, SHOE also allows relations among instances or instances and data so that any number of arguments can be constructed. Topic Maps, a recent ISO standard (ISO/IEC 13250, 1999), developed by the Hytime Community aiming to annotate documents with conceptual information. *Topics* is the term used corresponding to Classes in other ontology languages. *Topics* is an instance of *Topic Types* (other topics), which can be related to one another with *Associations*. *Associations* correspond to slots in other ontology languages. *Associations* belong to *Association Types*, which themselves are *Topics*. Topic Maps do not have a primitive for representing instances while any instance of a *topic type* can itself be a *topic type*.

RDF (Resource Description Framework) provides a data model, comprising nodes and arcs (Object -attribute -value triples). Nodes correspond to objects or resources and the arcs to properties of these objects. Uniform Resource Identifiers (URIs) are usually used to label the nodes and arcs to apply the hypertext concept for connecting the heterogeneous distributed resources. RDF, however, does not have any primitives for creating ontologies. RDF Schema (RDFS) is the extension of RDF for defining the primitives to create ontologies. In RDFS, there are classes of concepts, which constitute a hierarchy with multiple inheritances. For example, the class Building Project is a subclass of the class Project. Every class may have multiple instances, for example the class Project may have Project_A, Project_B, Project C as instances. In RDFS, resource is the primary notion to which both Class and Property belong. Resources have properties associated with them. The properties describe attributes of a resource or a relation of a resource to another resource. RDFS defines a property's domain and a property's range. A property's domain is itself a resource that can be the subject of a property while a property's range is a resource that can be the object of a property (see Figure 6.3 a, b). For example, the property participates_in (or works_for as in Figure 6.3a, b, c) may have a class Stakeholder (or Actor in Figure 6.3a, b, c) as its domain and a class Project as its range.

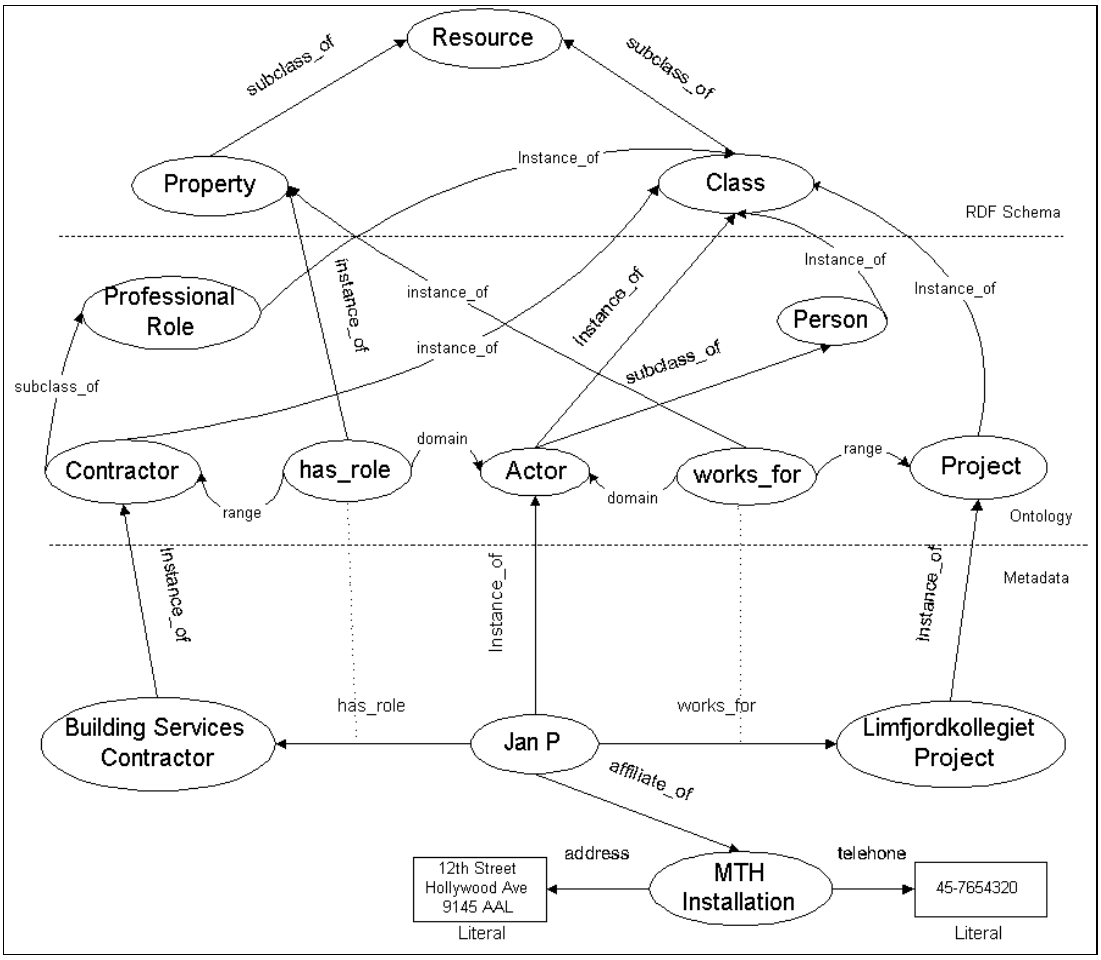


Figure 6.3a: An excerpt of representation of lightweight ontology (represented using RDF Schema (RDFS) formalisms) and the relevant instance that is called metadata in the figure (represented in RDF).

```
<?xml version='1.0' encoding='UTF-8'?>
<rdf:RDF   xmlns:rdf=" http://www.w3.org/1999/02/22-rdf-syntax-ns#"
           xmlns:rdfs=" http://www.w3.org/TR/1999/PR-rdf-schema-19990303#"
     xmlns:gnominie="">
<rdfs:Class rdf:about="Person">
        <rdfs:subClassOf rdf:resource="http://www.w3.org/TR/1999/PR-rdf-schema-
19990303#Resource"/>
</rdfs:Class>
<rdfs:Class rdf:about="Professional_Role">
        <rdfs:subClassOf rdf:resource="http://www.w3.org/TR/1999/PR-rdf-schema-19990303#Resource"/>
</rdfs:Class>
<rdfs:Class rdf:about="Actor">
        <rdfs:subClassOf rdf:resource="#Person"/>
```

```
</rdfs:Class>
<rdfs:Class rdf:about="Contractor">
                <rdfs:subClassOf rdf:resource="#Professional_Role"/>
</rdfs:Class>
.
.
.
<rdf:Property rdf:about="works_for"
                 rdfs:label="works_for">
                <rdfs:domain rdf:resource="#Actor"/>
                <rdfs:range rdf:resource="#Project"/>
</rdf:Property>
<rdf:Property rdf:about="has_role"
                 rdfs:label="has_role">
                <rdfs:domain rdf:resource="#Actor"/>
                <rdfs:range rdf:resource="#Contractor"/>
</rdf:Property>
<rdf:Property rdf:about="telephone"
                 rdfs:label="telephone">
                <rdfs:domain rdf:resource="#Company"/>
                <rdfs:range rdf:resource="http://www.w3.org/TR/1999/PR-rdf-schema-19990303#Literal"/>
</rdf:Property>
<rdf:Property rdf:about="address"
                 rdfs:label="address">
                <rdfs:domain rdf:resource="#Company"/>
                <rdfs:range rdf:resource="http://www.w3.org/TR/1999/PR-rdf-schema-19990303#Literal"/>
</rdf:Property>
.
.
.
</rdf:RDF>
```

Figure 6.3b: Excerpt of RDF Schema (RDFS) based on the graphical representation shown in Figure 6.3a (Note: The excerpt is only good for demonstrating the written syntax (abbreviated) of RDF Schema, it is incomplete for parsing in any RDF(S) parser).

```
<?xml version='1.0' encoding='UTF-8'?>
<rdf:RDF   xmlns:rdf=" http://www.w3.org/1999/02/22-rdf-syntax-ns#"
                 xmlns:gnominie=""
                 xmlns:rdfs=" http://www.w3.org/TR/1999/PR-rdf-schema-19990303#">
        <gnominie:Actor>
      <rdf:Description rdf:about=”Jan P”>
<gnominie:affiliate_of>
  <rdf:Description about=”MTH Installation”>
    <gnominie:address>2 Street Hollywood Ave 9845 AAU</gnominie:address>
    <gnominie:telephone>45-7654320</gnominie:telephone>
  </rdf:Description>
     </gonimnie:affiliate_of>
 <gnominie:has_role rdf:resource=”Building Services Contractor”/>
 <gnominie:works_for rdf:resource=”Limfjordkollegiet Project”/>
     </rdf:Description>
    </gnominie:Actor>
</rdf:RDF>
```

Figure 6.3c: Excerpt of RDF created according to the RDF Schema (RDFS) shown in Figure 6.3a and Figure 6.3b.

DAML+OIL (DARPA Agent Markup Language + Ontology Inference Layer) is another ontology language that is merged from two separate languages, DAML and OIL. DAML and OIL are two separate RDF implementations, which contain complex tagging schemes extending from RDF and XML. However, DAML+OIL (http://www.ontoknowledge.org/oil; DARPA, 2000-2006) takes a different approach to define classes and instances. In addition to defining classes and instances declaratively, DAML+OIL and other description-logics languages let the user create intentional class definitions using Boolean expressions and specify necessary, or necessary and sufficient, conditions for class membership. These languages depend on an inference engine to compute a class hierarchy and to determine class membership of instances based on the properties of classes and instances. For example, a class of Local Engineer can be defined as “a class of stakeholder who participates in the Local Project, which in turn is a subclass of the Project class". The distinctive point between DAML+OIL and RDFS is that the DAML+OIL has the primitives for its user to specify both the global and local properties of classes and slots while in RDFS, only the global properties can be specified.

The above-mentioned languages are only some of the examples of the currently available Semantic Web languages for representing ontologies and instance data. A diagram (see Figure 6.4) illustrating the main architectural premises of the Semantic Web as a stack of languages was first presented by Berners-Lee in his XML 2000 (http://www.w3.org/2000/talks/1206-xml2k-tbl/slide1-0). As shown in Figure 6.4, the fundamental of the languages stack of Semantic Web is XML (eXtensible Markup Language). XML is a specification for computer-readable documents. It is designed for mark-up documents of arbitrary structure. Markup means that a certain sequence of characters in the document contains information indicating the role of the document's contents. The markup describes the document's data layout and logical structure and makes the information self-describing. A *well-formed* XML document creates a balanced tree of nested sets of open and closed tags, each of which can include several attribute-value pairs. There is no fixed tag vocabulary or set of allowable combinations. Therefore, DTD (Document Type Definition), which has been gradually replaced by the XML Schema, is needed to enforce constraints on which tags to use and how they should be nested within a document. There is a controversy if XML and DTD (or XML Schema) are also a type of ontology languages because the applications of XML and DTD (or XML Schema) only specify syntactic conventions while any intended semantics are outside the range of the XML specification. XML is designed to provide an easy-to-use syntax for web data so that all kinds of data can be encoded for being exchangeable between computers. In other words, XML is the underlying syntactic carrier for ontology languages, but it only gives very vague semantics with respect to the relations between data.

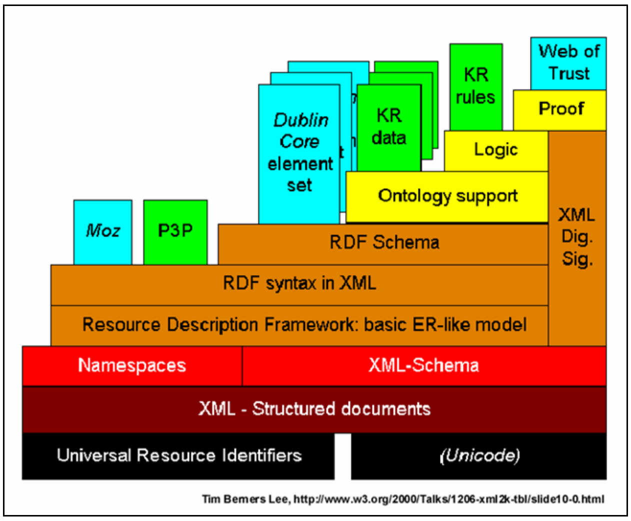


Figure 6.4: The main architectural premises of the Semantic Web (Source: http://www.w3.org/2000/talks/1206-xml2k-tbl/slide1-0).

6.8 The Information Management Practice within the Building Industry

Analysis of case studies in regard to the information flow at the early design stage was delineated in Chapter 5. Systems with a mix of various mechanisms including the paper- and digital-based, centralised and decentralised repository were used in the projects of case studies for managing the massive data/information generated. Figure 6.5 is a rich picture diagram that shows the *information flow* generalised from the case studies. As reported in Chapter 5 based on the analysis of the four case studies, digital-based centralised systems were implemented over the internet to enable fast sharing of information in conjunction with the conventional paper-based method by which information was stored in paper-based documents. These documents would be archived in file cabinets, which were distributed amongst the heterogeneous stakeholder groups. The situation of fragmented information flow that was revealed by the interviewees of the case studies was explained in Chapter 5. The fragmentation of information flow may deteriorate the efficiency in integrating and communicating design knowledge. The Memex machine envisioned by Bush (Bush, 1945) could be the inspiration for a system that may reduce the occurrence of fragmented information flow. The concept of hypertext mentioned above and the technologies provided by the semantic web could be the important tools applicable in the system development.

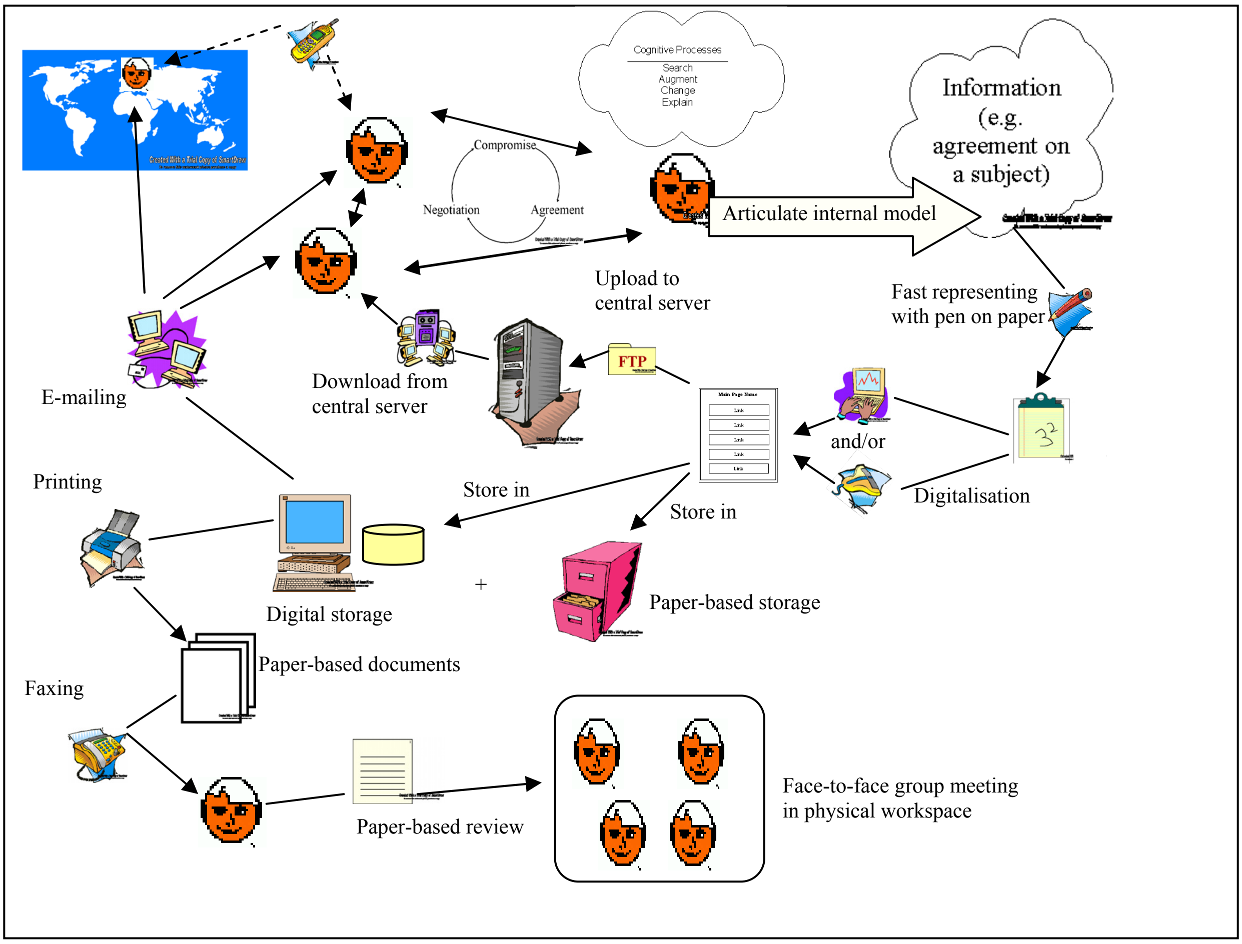


Figure 6.5: Analysis of the information flow during the decision making process within the A/E/C industry based on observations in case studies.

The cross-disciplinary early design stage requires close collaboration between the involved stakeholders to achieve the optimum state of understanding (data, information and knowledge) sharing. The large amount of information generated throughout the early design stage may not necessarily improve the state of understanding sharing amongst the stakeholders, but may induce the sensation of being bombarded with excessive information (Chapter 5: Section 5.4.1). The internet has become a common means via which information from heterogeneous digital sources can be shared. A project-specific information base, which is also referred to as Project Web, is the web portal based mechanisms that the project stakeholders within the A/E/C community often use to share information and data generated for a particular project throughout the project life (see Chapter 5). An information management system as the project web mainly functions as a document-centric repository. All project related information is contained in different types of documents that are up-loadable to, storable in, accessible and downloadable from the repository. The mass quantity of documents, some of which contain highly structured data (e.g. spreadsheets) while some of them contain weakly structured natural language chunks, are organised nested in hierarchies of infinite levels. Keywords search is the popular means used to assist a project web user to search for information.

In the event that a system user requires referring to the reasoning behind a decision made at a particular time during the design stage of a previous project, which was completed some years back, the system user may have no other clues for search except the name of the project's client and the approximate number of years ago that the project was completed, say 5-10 years ago. If the system user has only completed one project in cooperation with that client in the recent 10 years, it will be much easier for the system user to locate a precedent. On the other hand, if there are a number of projects that the system users have completed for the same client in these recent 10 years, the keywords search mechanism will probably display lots of search results. Moreover, the reasoning behind decisions has seldom been made explicit in any specific document although it has sometimes been documented implicitly in meeting notes/minutes. Under such circumstances, the system user may thus face the risk of being unable to find the desired information among all of the hits contributed by the keywords search based search engine.

The above scenario is to illustrate the shortcoming of the project web, a project-level information management system that uses the Internet as the information dissemination medium. Based on the interpretation of case studies described in Chapter 5, the efficiency of the system could be improved after paying attention to several underlying aspects, as outlined below from Section 6.9.1 to Section 6.9.4.

6.8.1 The aspect of knowledge representation

The knowledge representation approach used in the case studies tends to be document-centric. Information is contained statically as text, sketches and graphics in a document, which itself is an information container. Various types of documents are generated to present the results of collaboration activities and cognitive processes. The process when collaboration activities, such as brainstorming, discussion, negotiation and compromise, are conducted is usually not documented. The cognitive processes of problem solving are also usually neglected because of 1) the difficulty to find the right way to externalise them and 2) having the misconception that too much effort and time are needed to externalise them. As a consequence, the document-centric knowledge representation approach does not only conceal, but also reflect the risk of disposing of the valuable tacit design knowledge. Besides improving for instance the advanced product modelling approaches in a direction that may make the tacit design knowledge explicit, effort on structuring the natural language chunks that are sometimes used to describe the decision-making process, such as e-mails, progress reports and meeting minutes, would also be another alternative.

It is always difficult to find an appropriate way to represent the analogy of ideas, but finding an appropriate way to capture and store the idea is even more complicated. The appropriate way to represent the analogy of ideas is a way that could make the analogy tangible to the targeted audience. An appropriate representation and storage method could make the representation distributable, sharable, interpretable, and reusable in the future when needs arise. Verbal communication is usually chosen as the most appropriate way to represent the thinking process, but posing the weaknesses of being documented although sound recording is no longer a technical concern. Nevertheless, documenting verbal communication remains a difficult task based on the following reasons:

- Redundancy and repetition of contents.
  - Redundancy and repetition of contents is unavoidable while verbalizing the cognitions so that their meanings are perceivable. A paragraph of the written summary with respect

to a 20-minute verbal discussion/conversation might only take 5 minutes to read. On the contrary, twenty minutes are to be spent to playback and listen to the sound record.

- The structure of the contents is arbitrary and may result in unnecessary repetition.
    - The sequence of the conversation contents is not structured as orderly as in written communication though a general conversation outline is usually prepared beforehand. The outline is only good for guiding the conversation participants to achieve the expected conversation goal while the development of the conversation could turn up to be arbitrary and unpredictable during the process.
- The contents can be ambiguous if a well-defined context is absent.
    - It is a common phenomenon for one to feel lost while joining a conversation without knowing the conversation context. That is the reason why the audiences of an opera are always provided with a show guide, which briefly describe the context of the show in order to assist the audience to interpret that piece of artwork.

By presuming that the analogy of ideas is traceable when their representations are tangible to be presented and documented, the trail of reasoning behind decisions may then be plotted. This assumption is of vital importance for the purpose of keeping track of the discussion contents in a design meeting, in which the meeting participants use different approaches to communicate their thoughts, or in other words to *verbalise* their *cognitions through conversations*. On the understanding that if structuring these verbalised cognitive activities is plausible, the reasoning behind decisions including the design rationale might be capturable and storable for future reference. The carefully structured coding scheme of the Protocol Analysis was also proven able to portray the different kinds of mental events that the members of the design team experienced as well as the collaboration activities that they practiced in the problem-solving process (Caroll et al., 1990). In view of this, the principle concept on which the coding scheme of Protocol Analysis was built was adopted for structuring the collaboration activities that were observed in the case studies, aiming at identifying how the team members shared their understanding.

It is the human user's burden to identity the right information followed by interpreting the information so that it can be converted to knowledge, which is reusable. Documentation generated, disseminated, stored and retrieved in the case studies, however, indicated a general weakness, concealing the tacit design knowledge. The tacit knowledge carried in graphical representation, such as sketches, drawing, and even the computer drafted model, was insufficiently explicit to the receiver when such graphical representation was used as the medium for knowledge sharing. Under such circumstances, additional explanations would be required to assist the receiver interpret the embedded tacit meaning. The additional explanations were usually given orally in a face-to-face meeting or over telephone conversations. In most circumstances, these informal explanations were not incorporated in the formal documentation such as a 2-D plan drawing, which was to present the results of discussion, negotiation and compromise but not the process.

6.8.2 The indexing approach used

Besides having the objective to better information dissemination, a digital information repository is also expected to improve information integration. The functional requirements of a digital information repository become multi-faceted and more challenging in comparison with merely providing storage space for information in order to achieve these objectives. An efficient filing system is one of the basic needs during the storage of data and information, which is the process of keeping data and information in repository until the need for them arises. The e*lectronic filing system* inevitably plays an important role in the aspect of organising the digitalised documents when they are stored in a digital repository to facilitate future access and retrieval. The electronic filing system enables an unlimited level of hierarchical structure to be developed so that the classified digital documents can be kept in digital folders to which they belong, respectively. The complicated nested tree structure stemming from the electronic filing system differs from the natural human's memory structure that operates by association as suggested by Bush (Bush, 1945). The *tree-structure* like *indexing approach* has confined the ability of the hypertext notion, which is to build up dynamic links of associative trails of information. The tree-structure like indexing approach also neglects the notion of ambiguity of object. In reality, no object falls unambiguously into one single classification as what is expected in the tree-like classification hierarchy.

6.8.3 Keywords search and metadata

The notion of *metadata* has in fact existed in the aspect of information management far back to the time when paper was the dominant information storing medium. Paper-based library catalogues is a system that has long been used to help library users locate the collections of a library, such like books, periodicals, records, musical scores, photographs and so forth. Every individual collection in the library was described with a list of items printed on a piece of card, which is called the library catalogue card. The items list on the catalogue card may comprise descriptions such as title, author, keywords, publishing date, and so forth. Words like "title", "author", "keywords" and "publishing date" are the identifiers created to describe the properties/attributes of the collection. These identifiers are the metadata.

Metadata is defined as data about data, and are also data themselves. Metadata can be used to describe any object in the universe, and anything can be an object. When the metadata about an object are structured to provide a description, and all instances of the same object type can share the same structure, such a structure is also called a profile. The library catalogue card is the typical example of a profile that provides the description of each individual collection in the library. Metadata are usually embedded in the contents of a document that they describes/represents. In some cases, metadata, however, exist separately from the contents as another document or as headers of the document that they describe, such as a protocol. In the computer-based environment metadata can for example be defined as a profile in the header section of an HTML 4.0 file. The HTML 4.0 specification has an attribute named the *profile* attribute that can be included in the HEAD element of an HTML file.

The web sites of the project webs in the case studies used HTML documents. There are in general two scenarios for the project web user to locate a piece of information whose existence is merely a glimpse in the user's memory. It is quite usual for a human user to forget in which file the information is contained, under what name the file is saved, and where the file is stored. Some users would navigate the tree like hierarchy of digital folders that are created to classify information based on particular predefined characteristics. Human users *navigate* the hierarchical digital folders by using their *intuition* following the *trail* of the relationships between information that was formed in their own *mental model*. Most people who have the experience of using such manual search mechanism would know how time consuming, annoying and tedious the whole process is.

Using *keywords search* is another information searching scenario besides the navigational search mentioned above. The keywords search mechanism was developed to improve search process efficiency. A significant shortcoming of this search mechanism has, however, been revealed when information disseminated over the web increases exponentially at a rapid pace. The keywords search mechanism may generate a long list of search results whose relevance with the entered keywords relies heavily on the human user's justification. This significant shortcoming of the keywords search mechanism is closely related to how appropriate the notion of metadata is used.

Technically, a *search engine* finds information on the computers network of interest such as the web by indexing the documents stored within the network. The *index* generated by the search engine is one example of metadata. In order to get a top ranking in search engines, the web-master (or the person who is responsible to manage the information flow of a web site, say the project web) would use some strategy for controlling to some degree how the documents stored at the web site would be described by a search engine. Defining metadata as a profile at the header section of an HTML document with the HTML *Meta tag* element is one of the most commonly used strategies in this circumstance. The negative side of this strategy is the potential misuse of metadata. Meta tags that fit very popular topics, but have low relevance with the actual contents of the document might be added. As a consequence, irrelevant search results will be displayed by the search engine.

The second situation of the keywords search mechanism correlated with metadata could be totally the opposite of the one mentioned above. A document, could be any type of document in any file format, for instance progress reports in rich text format (*.rtf), or scanned-in sketches in jpeg format (*.jpg), uploaded to the project web without being given any description apart from a very creative filename. Again, this practice, which is quite common to run a project web (although keywords are created occasionally for some documents), which functions merely as a project basis repository, will thus result in a number of *irrelevant hits* on the entered keyword(s) at the end of the search process.

As mentioned above, metadata could be defined by using HTML Meta tags (HTML 4.0). Using this approach to create metadata to describe a document is not good enough for users (neither humans nor computer agents) to identify, acquire and compare information stored in distributed heterogeneous sources. The reasons are twofold. This approach defines metadata with respect to some *primary attributes* of a document, such as who is the author, what is the publication date, who owns the copyright, and so forth. These metadata are good enough to generally describe the document, but not the detailed contents of the document. Needless to say, the human interpretation on the contents of the document is also not one of the covering aspects of metadata created by the HTML Meta tag approach.

Another inadequacy of this approach is the *inherent weaknesses* of HTML. HTML is a language designed with functions for the representation of textual information and hyperlinks between various documents and subsections of them. Simplicity is the vital characteristic of HTML that has made this language so popular in the WWW. The simple underlying structure of the HTML enables markup of arbitrary information with predefined tags. It is intentionally designed to describe the structure of documents so that documents could be exchanged over the different computer networks using HTTP. The predefined tags of the HTML are good enough to describe the structure of document, but not the semantics of document. The data contained in an HTML document are not structured in a way to reflect the semantics of the data, but instead to portray the layout of the document. The techniques of HTML offered by embedding data into the layout structure have resulted in the major demerit, which further leads to the incapability of HTML to define *structured data content*.

6.8.4 No support for interpretative task by metadata

Overwhelming information within the A/E/C sector has not only occurred in this electronic-information based decades. Managing the ocean of information with high flow rate in the project web remains a huge challenge. A document provides no explicit semantics; it is the user who needs to interpret the contents of the document. Personal interpretations could be time consuming and subjective. The author argues that many metadata approaches to document description remain at a level that only focuses on improving data interoperability and retrieval. These metadata approaches describe documents by encoding the stable primary contents attributes of the document (e.g. Author, publishing date, copyrights, etc) in accordance with a metadata scheme or controlled vocabulary, for instance the Wordnet (http://wordnet.princeton.edu). Metadata approaches are used in most of the existing information management systems. These systems tend not to support personal interpretation augmentation because it imposes inconsistencies that may complicate the process of resource discovery and interoperability between the networked repositories. On the contrary, the author would argue that personal interpretations are the important attributes that a system needs to reify and support collective memory so that conceptual contents such as ideas, rationale, activity history, or lessons learned can be articulated and shared.

7. SEMANTIC WEB SUPPORTED COLLABORATION SYSTEM

7.1 The innovative use of meeting minutes

Close collaboration between the multidisciplinary stakeholders is of the utmost importance, particularly in the early design phase. As analysed in Chapter 5, face-to-face meeting is one of the most preferential communication means used within the A/E/C sector. Various collaboration activities are conducted in each face-to-face meeting amongst the meeting participants in order to achieve consensus on issues that require group discussion. These collaboration activities including brainstorming, compromise, and negotiation, may reflect the rationale of decisions made for the design.

It has been a common practice within the A/E/C community to transcribe the decisions made in a meeting from verbal into written form for documenting purposes. The resulting document is called meeting minutes. Meeting minutes are a summary or record of what is said or decided at a formal meeting. It is a collective memory resource in which the project related *conceptual contents* are articulated. The articulated conceptual contents may consist of ideas, rationale, lessons learned, and activity history, whose *capture* and *reuse* is of importance. Meeting minutes can be described as *interpretation-oriented discourse* in which verbal expressions and conversation were articulated in writing based on a *context* for subsequent reinterpretation.

In most cases the minutes are used mainly as a confined container of conceptual contents with limited computational support for constructing explicit, interpretive levels of indexing approach that may reduce the time for the human users to reinterpret the meaning and significance of an artefact or idea. The indexing approach used for managing the ordinary minutes mainly focuses on the encoding of the primary content attributes to improve the discourse *retrieval* and *interoperability*. The most commonly found primary content attributes, such as the date, author, and so forth, are manually codified based on a metadata scheme or controlled vocabulary as those developed by the Wordnet. This kind of indexing approach leaves interpretation of the conceptual contents to the personal level and thus may raise the risk of interpretation inconsistencies.

Moreover, meeting minutes usually focus on making the result of discussion explicit in written plain texts. The *reasoning process* is sometimes articulated implicitly within these chunks of natural language texts, such as those labelled as “Info Block” in Figure 7.1. The sense of “implicit” is actually very ambiguous and varies depending on the technology and context of use. Implicit elements could be referred to from a verbal expression that is not transcribed into written form, or written elements (data or information), but private or non-interpretable to a machine (computer).

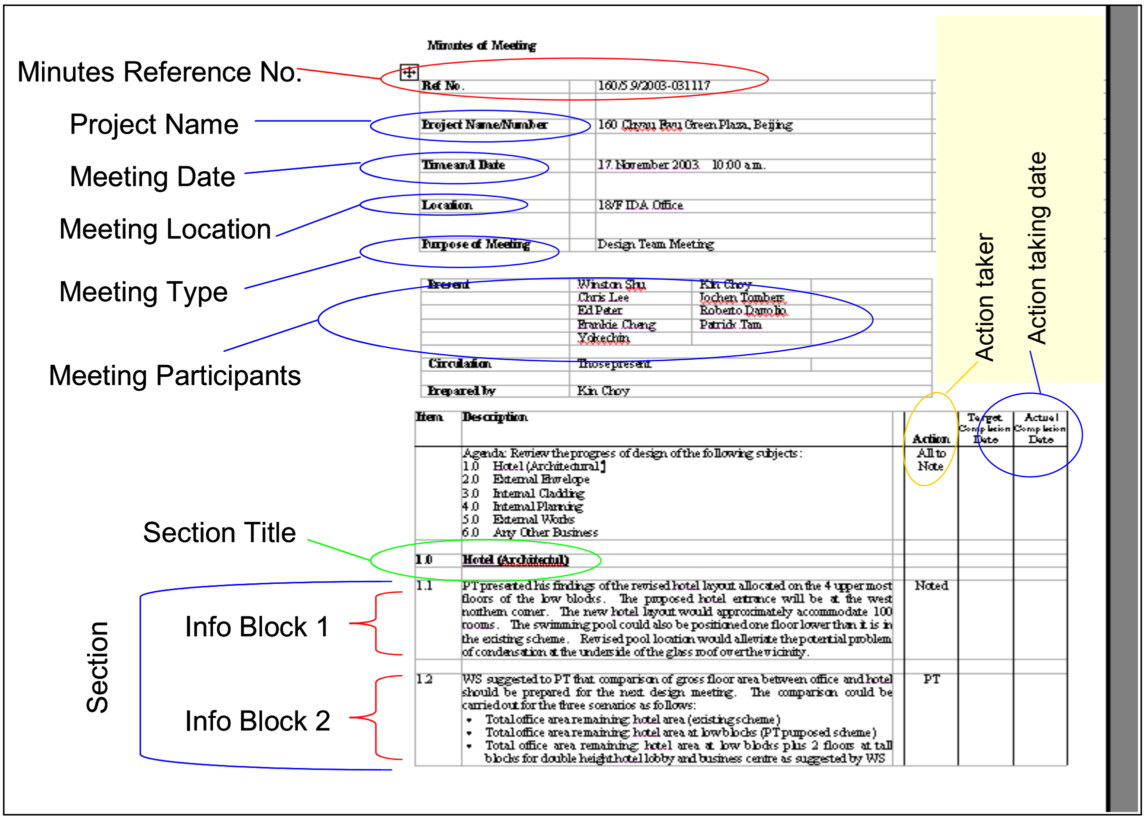


Figure 7.1: The generic structure of paper-based meeting minutes.

The above arguments can be grasped more clearly by examining meeting minutes acquired from the case studies. As indicated in Figure 7.1, meeting minutes are a collection of textual fragments. These textual fragments are the articulated discussion contents in written form. They are organised at different levels of granularity in an inherent structure such as a tree. In other words, there is always a top-level element to which all other elements nest. Each of these elements can be one or more paragraphs, each of which is a summary corresponding to a discussion session conducted in the meeting. These paragraphs are connected in a certain order so that the whole document is presented with a certain degree of coherence. The sequence of paragraphs is influenced by the semantics carried in texts establishing the coherence of the information contents. These textual paragraphs represent different discussion issues in a meeting. The relationships between these different information chunks are established in the human user's *mental model* after reading and comprehending the semantics carried in the natural language texts. There are no explicit links supported by computers that are useful for the human users to trace the information trails. This conventional type of meeting minutes is perceived as a *static container of information*.

Since meeting minutes have long been utilised by the A/E/C/community as part of the crucial design information, restructuring meeting minutes with an approach, which differs from the conventional document-centric one may be an alternative to assist the A/E/C community to achieve more efficient collaboration. The hypothesis here is that by structuring meeting minutes with a new discourse structuring approach, which could capture as well as make explicit the previously neglected or implicitly contained reasoning process conducted, attempting to reach consensus on issues of concern, meeting minutes could then serve as a *collective memory resource* that could be useful for more efficient knowledge (both tacit and explicit) sharing within and between projects. Some constraining factors, such as what is discussed, when, by whom, for how long, and how and why it is reified are taken into account while structuring the discourse to portray the context and content of discussions in meetings. The main objective of the new discourse structuring approach is to make explicit certain elements of the discourse that were previously implicit. However, structuring the discourse by using the appropriate technologies for making the record more reusable, but minimizing as little as possible the change in discourse practice is the *key challenge to this doctoral research stud*y. After investigating several concurrent technologies correlated to the semantic web including its silver bullet, the ontologies, the conventional meeting minutes can hypothetically be changed based on these technologies to a structured, reusable memory resource that could provide explicit semantics of the reasoning process to both the human users and machine.

7.2 The Inspirations for and Concepts of IT-CODE

The above-mentioned hypothetical discourse structuring approach is envisioned to alter the conventional notes-taking approach used for capturing the discussion contents of a meeting. There are in general four challenges that the hypothetical approach is required to tackle for assisting efficient knowledge management at the iterative early design stage within the A/E/C sector:

1. To *integrate information* that is distributed in heterogeneous sources without binding to one central repository to reduce repetition of workload as described by interviewees of the case studies analysed in Chapter 5
2. To *capture and store discussion contents* wherein design rationale and reasoning behind decision are intrinsically encompassed
3. To *organise the captured information* in a way that is both human- and machine-readable so that fast and precise search could be achieved for providing decision-making support in a multi-actors environment
4. To *represent the captured information* in a way that may improve the human efficiency to interpret its implicit meaning.

In order to address these challenges, the hypothetical approach adopts the following concepts:

1. the concept about building information trails is analogous to associating memory chunks in the human mind, and associative retrieval allowing learning and discovery (Bush, 1945; Schank, 1982);
2. the concept of ontological indexing, which is also the kernel of the semantic web technologies, as an alternative way to represent knowledge contrary to the document-centric knowledge representation approach in which a tree-like hierarchical classification mechanism is used;
3. the concept of metadata, which is inherently designed to integrate information in order to improve data interoperability between different information management systems and;
4. the concept of contextualising discussion contents to enable transparency of ideas. Transparency of ideas could make explicit the design rationale and the reasoning behind decisions and could thus improve the human efficiency in interpreting the implicit meanings.

The inspiring contributions to this hypothetical approach are from the vision of the Memex machine (Bush, 1945) and a concurrent research project, the ScholOnto project that attempts to formulate a setting for scholarly debate (Shum at al., 2000; Shum at al., 2002). The main objective of the ScholOnto project is to seek a method that is capable of supporting scholarly research communities in interpreting and discussing evolving ideas: overlaying interpretations of contents, and supporting the emergence of different perspectives. Adequately defined ontologies are the backbone of that research outcome, which is a collective memory system functioning as a digital library specifically concerned with the capture and recovery of conceptual contents correlated to scholarly discussion.

All sorts of discussions including idea contesting, negotiation, argumentation and compromise could be found in progress meetings conducted at regular intervals throughout the design process within the A/E/C community. The whole discussion session of a meeting reflects the reasoning process behind decisions made in the meeting. The discussion contents may also comprise explanations given by architects or other designers in regard to their designs, or in other words the design rationale.

Efforts of formalising the lineages of thoughts reasoned in progress meetings into written form as represented in the conventional meeting minutes have only been done to a very limited extent. In accordance with the case studies analysed in Chapter 5, these meeting minutes only function as records in natural language texts disseminated as e-mail attachment. Meeting minutes are only of interest for the ongoing project because the records they hold could be used to trace the project progress. However, it has seldom been considered an important medium for storing reusable knowledge for future projects.

In this doctoral research study, it is argued that meeting minutes could be used as a medium wherein project stakeholders may locate interesting information contents whether within the current project lifespan or at a future time point. If the information contents of meeting minutes could be structured in a way that the intellectual lineage of ideas and reasoning is traceable explicitly and is interpretable intelligibly, the functions of meeting minutes could be extended further than only being a static information container as it has usually been. Meeting minutes could then be developed to a *dynamic knowledge base* that the project stakeholders can apply to capture, store, disseminate and reuse their knowledge across the different geographical boundaries.

The principal method of devising the hypothetically innovative meeting minutes, which are expected to have a farsighted quality as knowledge base is primarily through building information trails based on the concurrent semantic web technologies. The basis of this innovative meeting minutes is to visualise the chunks of natural language text written in the conventional meeting minutes as *objects* (or information objects) while meeting minutes, the document itself, is the container for the information objects (see Figure 7.2). In other words, each of these objects thus corresponds to the summary of a particular issue discussed in a meeting. As mentioned earlier, the meaning of the plain text meeting minutes is interpreted mainly based on the human's cognitive processes. The relationships between these information chunks could thus be considered as implicit relations between objects. Seeking a way to make these implicit relations explicit is one of the main concerns in this respect.

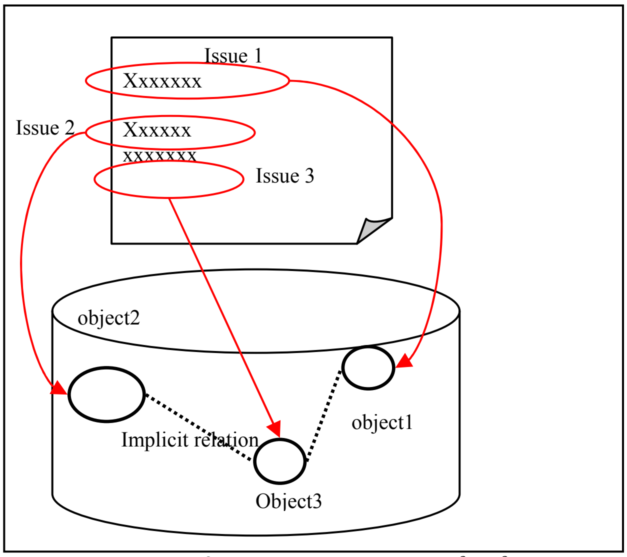


Figure 7.2: Representation of information and document.

In Figure 7.3, an excerpt of a meeting minutes acquired from one of the case studies with the person's name made anonymous is presented.

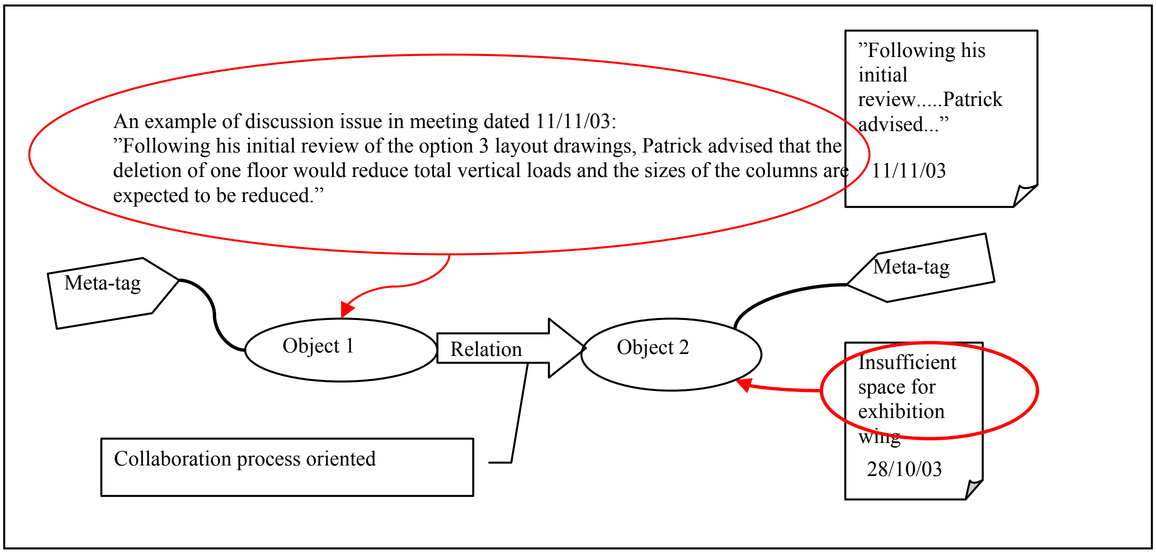


Figure 7.3: The concept of annotating information.

The excerpt of meeting minutes presented in Figure 7.3 was recorded from a design meeting dated 12 August 2003. By probing into the excerpt, several interesting features could be noticed:

1. It outlines a discussion topic.
2. There is implication of follow-up action, i.e. reduce the size of the vertical load-bearing structure.
3. Cause of action, i.e. change of design, is stated.
4. Rationale of action, i.e. reduction of number of floors, is also given.
5. How the rationale was made, i.e. after reviewing several layout drawings, is also indicated.

The discussion topic is apparently not a new topic, but instead it has been a matter of concern for a period of time. A trail of discussion contents on the same topic could actually be traced through collating the series of document-centric minutes, which have been documented in parallel with the design progress. As mentioned previously the inflexible structure of the document-centric minutes has been a drawback in establishing the trails.

Annotating information chunks with metadata is the fundamental method suggested in this doctoral study first to reveal the implicit meaning embedded in the natural language text then to establish the trail in order to integrate these different information objects contained in heterogeneous containers. The ultimate aim at making the relationships between the different chunks of information explicit is to disclose the implicit meaning that the meeting participants applied in the decision making process during the meeting.

7.3 The Rationale behind the Annotation Approach of IT-CODE

Metadata used for annotation purposes throughout the IT-CODE development process were arbitrarily defined in an ontology model. Vocabularies used in the ontology model were chosen on the basis of their expressive semantics in describing the collaborative design process as well as the primary attributes of the information object. A more detailed explanation could be given by re-examining the excerpt of minutes presented in Figure 7.3 based on the principle that building discussion trail was useful to reflect the tacit knowledge (e.g., intuition), which the meeting participants applied during their decision making process. The discussion trail could be revealed through imposing several questions classified based on the generic collaboration activities generalised by Kvan (2000), i.e. agreement, negotiation and compromise:

1. Agreement
   a. Was any agreement achieved in the end of the discussion?
   b. What was the main topic of the agreement?
   c. Who was involved in making the agreement?
2. Negotiation
   a. Were there any alternatives discussed in the previous meetings?
   b. Why was this agreement made?
   c. What would happen after this agreement was made
3. Compromise
   a. Did anyone compromise? If yes, who were they?
   b. How did they compromise?
   c. Why did they compromise?
   d. What direct and indirect process/component of work would be influenced?

In general, the assumption made was that the discussion trail of the correlated issues could be traced when the discussion contents were contextualised based on for instance the above listed questions. *Contextualisation* was the approach implemented to outline the essence of information, from which the human user would gain knowledge. Examining the context of the discussion contents was also the preliminary step taken before outlining the underlying ontology model, which was here assumed as the *meta-knowledge* needed in performing the task of integrating not only information, but also knowledge. Context played a vital role in this aspect because the author argued that context shaped our perception and interpretation of meaning. This argument is affirmed by Polanyi in his statement that tacit knowledge, which is important for decision-making support is context dependent (Polanyi, 1983). In other words, all information and knowledge that we have are immersed in a variety of contexts. In order to understand and communicate meaning, we must thus attend to the contextual clues attached to each meaning. The contextualisation approach was experimented on the demonstrator, which was devised as the doctoral study outcome. Detailed discussion in regard to implementing contextualisation to annotate information chunks to support information interpretive tasks in the demonstrator is given in Chapter 8 of the dissertation. The contextualisation concept implemented in the demonstrator was proven to function reasonably satisfactorily as a meta-knowledge stimulator, which was devised to assist knowledge integration. Further improvement is, however, needed from the usability perspective as discussed in Chapter 8.

A more general set of questions were derived based on those listed above intending to offer a setting that is applicable for establishing the underlying ontology model:

1. Who raised the discussion issue?
2. When was the issue raised?
3. What was the issue type; a problem, proposition, alternative, solution or agreement?
4. Were there any precedent cases that were correlated with the current one?
5. What was the status of the current issue, which was under discussion?
6. Why did the issue have such status?
7. What would be the potential impact or consequences?
8. How to deal with the potential consequences?

The answers to these questions were sufficient to be adopted as metadata as well as the relationships between metadata, which both were the crucial components of the ontology model. In essence, the ontology model should be sufficient to represent the reasoning process including the analogy of ideas, which was undergone in most circumstances of progress meetings.

Figure 7.4 is a graphical representation that illustrates how the ontology model was developed with reference to the above questions. The content of the ontology model was based on a fraction of the conversation contents as documented in the meeting minutes presented in Annex 5.B., Figure 5.B.4. The ontology model was the framework on which the proposed innovative meeting minutes approach was built. A demonstrator was devised to test the notion of this innovative approach. A more thorough discussion with respect to the technologies used in devising the demonstrator is available in Chapter 8 of the dissertation. An overview of the demonstrator development process, which was in compliance with the Contextual Design formalisms (Beyer et al., 1998), is illustrated in Figure 7.5. Figure 7.5 also indicates the primary output that corresponds to each of the development process steps, as well as the methods implemented to obtain the corresponding output.

A deeper study on Figure 7.5 indicated, for instance, that before the demonstrator was set up, the basic key task to be supported by the demonstrator was first represented in storyboards. Story-boarding is a technique used to capture pictorially the new procedure for doing a task in a way like a storyboard for a film/movie (see Figure 8.5). After storyboarding, the design process of the demonstrator was further elaborated by using User Environment Design (Beyer, 1998; Preece, 2002) to reveal the underlying system structure by showing all the system components, what aspects of each component supported and how the components related to each other for achieving the defined tasks. Each of the system components was tested based on test scenarios, which were prepared with reference to the user requirements acquired from the case studies. The excerpt of the test scenarios is available in Annex 7.A. Figure 7.5 showed further that the design of each component was refined with reference to the test results. The design process loop was undertaken repeatedly until a satisfactory test result was obtained. Integrating the different components to form a coherent system was one of the most complicated steps throughout the system development process in this research study. The complications with respect to bridging the different components are reported in Chapter 8 after several interface tests were conducted to examine the compatibilities between components.

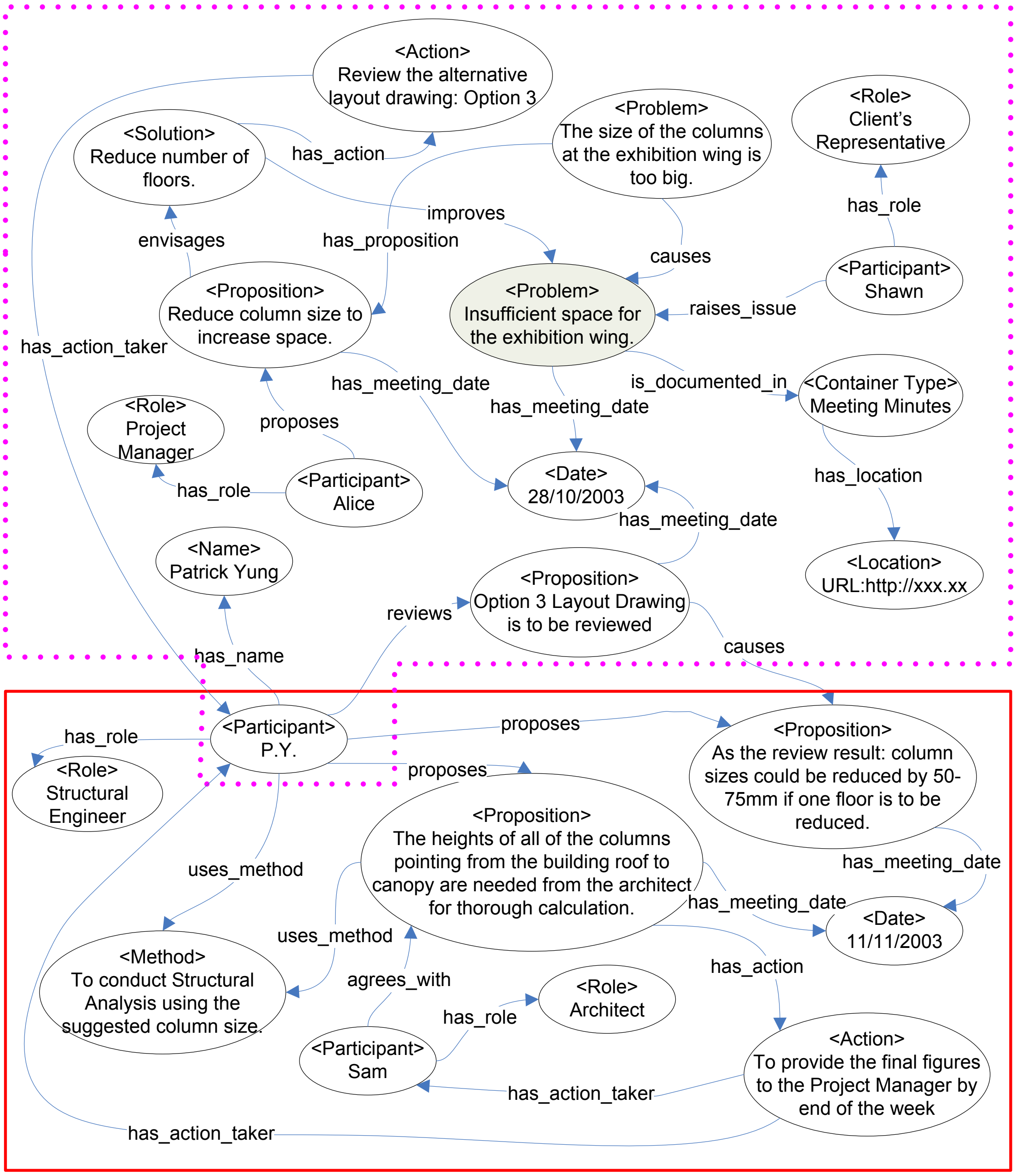


Figure 7.4: The Graphical Representation of the Conception of an Ontology Model

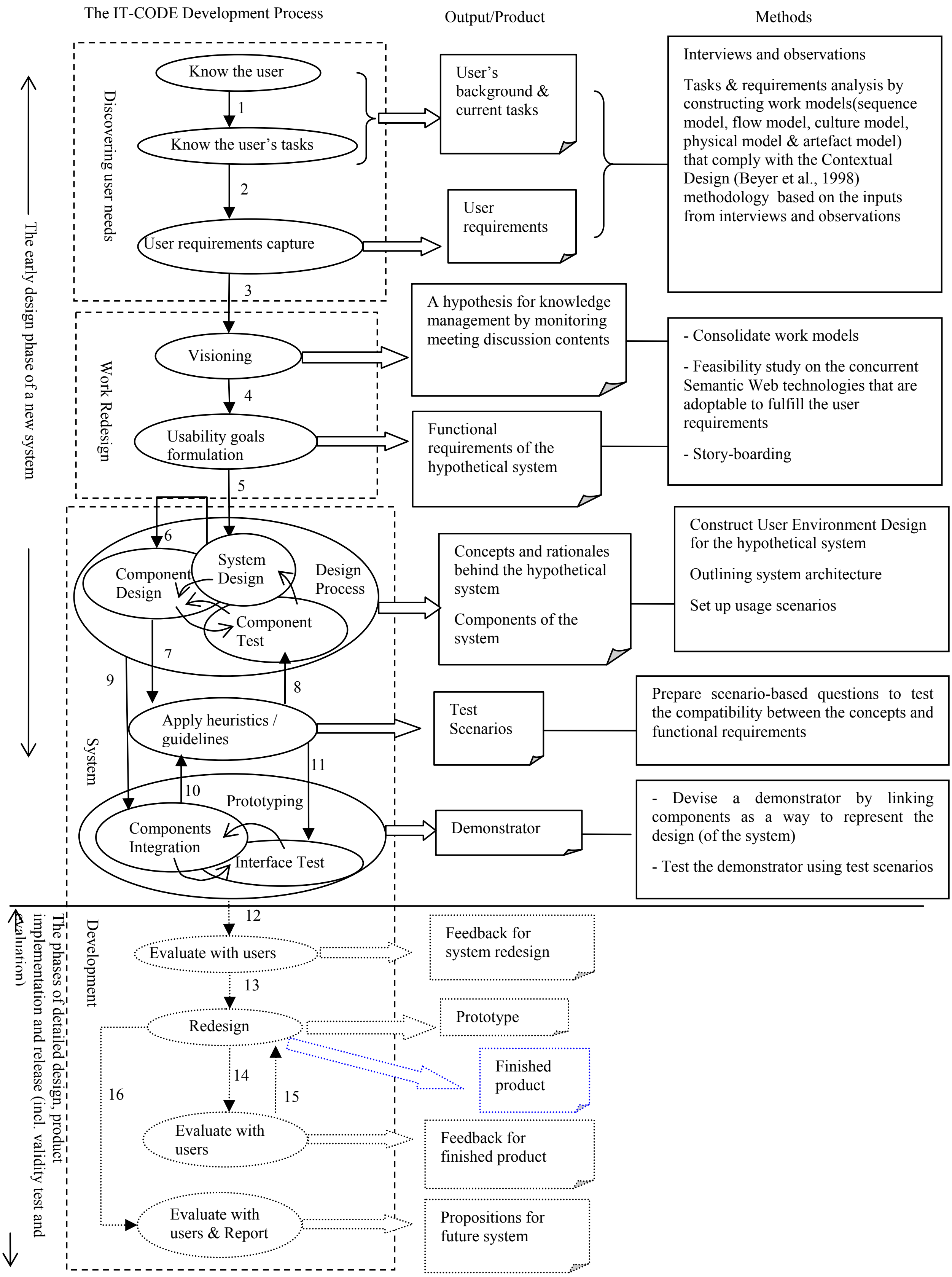


Figure 7.5: An overview of the IT-CODE development process

8 THE DEMONSTRATOR DEVELOPMENT AND TEST

«This? It is called a Pensieve,» said Dumbledore. «I sometimes find, and I am sure you know the feeling, that I simply have too many thoughts and memories crammed into my mind. …I use the Pensieve. One simply siphons the excess thoughts from one's mind, pours them into the basin [Pensieve], and examines them at one's leisure. It becomes easier to spot patterns and links … when they are in this form. » «You mean... that stuff's your thoughts?» Harry said, staring at the swirling white substance in the basin. «Certainly, » said Dumbledore.

-- J.K. Rowling, Harry Potter and the Goblet of Fire, pp. 518-519--

A demonstrator was developed at an early prototype stage to experiment the practicality of the proposed concepts with respect to devising knowledge-based meeting minutes that could support design knowledge management. An extensive discussion about these underlying concepts is available in Chapter 7. The demonstrator is devised attempting to fulfil the following requirements, which comply with the main objectives of the research study:

1. To provide a platform independent infrastructure to facilitate cross-disciplinary sharing of design knowledge in an attempt to improve the effectiveness of the multidisciplinary collaborative design.
2. To seek an alternative to organizing information in an attempt to improve the efficiency of information exploration, exploitation and retrieval within the A/E/C sector through using the concurrent Information and Communication Technologies.
3. To seek a method to integrate information in an attempt to reduce repetition of workload with respect to coordinating and managing the huge quantity of project-related information.
4. To experiment with an approach that could support decision making at the early design stage through improving the efficiency with respect to interpreting and deducing design information.

In order to fulfil the above-mentioned requirements, the demonstrator is devised to have the following functions:

1. To annotate/markup information chunks with metadata attempting to describe the information content.
2. To search information other than by using a keywords search in an attempt to obtain a more precise search result.
3. To archive information in a sufficiently structured manner to permit both human and machine comprehension.
4. To index information based on an associative approach to facilitate information tracking from multiple perspectives.
5. To be sufficiently flexible for further expansion.
6. To support interpretive tasks through making explicit the semantics of conceptual contents.

The ontology model, from which the metadata used to annotate information chunks are defined, is derived based on a number of questions constructed in an attempt to contextualize information contents (see Chapter 7, Section 7.2). With reference to Figure 7.4, metadata are defined 1) to describe the primary attributes of information contents, and 2) to describe the relationships between information.

8.1 The Underlying Technologies of the Demonstrator

With reference to the concept illustrated in Chapter 7, the demonstrator is devised as a knowledge-based application with which the contents of design group discussions could be captured, structured (classified and annotated), stored, disseminated, and accessed (searched and retrieved). The demonstrator is devised based on the following underlying technologies:

Semantic Web – to enable the demonstrator to operate platform independently, and
Ontologies – to provide the framework for structuring information semantically in contrast to the prevalent document-centric mechanisms as pinpointed in Chapter 5 & 6.

In order to fulfil its tasks, the demonstrator is built based on an underlying ontology model so that the discussion content can be organized in a semantic-based network. The underlying ontology model consists of a few modular components, each of which is respectively an ontology, as illustrated in Figure 6.2. Each of these ontologies describes an aspect of interest, for instance the "team-profile ontology" describing the profile of the design team. The modular characteristic of the ontologies network provides the flexibility for future expansion. Each modular component within the ontologies network is accessible through uniquely specified URI (Uniform Resource Identifier). This modular characteristic integrates the scattered information including the existent data and their respective ontologies, but does not require collection under one central repository.

The ontology model is the framework of the knowledge-based application, the demonstrator, which could be used as an alternative to the conventional notes-taking approach for managing discussion contents. The model is developed to outline the different levels of granularity of the different aspects to which a progress meeting would correlate. The ontology modelling process is conducted at different levels moving from a macro-perspective to a micro-perspective (see Figure 8.1). At the macro-level, the model represents the meeting related knowledge by defining the concepts with respect to some aspects that are essential to outline the profile of a project. These concepts are for instance the project's name, project start date, project end date, and so forth. Furthermore, it defines concepts of aspects correlating with a meeting. These concepts are for instance the meeting date, the meeting participants, the meeting objective, and the meeting venue.

The modelling scope then focuses on a lower level to tackle the structure of the document, i.e. the meeting minutes. The model defines essential concepts that prevalently exist in the ordinary document-centric meeting minutes. Such concepts are mainly comprised of those used for describing the profile of the document-centric meeting minutes, for instance, the document's reference number, the title of the document, and the version of the document. The document is then examined and represented at a finer level of granularity, in which the contents of the document are taken into account. This is the level where the implicit semantics of the conventionally recorded plain-texts are to be made explicit. "Issue" is the generic concept defined for any issue discussed in a meeting whose summary is conventionally transcribed in plain-text supplemented occasionally with graphical representations such as sketches, photos, diagrams, and so forth. Besides the "Issue" concept, the plain-text record could also be broken down to several sections for classifying purposes based on the inherent characteristic of the discussion issue. Such an issue discussed or raised in a meeting could be a newly identified problem, a suggestion to solve the problem, or the solution to the problem. Thus, several concepts that the author perceives essential to represent the inherent characteristic of the discussion issue are defined in the ontology model. These concepts, such as "Problem", "Solution", "Decision", "Method", and "Proposition" are defined based on the cognitive processes suggested in the Protocol Analysis encoding scheme, which attempts to enable the establishment of the trail of conceptual contents.

Ontologies may be expressed as sets of triples. The relations for associating the different concepts are carefully defined to construct the semantic network that could capture how people think and talk in a meeting. In a triple, such as "Actor—*works_for*—Project" (see also Figure 6.3a), "works_for" is a relation defined to associate the two different concepts "Actor" and "Project". "Actor" is one of the concepts defined to describe the project team profiles while "Project" is to describe the project profiles. A semantically associative trail could then be established when information marked-up by these two concepts is linked with a relation (e.g. works_for) that could delineate the meaning between them explicitly in a graph-like triple. Causal relationships between different issues discussed in either the same or different meetings could also be built by using the associative links, i.e. "cause" and "effect", which are also defined in the ontology model.

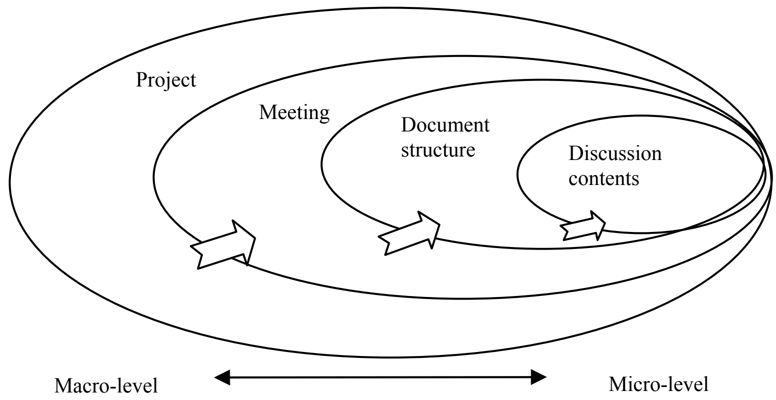


Figure 8.1: The different perspectives that the ontology model covers.

There are more relations developed to trace idea flows as well as outlining the relevant context of discussion contents in order to facilitate the process of abstraction in gaining knowledge from the recorded information. Relations such as "solves", "has_alternative", "proposes", "has_action_taker" are included for these purposes. This is the hypothetical experimental approach taken in response to the challenge claimed by Goel (Goel, 1995). Goel (Goel, 1995) claims that tracing of idea flow could be possible if there are means to analyse the contents from a group discussion. With one of these relations, issues could be associated with one another while being contextualized. "<Method>reduce number of floors</Method> *solves* <Problem>too big column size</Problem>" is a triple that illustrates two issues, each of which represents a different context as annotated -- <Method> and <Problem>, are correlated to delineate the interpretive semantics of the discussion trail explicitly to both humans and machines.

The Resource Description Framework (RDF) and Resource Description Framework Schema (RDFS), abbreviated to RDF(S), are two of the concurrent semantic web technologies proposed by the W3C industry group (W3C, 2002). RDF(S) is one of the de facto standards applicable for developing lightweight ontologies that are machine readable. RDFS provides two important contributions for ontology modelling: a standardized syntax for writing ontologies and a standard set of modelling primitives such as instance-of (type) and subclass-of relationships. RDF description is in fact a list of statements, each of which describes an object (a resource) with an attribute (a property) and its value (a resource or free text). The statement as such is also named a triple because of its similarity with the basic construct of ontology. XML aims to provide an easy-to-use syntax for improving data interoperability between computers. XML does not provide any interpretation of the data and thus it does not contribute much to the "semantic" aspect of the Semantic Web. Unlike XML, RDF does not emphasize syntax, but provides a model for representing metadata. In order to achieve better interoperability, RDF could adopt XML as its underlying syntax for encoding data. As a result, the metadata representation would become an XML-encoded RDF data model. RDF does not define the semantics of any application domain, but it provides a domain-neutral mechanism to describe metadata (or facts about resources). However, this feature of RDF gives some interpretations of the resources it describes. RDFS, a more expressive vocabulary language, extends those interpretation possibilities further and thus it fits to describe the semantics of resources. This is one of the reasons for choosing RDFS as the ontology language for defining the underlying ontology model of the demonstrator. RDFS is relatively simple compared to full-fledged knowledge representation languages (e.g. first order logic) and thus it does not provide as detailed semantics as those languages do. However, the primitives that both the RDF and RDFS possess are sufficient for application in the demonstrator. The third selection criterion for the ontology language of the demonstrator is based on the availability of several open source RDF(S) tools.

8.2 The Components of the Demonstrator

The demonstrator is based on several components that are under development by other research groups across the world. These components are open sources that are freely available from their respective websites. A brief description with respect to the functionality of these components will be given below.

8.2.1 Protégé

One of the underlying components is Protégé (3.0). Protégé is an open source ontology engineering and knowledge acquisition tool created at Stanford University (please see http://protege.stanford.org for details). Protégé uses a frame-based knowledge representation formalism to allow users to model domains using classes (which correspond to concepts in the domain), instances of classes, slots (which are properties of classes and instances) and facets (constraints on the slots). Protégé is written in Java and developed on top of a modular based architecture that allows adding extensions via a plug-in metaphor. The key modules that underlie Protégé are the knowledge model, the user interface module and the adaptability module in which the storage model is incorporated as plug-in (see Figure 8.2). Protégé uses OKBC (Open Knowledge Base-Connectivity) knowledge model as the basis for its own knowledge model. OKBC is a standard mechanism (protocol) to access knowledge bases stored as frames. Protégé is also adaptable to different knowledge models, among others the RDF (S), which itself is also a frame-based modelling language.

The storage plug-in is a non-visual module that saves and loads the knowledge models in a certain file or database. Protégé currently supports the following file storage formats:

CLIPS (C Language Integrated Production System, which is also the standard format of Protégé)
XML
XML Schema
RDF(S)
OIL (Ontology Inference Layer)
DAML+OIL (DARPA Agent Markup Language + OIL)
UML
XMI (XML Metadata Interchange (MOF (Meta-Object Facility) metamodels))
OWL
RDBMS (Relational DataBase Management System)

With Protégé, an **administrator** (e.g. the project manager) could create and edit the required ontologies for capturing and representing group discussion contents, team member profiles, and project profiles. Protégé enables inspecting, browsing, codifying and modifying ontologies and therefore support the ontology development and maintenance tasks. The ontologies are first modelled at a conceptual level and independently of the formalism of the final representation language. Protégé offers views on conceptual structures, such as concepts, concept hierarchy, and relations. Protégé also offers features for developing form-based user interface that in this case would allow the meeting participants to record meeting contents by filling in the information categories as arranged in the template forms. The form filling user interface is chosen because form filling has been a familiar activity for most computer users. The filled-in form represents dynamic meeting minutes with all of the annotated information populated in the RDF data file, which can be disseminated as it is or uploaded to a persistent RDF(S) based repository.

Arguments in favour of Protégé might be adherence to its user friendliness in establishing knowledge acquisition forms. No extra effort needs to be spent to develop a mechanism for acquiring domain knowledge while the process of developing the knowledge framework (ontology) is undertaken. By filling up the knowledge-acquisition forms, domain knowledge or instances is created and structured according to the underlying ontology (the knowledge framework). An RDF data file (*.rdf) is created every time the knowledge-acquisition forms are saved. Through this file, domain knowledge is conveyed and shared.

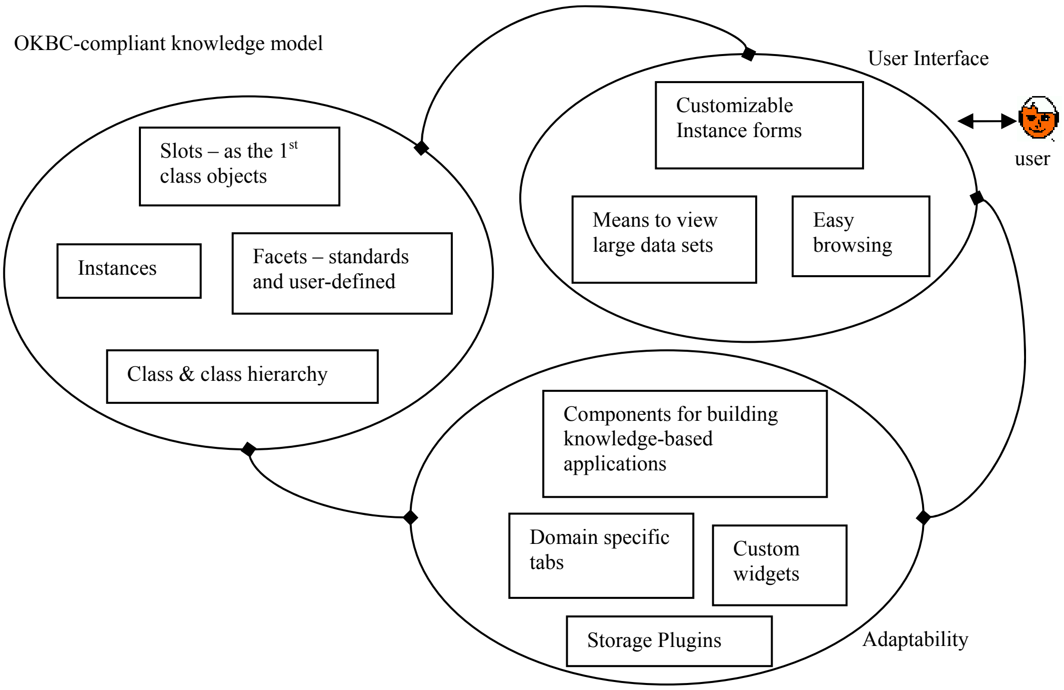


Figure 8.2: The component-based architecture of Protégé.

8.2.2 Sesame

Sesame 1.0 is an open source RDF/RDFS based storage and retrieval system. It was a research prototype for the EU research project On-To-Knowledge. It is now developed and maintained by a company called Aduna (http://openrdf.org) in cooperation with NLnet Foundation, the developers of OntoText, and a number of volunteer developers who contribute ideas, debug reports and provide application fixes. Sesame allows the user to interact with an RDF description using powerful query languages. It is a persistent RDF(S) storage that internally stores data in a relational format, and is able to support multiple run-time queries much faster than a plain-text representation such as the rdf data file would be able to.

Sesame is adopted as the continual RDF(S) based repository for the demonstrator. Within the demonstrator, Sesame stores the underlying ontology model (a combination of models of meeting minutes, discussion contents, project and project-team) as an RDFS, and the instances of the ontology concepts as RDF facts (RDF – data file). Sesame supports expressive querying of RDFS and RDF data by means of a querying engine for the RQL query language (detail see Broekstra & Kampman, 2001).

Sesame is chosen above other comparable tools (e.g., *RDF Suite*[5] and *Jena*[6]) because of the most recent "inference-centric" updates of RDF, and some features of its original query language, SeRQL (RQL in Sesame). Given also that the experimental nature of the research project, response time, reliability, and quality of editing interface do not play a crucial role in choosing this RDF(S) based persistent storage. Lack of a mechanism to allow the user to organize the uploaded RDF(S) statements into contexts (e.g., the date and time when the statements were uploaded, the person who uploads the statements) is the shortcoming of Sesame that was encountered when the discourse was prepared. This shortcoming is a barrier for its user to structure the data repository to different user defined levels. In our setting for Sesame, we opted for RDBMS back-end to enable easy search in the data repository. An HTML interface for query purposes is developed with pre-fabricated templates.

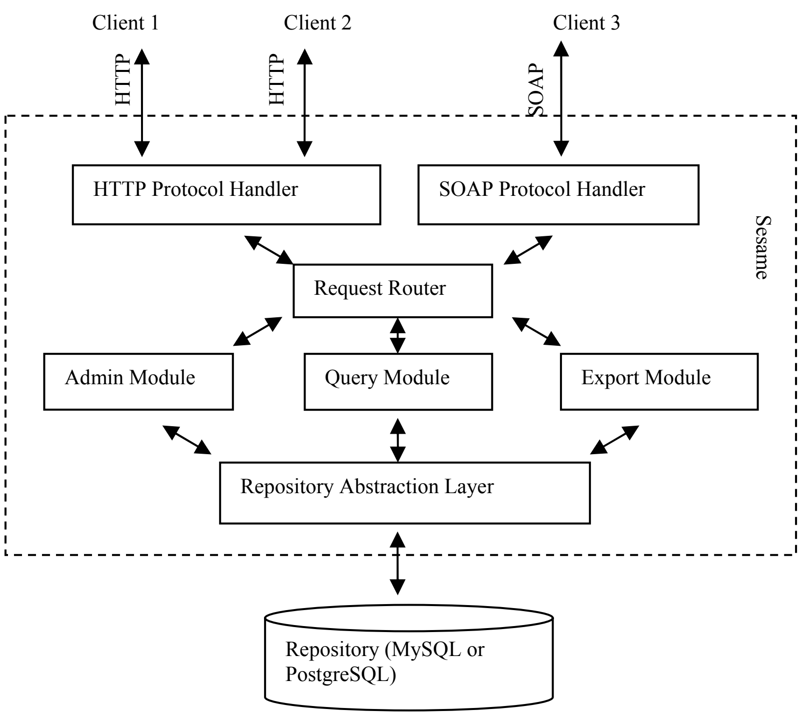


Figure 8.3: The system architecture of Sesame (Source: Broekstra & Kampman, 2001).

[5] http://139.91.183.30:9090/RDF. It is a tool for RDF(S) storage and retrieval developed by ICS FORTH, Greece. RDF Suite supports fast and large queries because of its flexible adaptation of database schema to the given RDF Schema. It also supports full RQL query language and enables dynamic loading of multiple RDF schemas.
[6] http://www.hlp.hp.com/semweb/jena2.htm. A tool developed by HP Labs, Bristol, UK. It offers a user-friendly user interface for creating RDF schemas. It offers an API for other ontology language such as OWL and DAML+OIL. It supports only RDQL query language.

8.3 How does the demonstrator work?

The architecture of the demonstrator is illustrated in Figure 8.4 showing integration of the different tools adopted as the components of the demonstrator. A Protégé applet allows the user to create, browse and store instances - the project-level information. These instances are stored in an RDF data file (*.rdf). The project-level RDF file is saved in the user's local machine. The saved (local machine stored) RDF file can be uploaded to Sesame to be persistently stored and accessed by multiple users. All project level information stacked in the same repository belongs to one organization. This arrangement is done to allow the experiences of previous projects to be efficiently searchable.

A brief overview with respect to the user environment design of the system is illustrated in Figure 8.5 showing the main components of the demonstrator associated with their respective functions. User environment modelling and design, which is based on the concept of the contextual design methodology, is conducted to formalize the functional needs of the demonstrator to be able to perform its task. The user environment design for the demonstrator is illustrated in detail in Figure 8.6 showing all parts of the demonstrator that end user would need to care about, what aspects of work each part supports, and how the parts of the system relate to each other. In brief, the formalism of the representations highlights the key concepts for designing the demonstrator.

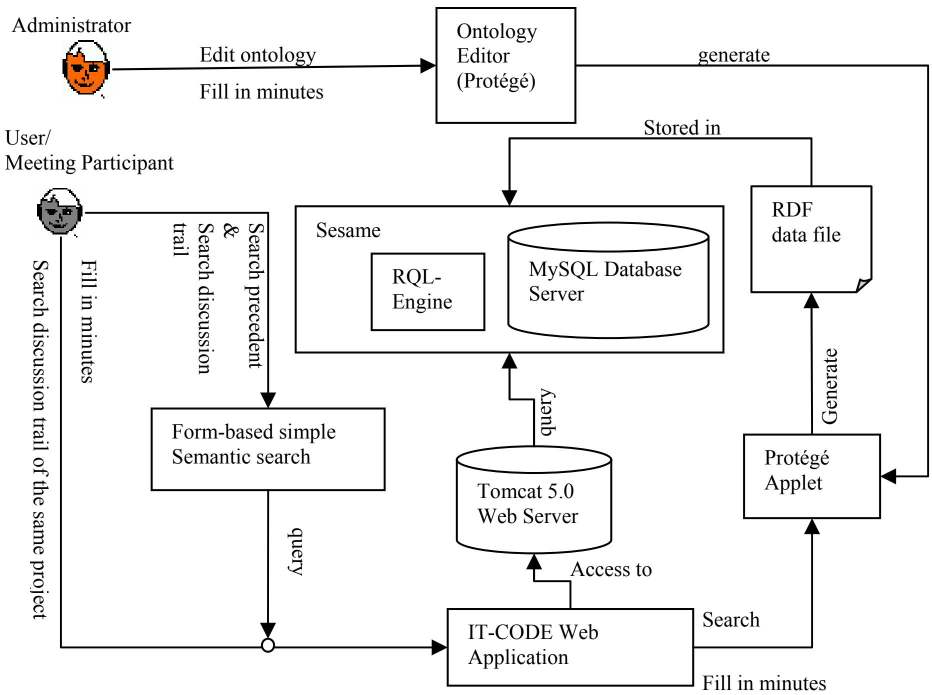


Figure 8.4 Architecture of the demonstrator.

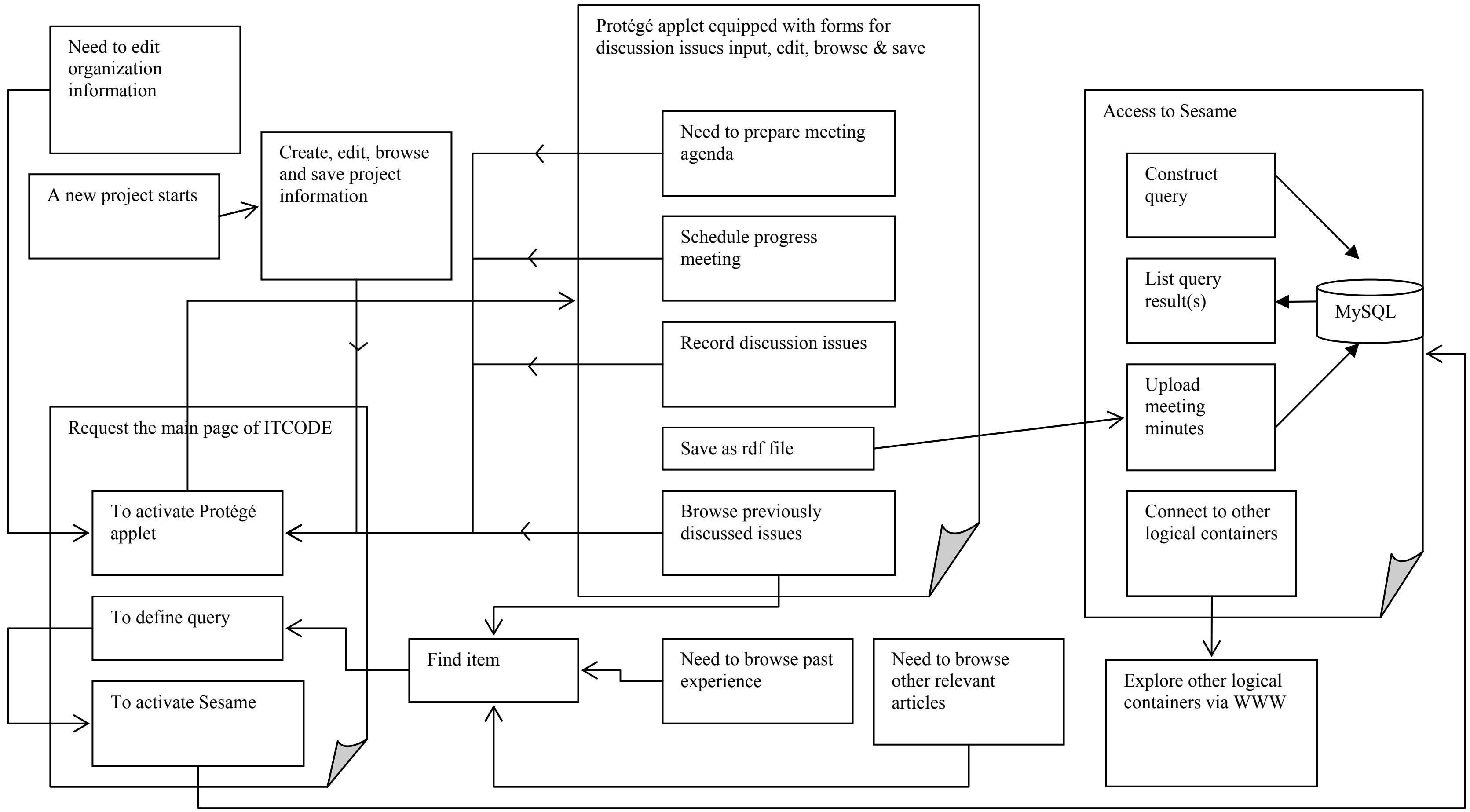


Figure 8.5: A simple storyboard of the prototype system.

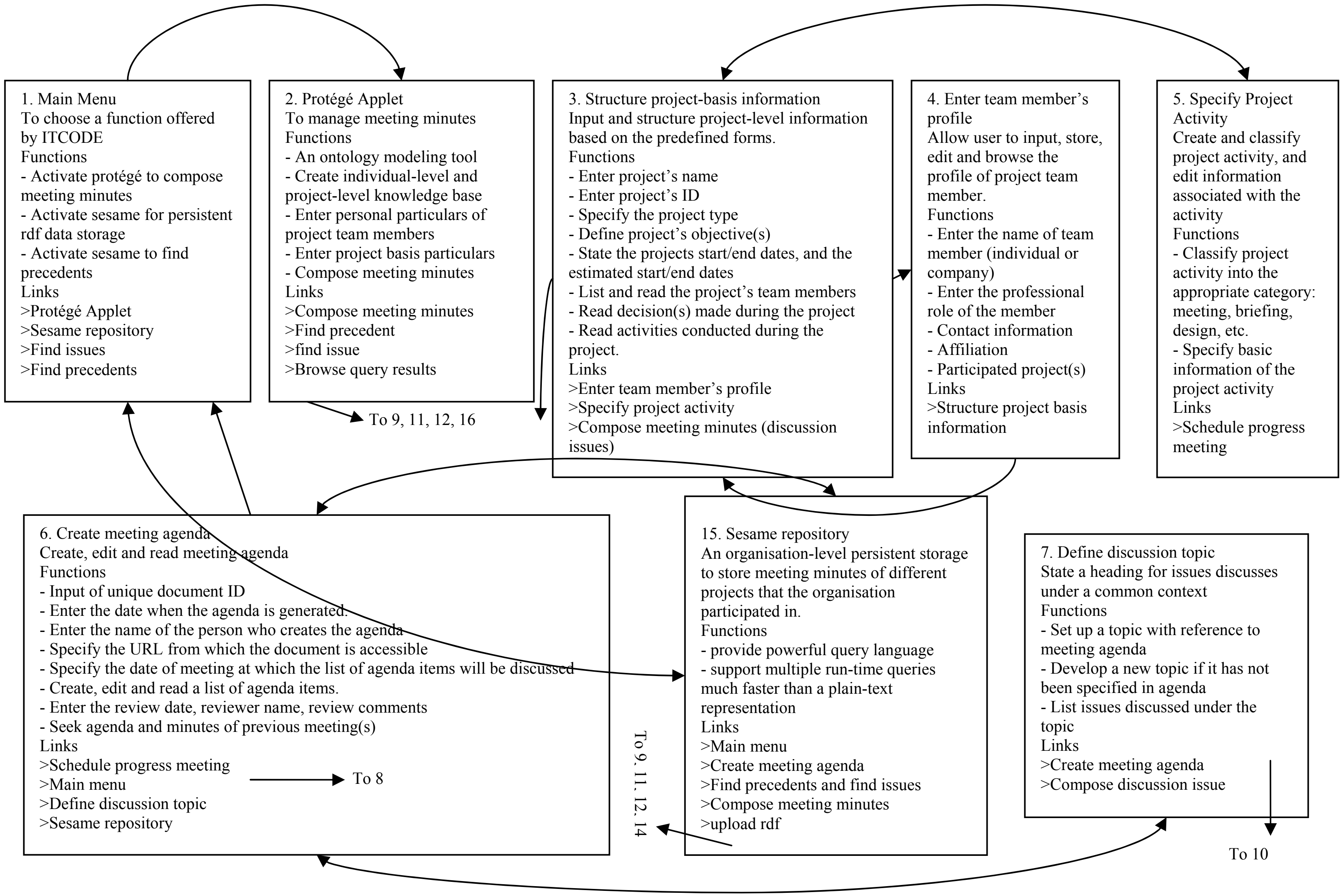
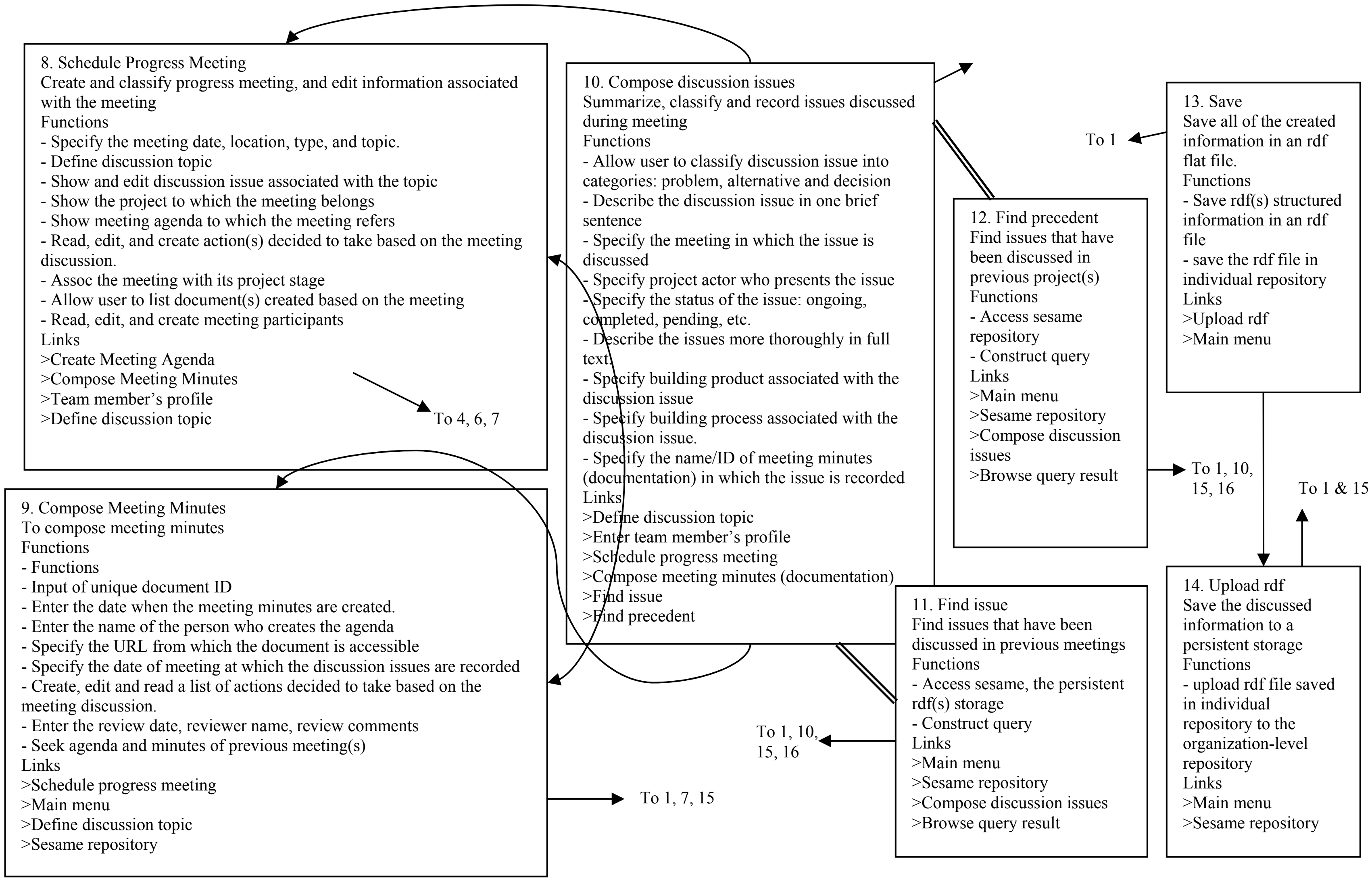
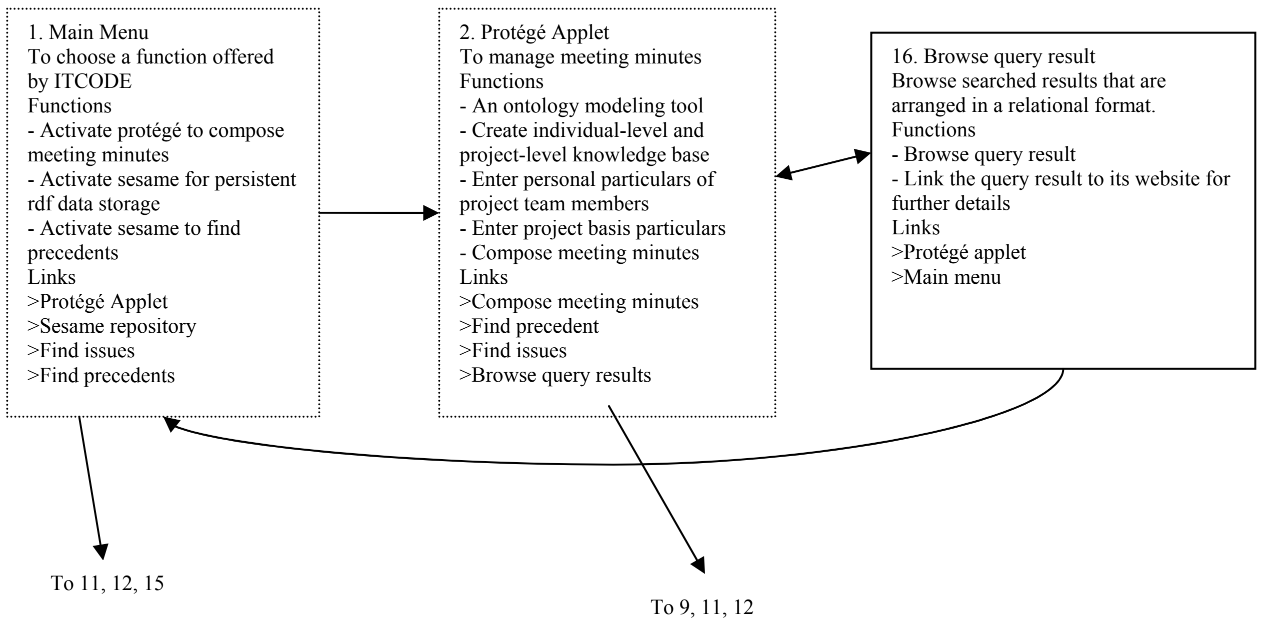


Figure 8.6: Artefact models from the User Environment Design of the Prototype



Continued from Figure 8.6.



Continued from Figure 8.6.

8.4 The Usage Scenarios of the Demonstrator

The demonstrator is devised to be shareable via the Internet or Intranet. In Figure 8.7, three usage scenarios are depicted to explain the fundamental interactions among the actors (users) and main components of the demonstrator. The three scenarios are delineated in further detail below from Section 8.4.1 to Section 8.4.3.

8.4.1 The data input scenario

This is a scenario to illustrate how the actors (users) and the demonstrator interact in achieving a goal-oriented activity, which is to input data/information into the system (the demonstrator). The information of interest is among others the project profiles, project-team profiles, meeting particulars and/or the discussion contents of meeting to the system. The user may first activate the Protégé applet found at the main page of the ITCODE website. The form-based user interface as shown in Figure 8.8 (a, b, c) is designed with reference to the metadata defined in the underlying ontology model. Having filled in the form, the filled in information is annotated with the defined metadata. The annotated information is saved as an RDF data file (*.rdf). The RDF data file could be uploaded to the Sesame repository for persistent storage, archived on the personal computer system of the user, or disseminated via other communication means such as e-mail.

The demonstrator also supports another user interface allowing the user to graphically model the trail of ideas. This is a function devised to contextualise information through graphical modelling by overlaying the interpretation of contents based on the semantic network derived from the underlying ontology model. As illustrated in Figure 8.9, this user interface is given the name contextual map, allowing users to model the semantic relationships between information graphically by binding the different sets of annotated ideas with context dependent relations. With reference to Figure 8.9, <*Solution*> and <*Problem*> were two of the examples of metadata used to annotate the information contents, and *is_solved_by* was the example of relations used to disclose the semantic relationships between information instances categorised under these two metadata. In brief, this function is regarded as a knowledge authoring approach that may reduce the time users need to digest the non-relevant information by disclosing the semantic relationships between information graphically. In this respect, the user could thus be able to manage information of interest more efficiently.

8.4.2 The Discussion Trail Query Scenario

The user may search discussion trails archived for a particular project by activating the Protégé applet. The simple user interface supported by the Protégé enables the user to construct a simple query for inquiring for information with reference to the RDF data file archived on his/her personal computer system. As illustrated in Figure 8.10, a query for searching all issues that were discussed in a meeting on a specific date, say 25 November 2003, was constructed by narrowing the searching scope based on the underlying ontology framework. The searched results were displayed at the side bar, and by clicking on each of them, the user could acquire the contextualised details of the issue.

8.4.3 The precedent query scenario

The demonstrator also allows query precedents archived from previous projects. The goal of this search activity can only be achieved when the user (actor) interacts with the Sesame repository component. This is because the Sesame repository is where the hypothetical dynamic meeting minutes archived from different projects are accumulated. Meeting minutes of every single individual project, which are structured in RDF data files, are uploaded to this RDF(S) based persistent repository (Sesame) for cross-project knowledge sharing.

The user could construct either a simple or more complex query by filling in the form-based user interface as illustrated in the upper part of Figure 8.11. This form-based query user interface is the front-end portal through which the user can access the inherent SeRQL search engine of the Sesame component (see Figure 8.3). Specific search results could be expected from the complex query search when the user explicitly defines the search scope. The user could choose the context to which the search is related, for instance, the professional discipline on which the discussion was conducted, the project stage in which the discussion was carried out, and the causal relations between issues (Issue is also a concept defined in the RDFS ontology model of the demonstrator) that have been discussed during a specific project. At the time of writing this thesis, a simple HTML form-based query template is available to assist users without much knowledge of the complicated syntax of the query language (SeRQL) build a search query. An alternate text box user interface (upper right window) is also available for users who are knowledgeable in the SeRQL syntax to construct more complex query. A query that is programmatically constructed from the form interface will also be shown in the text box to serve two purposes: 1) to allow double checking of the search query, and 2) to educate the users about the query syntax. The query imposes a semantic search upon the RDF triples (statements) stored in the Sesame repository. Instances of the concept "Issue" that match the pattern of the stored RDF triples will be returned in the lower window as the search results. In brief, the complex query handled by the SeRQL allows effective search through pattern matching along the path defined in the RDF triples based on their corresponding RDFS (ontology model).

The search engine can display its search results as lists of URIs organised in RDF triples (see the lower part of Figure 8.11). The search results are displayed simultaneously with some ontologically related metadata conforming to the inherent structure derived from the underlying ontology. In other words, the RDF triples of the instances of search query are displayed based on the underlying structure of *subject*, *predicate* and *object*. Such a presentation mechanism provides the user with a deeper understanding about the contextual belongings of the search results. Listing the selectable properties and concepts (classes) is also considered as an alternative applied to overcome misunderstanding. Such listing is a means to summarise the structure of the selected ontology so that users are certain that a search is on the right path. Thus, users could avoid spending excessive time in browsing irrelevant information compared to the apparent shortcomings of the conventional keyword search.

Each of the search results is a universally unique resource pointer via which the electronic information of interest is retrievable provided that the corresponding repository (the logical container where the searched result is stored) is Internet accessible and possesses the content. Under these circumstances, it is no longer necessary for information to be stored in one centralised repository as practiced by the interviewees of the case studies.

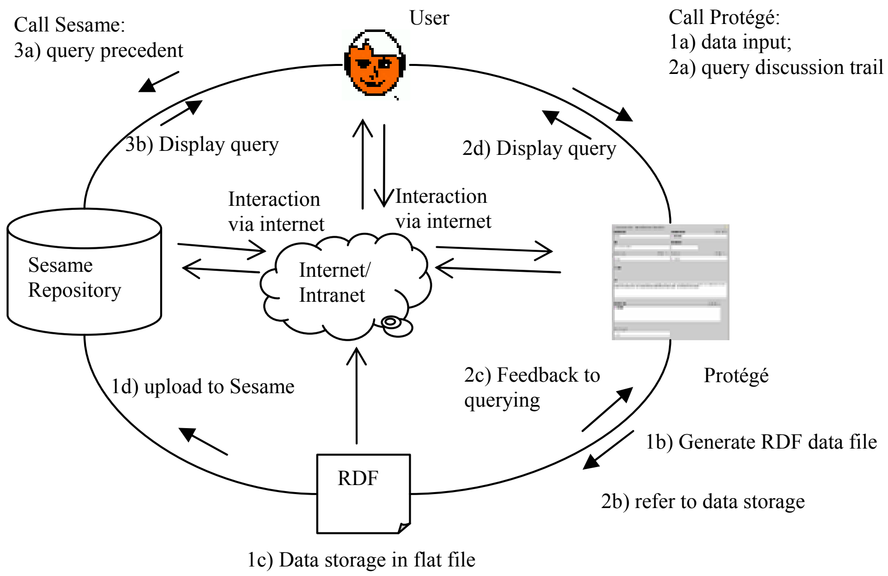


Figure 8.7 The cycle of three different usage scenarios supported by the demonstrator.

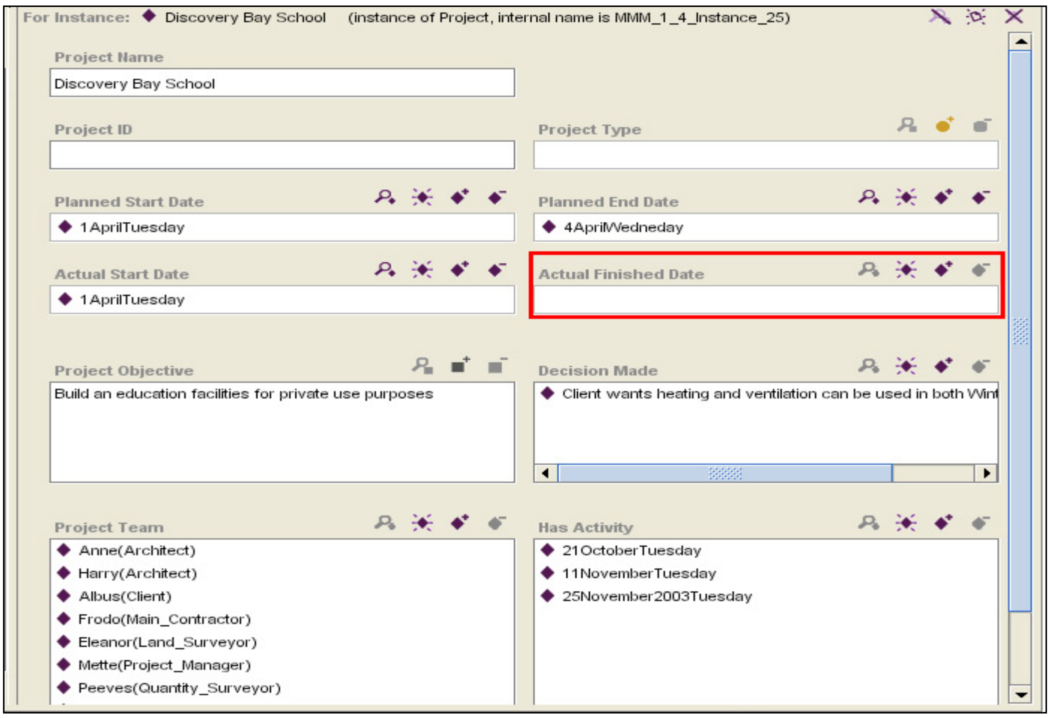


*Figure 8.8a: The form-based user interface supported by the demonstrator to generate dynamic and semantically structured meeting minutes: **for information related to project attributes** (e.g., project name, project start date and planned finishing date, list of project members, list of project activities including progress meeting, and so forth.*

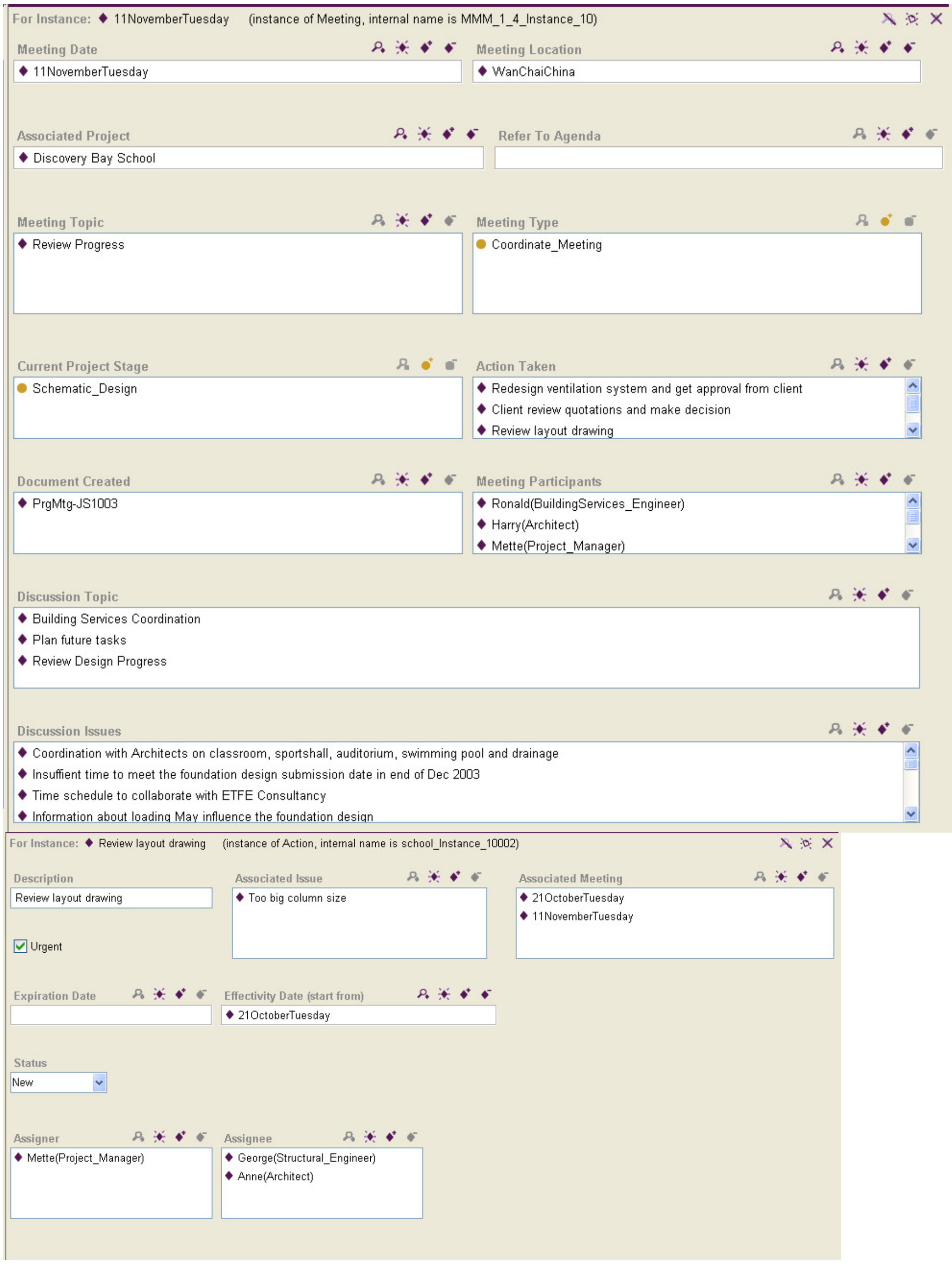


*Figure 8.8b: The form-based user interface supported by the demonstrator to generate dynamic and semantically structured meeting minutes: **for important meeting attributes**. The upper form collects meeting attributes such as meeting date, meeting purpose, meeting participants, topics of discussions conducted, actions agreed to be taken, and so forth. The lower form is a sub-form that pops up when user instantiates the agreed action using the "Action Taken" form field. In the lower form, the user may fill in information including the action assigner and assignee, respectively.*

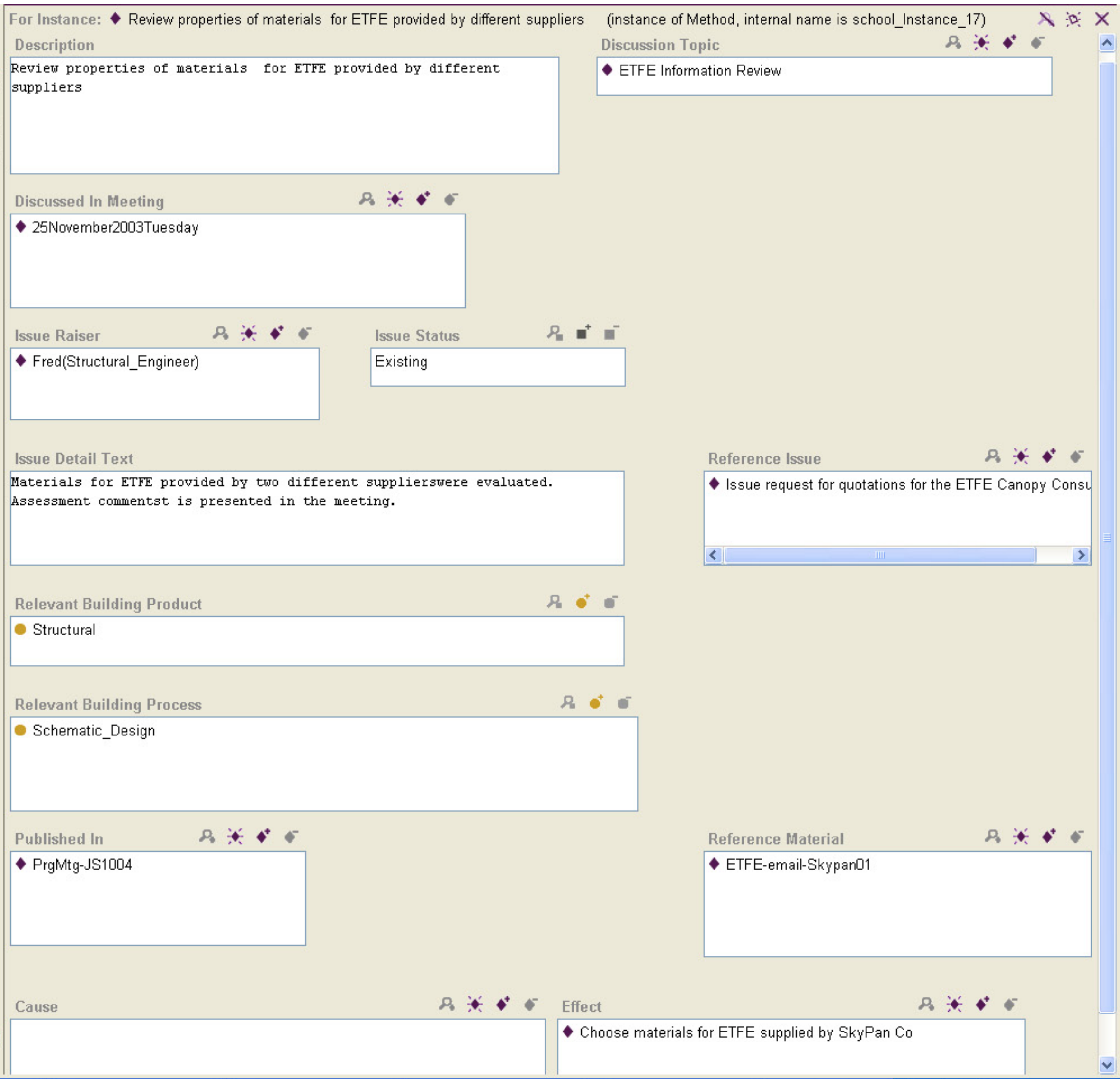


*Figure 8.8c: The form-based user interface supported by the demonstrator to generate dynamic and semantically structured meeting minutes: **to contextualise issues discussed in the meeting**. This is the form in which discussion contents can be structured accordingly to different contexts as described comprehensively in "Section 7.2: The Rationale behind the Annotation Approach of IT-CODE". The annotated information creates the information trail (e.g., the "cause" and "effect" fields are devised to make explicit the causal relations between discussion issues) that may reduce the user's interpretative tasks.*

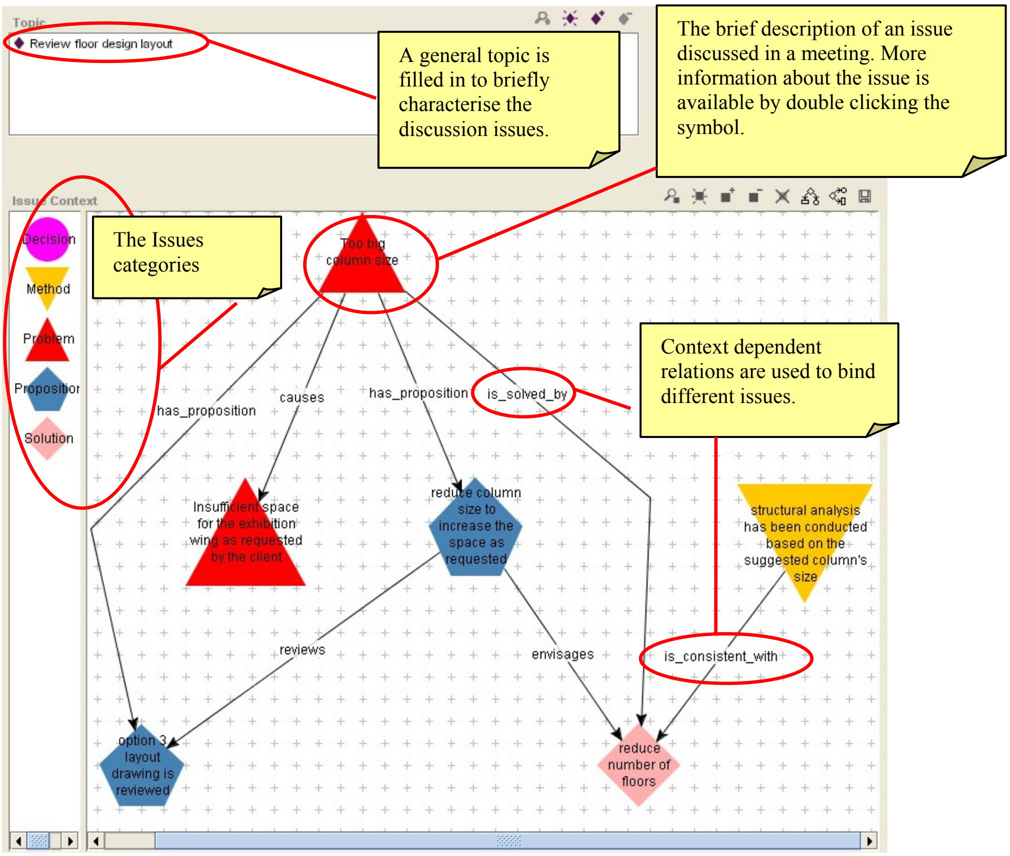


Figure 8.9: The Contextual map feature supported by the demonstrator as a means to make the relations between issues explicit based on reasoning derived from the ontologies network.

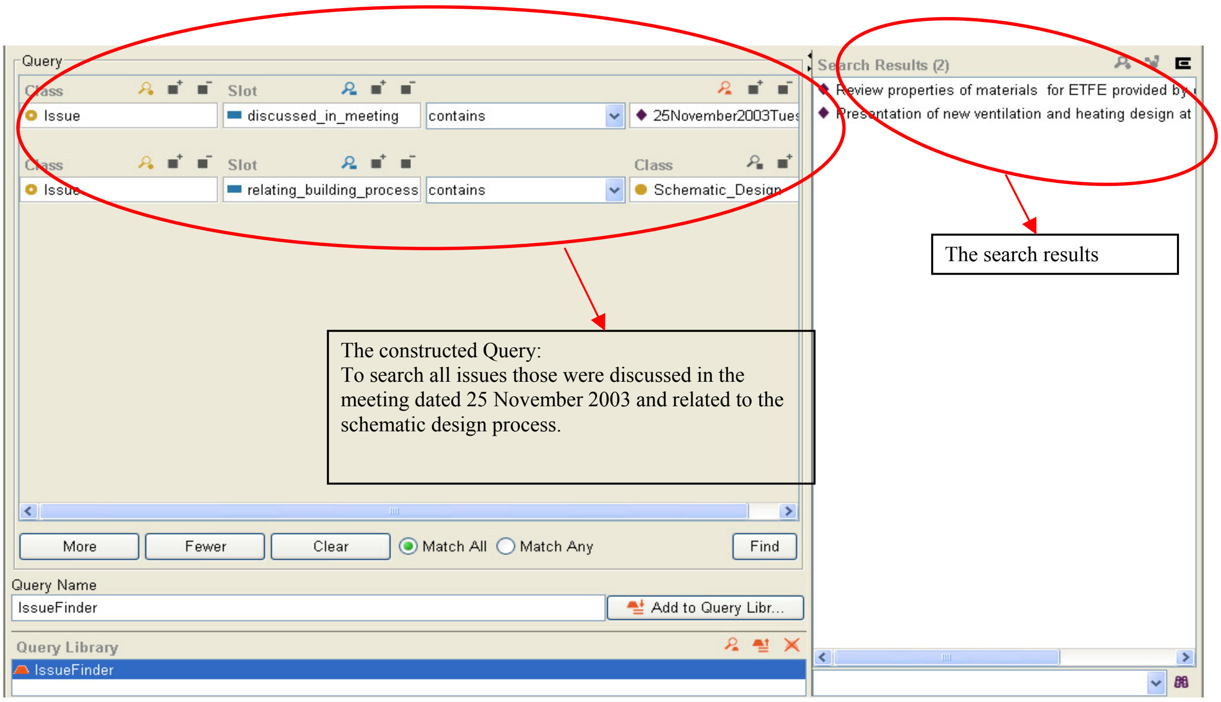


Figure 8.10: The form-based user interface for the discussion trail search (restricted to only project-wise information search and applicable only in Protégé)

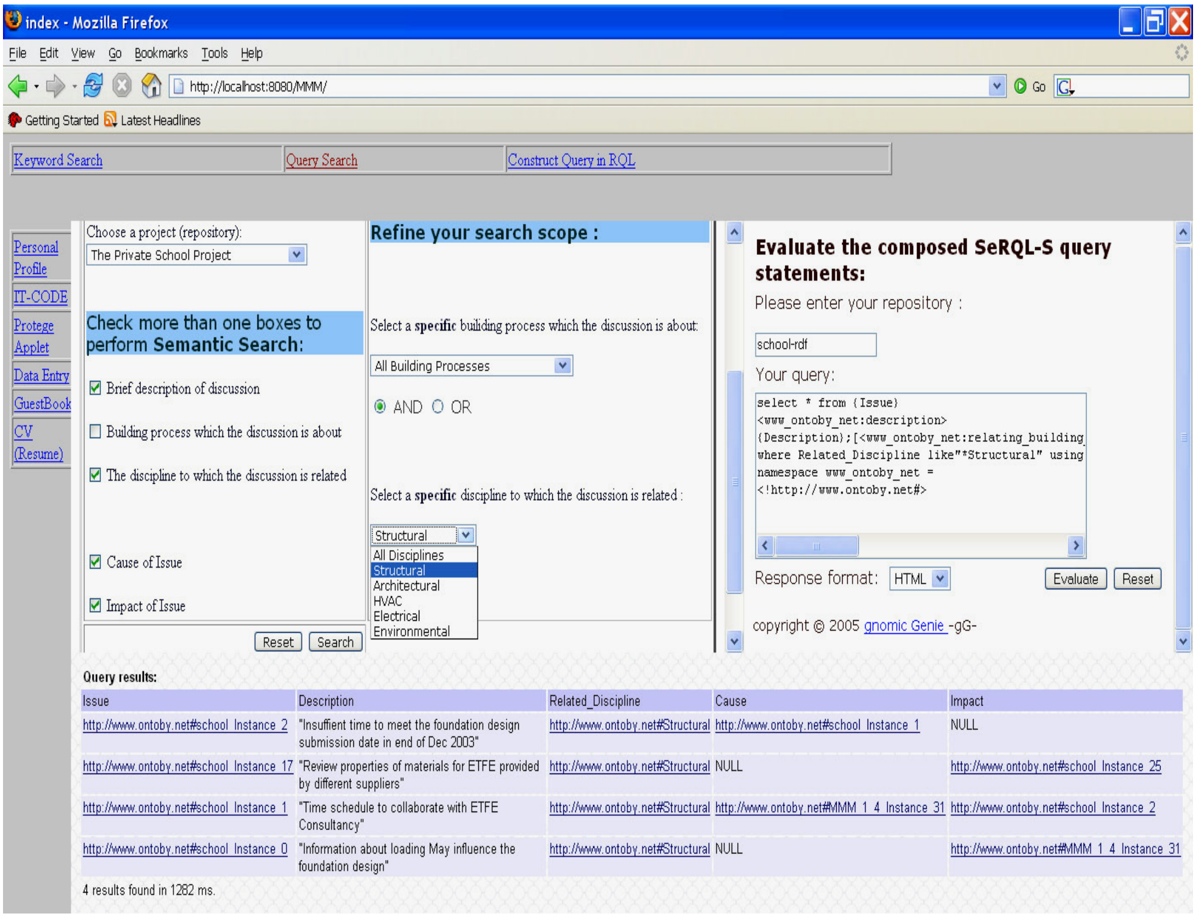


Figure 8.11: User Interface (UI) of the Semantic Search and the associated Search Results. Complex queries (the upper right frame) can also be built. The searched results are displayed as lists of URIs.

8.5 Evaluation and Discussion

The undertaken case studies have led to the development of the demonstrator, a prototype in its very infancy, which attempts to test the formulated hypothesis whether the Semantic Web can contribute to the collaborative design knowledge management. A user-centred development methodology was used as guidelines in planning the demonstrator development process. Having analysed the current prevalent practice of the informants of case studies (users) through several interviews and observations, a conceptual model of the demonstrator was shaped based on a metaphor, which illustrated how meeting notes were documented, disseminated and used.

The user-centred development approach was, however, not applicable throughout the entire development process, in particular at the stage of implementation and evaluation, respectively. The informants in the case studies, which were also the targeted users, were not fully involved throughout the evaluation and implementation stages. The reasons for this were two-fold:

- The case studies were conducted based on an objective, which was to examine design information flow and its management as well as how the design team members effectively communicate amongst themselves during a decision-making process at the early design stage of a building project. One of the big constraints of this research study was to find a new building design project for performing the observation study. The reasons for this were a) most of the design teams could find an observation study obtrusive, and b) the discussion contents at the early design stage could be perceived as highly confidential, in particular from the commercial perspective, by most of the design teams.

- A series of continuous observations in order to follow the entire early design phase of one project was another constraint encountered in this research study. Since the design team under study could gain no direct benefit from the study, such continuous observation studies were not encouraged by the project client. Time was another constraining parameter, because the author would not be able to sit in on all meetings conducted throughout the early design phase that could last for several months or even a year. In this respect, feedbacks from informants who were also overwhelmed by their respective workloads were thus another unrealistic expectation.

An evaluation helps clarifying the users' needs. The goals of the evaluation can include determining the best method for a conceptual design; fine-tuning the interface; examining how technology changes working practices; or informing how the next version will refine an existing product.

The demonstrator was evaluated by the author according to its functional requirements at the time of the writing of this research discourse. The reasoning structure of the demonstrator was evaluated by populating instances to the underlying ontology model via a form-filling interface. The SeRQL-based semantic search was evaluated using a "Quick and Dirty" (Preece et al., 2002) evaluation paradigm in which observing and questioning users were the implemented techniques. Several search scenarios as given in the following examples were outlined as the goal-directed tasks for the functional requirements assessment purposes:

"Say Bob wants to know all the issues related to structural design that were discussed in Project C. Very quickly, he just input the name of Project C to access the ontologies (RDFS) built. A list of choices in relation to the different professional disciplines involved in the project is then displayed in the drop-down list box to assist Bob in searching the information of interest. By choosing the option "Structural_Design", a simple query whose search scope has now been narrowed is constructed opaque to Bob. By pressing the "Submit" button, the constructed query will be shown to Bob in a Text Area (text box) to the right of the search form. Bob may double check the constructed query or just ignore it and continue the search process by pressing the "Search" button located below the text box. The search result is then displayed to Bob. The result consists of the issues correlated with structural design that were discussed since the beginning of Project C up until a particular date."

"Bob now wants to find all Project B documents concerning space planning that were finished before 29/3/200, the stakeholders who contributed in the planning, and where, respectively, these documents are stored. Bob needs to choose the project-specific ontology by inputting the project name, i.e. Project B. His next step is to construct a query by choosing a project stage that he is interested in. He may then input such information as "Search documents and authors of documents with keyword of space-planning and the cut-off date of 29/3/2001"to the text box to construct a precise query. The requested answers are then displayed and associated with the respective URIs of the document."

The demonstrator remains at its conceptual and pre-matured stage to be evaluated from the non-functional requirements aspect. There is actually no definitive list of non-functional requirements because they are domain specific and are only identified as the system is implemented. Usability, scalability, extensibility, performance, security, maintainability, security and reliability are, however, among others the most prevalent non-functional requirements to be incorporated in a system (e.g., a software application). A brief discussion with respect to the non-functional requirements assessment as in the following was given to provide the basis for a detailed evaluation plan as the next developmental phase of the demonstrator.

Usability is defined by ISO as "a measure of the effectiveness/effectivity, efficiency, and satisfaction with which specified users can achieve goals in a particular environment" (ISO 9126, 1991). Usability is further elaborated by Jakob Nielsen (Nielsen, 1993; 2005/1994) as methods for improving ease-of-use during the design process. Usability consists of five prevalent quality attributes, which are learnability, efficiency, memorability, errors, and satisfaction (Nielsen, 1993). In other words, usability is an important criterion that supports the users staying on task and not being unnecessarily distracted with interface issues. Usability is a parameter for a system to constrain the complexity and variety of metaphors and techniques which the system could use to provide user support.

The demonstrator was found by the author to be adequate to perform the predefined functional tasks, but was relatively insufficient in the usability aspect. For instance, the demonstrator at its current stage requires a few improvements to effectively and efficiently meet the functional requirements due to the poor design of system coherence. The system user was presumed to be a knowledge worker that possessed good ICT knowledge, and was familiar with the different demonstrator modules. The different modules were not well integrated to form consistent bi-directional connections, which resulted in obvious fragmentation of communication flow between modules. For instance, there was no direct communication bridge between the Protégé and Sesame repositories, and RDF(S) files could only be uploaded manually and repeatedly to the Sesame repository because an automatic update feature did not exist. The lack of a communication bridge occurred because the Protégé and Sesame architecture could not be integrated. The reason was that both Protégé and Sesame use RDF(S) file, but Protégé uses an old namespace version of RDF(S) compared to Sesame. Additional effort, which itself could lead to another new research project, would be needed to export RDF(S) from Protégé directly to Sesame by communicating with the respective modules of Sesame. This effort would involve a series of complex data conversion and matching processes before the communication channel between Protégé and the different functional modules of the Sesame server could be established. However, this has good potential for future development in which a change in the architecture of the demonstrator is necessary.

The form filling interface, which is the main knowledge input portal to the demonstrator, also plays a significant role influencing the system effectivity/effectiveness for tacit knowledge capture. Work culture and human behaviour, from which the work culture is derived, are the biggest impediments to knowledge capture, particularly involving the processes of tacit knowledge externalisation and transfer. Users may find that filling in forms is a tedious and inflexible task that may discourage inspiration for new ideas. In order to fill-in the forms, users need extra cognitive efforts to organise their mental models with reference to the on-screen instructions supported by the predefined form structure. This is the biggest challenge to the work culture, which has been developed for years using the sequential essay writing technique for documenting meeting minutes. The reluctance of human behaviour to change will decrease the user's motivation to fill in the forms.

Ambiguity with respect to the classification of information contexts may confuse the user particularly when the users try to sort through the different ideas/issues that are raised, discussed and evaluated in meetings and place them into the predefined contexts, such as "Problem", "Method", "Proposition", "Solution" and "Decision". The same issue discussed in meeting can be classified to more than one context at the time of discussion, for instance, a proposition could also be a method that could solve a problem (and thus it is also a solution). Though this concept of ambiguity was one of the functional requirements for the demonstrator, a novice user, particularly one who lacks experience in object-oriented thinking may find it difficult to understand and thus will not be motivated to use the system. In brief, the effectivity of the demonstrator to meet its functional requirements can be improved in various aspects as discussed above. Investigation with respect to improving the human-machine interactions is suggested here as one of the research objectives for the future development plan.

Learnability, which can be defined as the speed at which a new user can become proficient with the system, is another requirement that needs to be assessed in the future. A system with good learnability requires the most important functions of the system to be salient and visible to the user (Eisenstadt et al., 1990). Further refinement on the demonstrator in the aspect of system coherence is required in order to attain a satisfactory level of learnability for the end user.

A system with high scalability should be able to handle large problems. Usability and scalability are best assessed through direct user evaluations based on an evaluation plan that includes preliminary user studies, as well as a heuristic evaluation of the interface. The demonstrator had not reached the stage for direct user evaluation at the time of writing.

Use of formal ontologies as the knowledge framework has indicated a potential of high extensibility. Ontology is a knowledge management approach incorporated with the features of both the top-down and bottom-up knowledge representation principles. The drawbacks identified from both the top-down and bottom-up approaches have encouraged the use of hybrid knowledge-management strategies in which both approaches are implemented and are complementary to one another. Based on its inherent characteristics: extensibility and flexibility, ontology has become an alternative which itself can be designed top-down and bottom-up simultaneously. One of the significances of ontology (which is RDFS-based in this research study) in terms of extensibility is that new components could be added in at any time point without dismantling the whole knowledge structure, as otherwise usually occurs in the top-down knowledge management scenario.

Customizability is a criterion measuring how well a tool allows an end-user to customize a tool's function support to his/her needs. Using protégé in the demonstrator was an advantage when addressing the customizability goal because it allowed the creation of a user-modifiable ontology. Modification on the ontology allowed the application (meeting minutes) to be customizable by either end-users or their technically proficient colleagues (says the administrator or the project leader).

8.6 Concluding Remarks of Chapter 8

As the user interface aspect of this demonstrator is not in the main focus at the current stage, the author decided not to program an exhaustive interface, but instead reuse existing technology, preferably free open source tools. The chosen tools are two among others that are dedicated to support the current fast developing Semantic Web. Both of these tools, Protégé and Sesame are being developed and maintained by their respective dedicated technical communities. They provide the basis for allowing further development of new applications either as plug-ins or standalone tools. Protégé was chosen mainly because of its useful and easy-to-use graphical user interface (GUI), and its RDF files generating capability. Sesame has an adaptable server functionality that allows the storing and the retrieving of large amounts of RDF-based data in many-user environments while allowing the use of complex queries and inferencing.

Although the two tools were not well integrated at the current stage of this demonstrator at the time of writing this thesis, a number of improvements in this aspect were, however, noticed feasible in the future development phase in order to attain a higher level of system coherence.

9 SUMMARY AND CONCLUSIONS

It's a job that's never started takes the longest to finish.

--J. R. R. Tolkien --

This thesis investigated how collaboration and knowledge transfer in design teams can be supported by the Semantic Web technology. The author hypothesises that an infrastructure can be developed to change the notes taking approach, which has been conventionally practiced for recording the discussion contents of a meeting. The hypothesized infrastructure has the ability to model and analyze the discussion contents based on an underlying ontology model so that the discussion contents are organized in a semantic-based network. A demonstrator was devised to demonstrate how the ontology model can make the connections between ideas/information stored in different documents explicit, and enable novel and powerful queries of these stored design ideas.

There is always a fuzzy distinction between knowledge and information. Excessive information may result in information overload while insufficient information may increase the risk of forming knowledge with distorted meaning to some extent. This thesis attempted to examine the roles of both information and knowledge during the design stage within the A/E/C community. The study started by analysing the prevalent information flow of design teams through several case studies in an attempt to understand to what extent design information is managed to be reusable as knowledge. In this thesis, several centralized web-based project information management systems were analysed by the author (see Chapter 5). Each of the centralised web-based project information management systems under study is, respectively, the typical example of groupware that has been practised in the A/E/C sector. In the author's opinion based on the analysis of the case studies results, the studied web-based applications are not the definitive solution for total knowledge management.

The study findings revealed that the web-based information management system is one of the external memory sources to which the practitioners within the A/E/C industry have attached in an attempt to facilitate collaboration via sharing project information including the design information. Such information management systems were criticized as inadequate to provide efficient knowledge sharing. This is based on the argument that the studied web-based information management system usage is restricted to sharing only codified knowledge while neglecting the importance of tacit knowledge. This argument was presented based on thorough studies with respect to the underlying technologies of web-based information management systems implemented in the case studies. This finding thus postulated a total knowledge management approach, which would broaden its coverage to manage the prevalently neglected intangible design knowledge in a way that future reuse and sharing are plausible.

The total knowledge management approach was founded on the principle that knowledge is gained via abstraction of information. There are to this date many different definitions of what knowledge management is. Tacit knowledge has become an essential aspect in understanding the concept of knowledge management.. Making explicit the tacit knowledge, which is a term introduced by Polanyi (Polanyi, 1983) for knowledge that exists in the form of know-how and cannot be codified, but can be transmitted via training or gained through personal experience, has now become a popular concern in many information-driven industries including the building industry. Making the tacit design knowledge (see Chapter 4: Section 4.5) explicit before it was disseminated and stored, was thus one of key challenges addressed in this thesis.

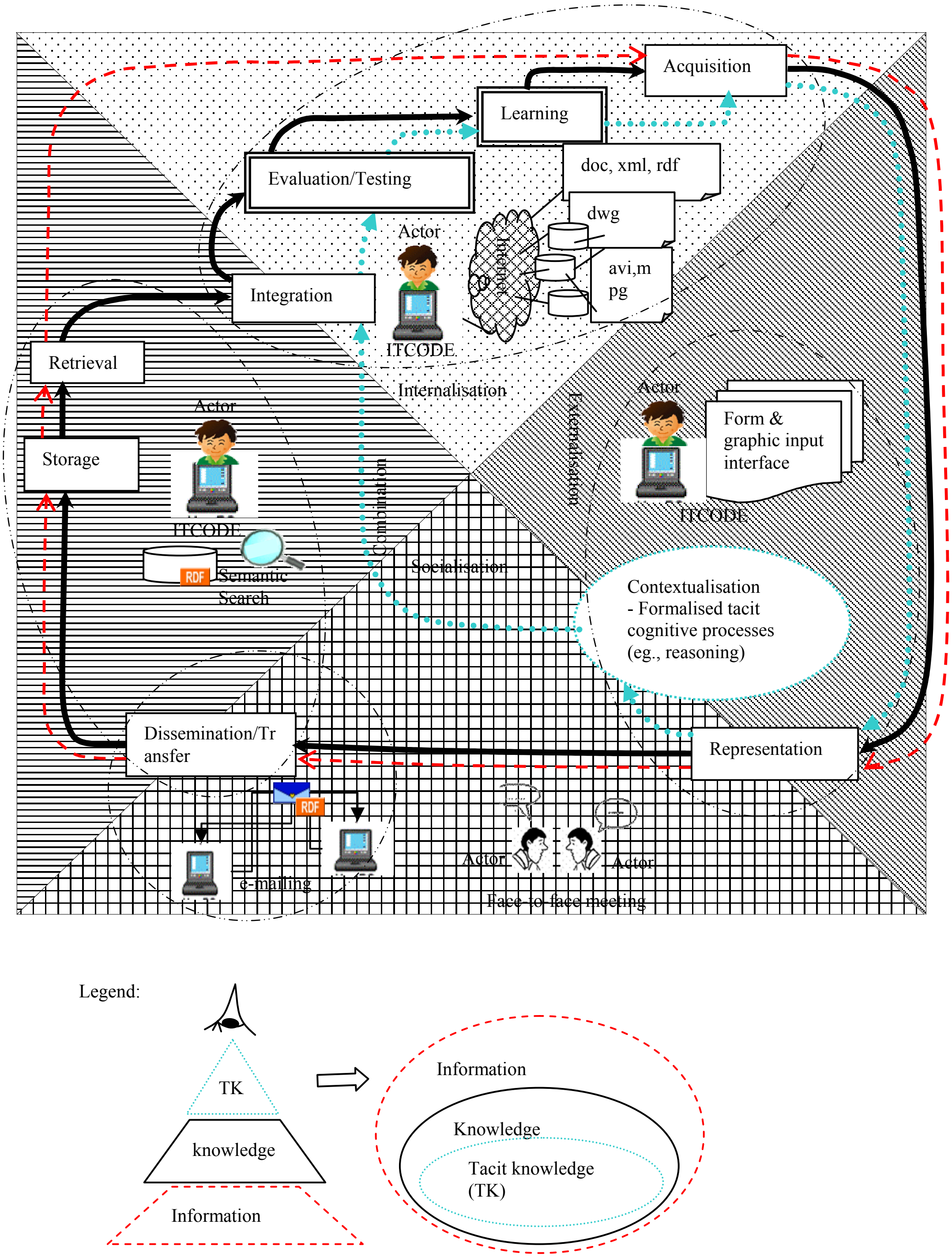


Figure 9.1: The proposed total knowledge management cycle supported partly by the demonstrator.

Figure 9.1 illustrates the conceptualisation of the total knowledge management approach, which is aimed at supporting total knowledge management, including the tacit knowledge. The four knowledge transformation processes formulated by Nonaka (Nonaka et al., 1995), in which knowledge is transformed between tacit and explicit forms, were the underlying framework of the total knowledge management approach. These four processes, which are internalisation (from explicit knowledge to tacit knowledge), externalisation (tacit to explicit), socialisation (tacit to tacit) and combination (explicit to explicit), do not occur in isolation, but work together in different combinations in daily activities and business situations with or without using ICT. Total knowledge management formed a cycle of several key aspects as shown in Figure 9.1. Each of these aspects was discussed comprehensively in its respective section of this thesis. Since total knowledge management was to complement prevalent information management, it was thus established on the basis of information management which is shown by the *(red)* d*ashed* arrows in Figure 9.1. Apart from performing tasks of disseminating, storing and retrieving knowledge, total knowledge management, as shown by the (*black) full* arrows, was proposed to support evaluating as well as incorporating (integrating) information and past experiences to facilitate the learning process that would lead to the creation (or acquisition) of new knowledge. Contextualisation, as shown by the (*blue) dotted* arrows, was the key aspect devised for the demonstrator to support more efficient knowledge and information integration. Thus, the internalisation and externalisation processes, which involved tacit to explicit knowledge transformation and vice versa, could be facilitated.

The key issue of total knowledge management, as suggested in this thesis, was knowledge representation. An *ontological knowledge representation approach* was the main focus in this research study because of its inherent characteristic to represent knowledge by constructing statements of triples that could express the semantics of the represented knowledge explicitly. The contribution of Semantic Web technologies, which are closely associated with the ontological knowledge representation approach, was tested in this research study in order to find an alternative for the A/E/C industry in managing the design rationale and reasoning behind design decisions. This is an alternative that would provide more efficient accessibility, comprehension, learning and reuse.

Having identified the usability of the Semantic Web technologies, a novel concept was proposed to alter the conventional document-centric meeting minutes taking approach to one that was organized based on a *semantic-centric* structure. The author argued in this thesis that the design rationale and reasoning behind decisions are intrinsically embodied in the discussion contents of the design progress meeting. The discussion contents have been conventionally captured in meeting minutes simply as a piece of plain-text document, which was described as unstructured in the thesis. Sources of design information that were referred to during the discussions were usually specified in this plain-text record. Instead of viewing meeting minutes as a by-product of collaboration activities, minutes should be viewed as having good potential for being an instrument for promoting efficiency in collaboration. Meeting minutes were thus proposed in this thesis as a medium that could be capable of handling effectively the mass quantity of design information by eliminating the extra workload, either real or perceived, of having to use extra applications to run another project-oriented knowledge (information) base.

Another proposition of this thesis was a method that could generalise information in a way that was very similar to *associative thinking*, which is a subconscious practice used by human beings to learn and memorize. This method was incorporated into the novel concept of the *semantic-centric meeting minutes* taking approach by attempting to abstract knowledge from the mass quantity of information produced throughout the design process. The ontological knowledge representation approach, associated with the chosen semantic web technologies, was in this respect playing a significant role in shaping the functional features of the proposed semantic-centric meeting minutes-taking approach.

A *demonstrator* was devised complying with the notion of total knowledge management as the basis for testing the dynamic and semantically structured meeting minutes. Several findings could be generalized from this thesis:

1. Meeting minutes would be a reasonably good *medium* for managing design knowledge and information including the tacit design rationale, which is prevalently embedded in discussion contents of progress meetings. Meeting minutes could be an alternative approach applicable to structure, organise and integrate design information and knowledge besides the advanced but rather complex product and process modelling approaches.
2. *Contextualising* discussion contents could be an alternative solution to make the hidden meaning in the contents explicit. Information, ideas, and different issues discussed in a meeting could be organised based on an ontological knowledge representation framework into a tangible form that could support more efficient accessibility, learnability, and reusability.
3. *Ontology* and *Semantic Web* technologies (RDF(S) in this study) were found applicable for establishing an information/knowledge trail, which could facilitate tracking of information from different perspectives based on predefined metadata. The unique namespace feature supported by RDF(S) provides the opportunity to avoid collecting information under one centralized information base. In this respect, digital resources could be scattered in different repositories geographically apart, but yet inter-connectable provided that those repositories are accessible via internet/intranet.
4. *Reasoning* behind decisions made could be captured as easy as filling-in electronic forms. The captured contents could be structured in machine processable formats while also being displayed in semantically rich human readable views. The *machine processable data structure* was found to be important for automatic data/information processing that could benefit for instance the search function of the knowledge base.
5. Metadata are data about data; they are defined to describe data. Thus, *meta-knowledge* is knowledge about knowledge, and it is to describe knowledge. Meta-knowledge is knowledge at a higher abstraction level (see Figure 4.1), which is defined by the author as knowledge an individual possesses to formalize reasoning behind cognitive activity including decision-making, learning, and designing. Meta-knowledge is important during a learning process because it explains how and why knowledge about something was created. In this respect, it could be useful for formalising tacit knowledge. It could be an instrument to facilitate tacit knowledge transfer from one individual to another. It is thus an important stage for an individual to progress through before adopting and adapting new knowledge as own knowledge and/or furthermore converting to wisdom. However, this research study found that formalisation of reasoning used to be neglected in the documentation process. Under such circumstances, the key for creating new knowledge could be lost while the recorded reasoning results might have only limited reuse value in the future. A properly modelled ontology framework was found devoted to represent a meta-knowledge structure. Based on the ontology model established for the demonstrator delineated in this thesis, relations between different concepts were developed to construct a "mindmap" in which trails of reasoning were reflected. The reasoning trails were found capable of giving a glimpse of the relevant discussion context expeditiously so that the procedures with respect to keeping track of reasoning behind the decision as well as design rationale were simplified. The author would thus conclude that the demonstrator at its current primitive stage was functioning adequately to demonstrate how the idea of meta-knowledge could be put into practice.

9.1 Future Research

This research study has demonstrated the potential use of semantic web technologies as an alternative applicable to improving collaboration within the multidisciplinary A/E/C industry in the aspect of knowledge management. A demonstrator was established aiming at demonstrating how ontologies might lay a conceptual foundation, which supports the novel concept of meeting minutes that could serve as intermediaries for knowledge access and sharing across organisations and projects. This research study provides a feasible foundation for a number of opportunities for future research. There are in general two directions to follow: 1) improving the existing approach; and 2) integrating the proposed approach to other contemporary technologies.

One of the propositions of further research following the first direction is to examine the possibility of *incorporating standards for metadata* as proposed by, for instance, the ISO/IEC 82045-5 in the ontology modelling process. ISO/IEC 82045-5 is a developing standard for the use of metadata in the construction industry. This standard provides four metadata sets, and each set directs to a specific phases of the construction process (Lai et al., 2004). This consideration may offer a coordinated strategy for better mapping of metadata between different knowledge management systems. A promising standard may allow expansion of the proposed knowledge management approach to include ifcXML accessibility to the IFC based product model. This would further improve its functionality with respect to information interoperability offering an additional advantage in information tracking and integration, which are particularly important in the early design phase.

The modular characteristic of ontologies is a great advantage that does not delimit the further development directions of the proposed knowledge management approach. The proposed *total knowledge management* (see Figure 9.1) has portrayed two envisioned development aspects, which are to support knowledge evaluation and testing followed by learning. The validity of information or even knowledge is a dependent variable, which is largely influenced by time and various other parameters. Knowledge evaluation and testing as proposed in total knowledge management is a transitional, but vital activity for an individual to assess the validity of the existent knowledge as well as analyzing the suitability of such knowledge for his/her current application. Knowledge evaluation could be carried out through simulation of the decision-making process based on the network knowledge and/or information accessible by the demonstrator. However, the ontology languages used for devising the demonstrator, the Resource Description Framework Schema (RDFS), are not fully capable of representing the more complex logical expressions, which are required to perform the simulation task. A more expressive semantic-web based ontology language is urged to replace the RDFS in the future research. The best contemporarily available candidate for this is OWL (Ontology Language Web) due to its advantages of high expressivity, interoperability and user-friendliness.

At this stage, the demonstrator was developed with the assumption that the building project stakeholders have good knowledge of ICT. It is assumed they are able to create ontology and metadata occasionally to update the semantic contents (collections of ontologies and metadata) of the system after intensive training is given. In particular, future applications will need to integrate more *automatic techniques* – for building ontologies and for providing metadata, and to provide a better system coherence for supporting a higher level of user-friendliness.

Weblog, Wiki, and Bloki (weBlog + wiKi) are among the contemporary web-based information management tools (also called content management tools) that interest different professional communities because of their simplicity to use. In general, these tools share some common features, which enable users to store, find, link and classify documents on the web. These tools, however, use different specific techniques for managing including publishing the web contents. These tools have shown promising results after being extensively used for collaborative documentation of large systems, for instance a news website. They support basic idea management, personal information management and are being tested for integration into the semantic web. Platypus Wiki (http://platypuswiki.sourceforge.net) and Blojsom (http://wiki.blojsom.com) are two examples of the ongoing projects that are to merge the Wiki and Weblog, respectively, with the Semantic Web technologies, at the time of writing this thesis. One of these web content management tools is perceived adoptable to improve the demonstrator with respect to networking performance, human-system-interaction, usability, and ubiquity.

Capturing tacit knowledge (e.g., decision rationale) transferred during face-to-face meetings automatically without user (human) effort to prepare meeting minutes of any kind (digital or paper-based) manually (by writing, typing or filling in forms) has always been a dream novelty for the project actors. The author perceives this to be another possibility for future development. The envisioned processes of this future research possibility can be as simple as the following steps. By setting up voice and/or image recording equipments in the meeting room, the meeting contents can be documented as multimedia objects (e.g., digital audio recording). The digital audio recoding can be fed through a speech recognition tool to obtain transcripts of meeting contents (text-based documents). The transcripts can then be processed using discourse annotation tool(s), which has been actively developed by various research communities, for instance, the S-CREAM (Handschuh et al, 2002) and Ont-o-mat (http://annotation.semanticweb.org/ontomat/). S-CREAM is a webpage annotation tool that allows semi-automatic metadata creation while Ont-o-mat is one that fully relies on human user to complete the annotation task.

There are at present at least two primary areas that require exploration for improvement in order to make this dream novelty a reality. A certain degree of human-system-interaction remains necessary for the currently available text-based discourse annotation tools, which mostly exist as research prototypes, to complete the annotation task. Some of these annotation tools are able to markup text-based discourse according to a predefined ontology model without much human intervention. However, these annotation tools continue to rely on human efforts to establish the semantic relationships between the tagged (marked-up) texts, in particular the reasoning (e.g., causal) relationships, as what was proposed in the IT-CODE demonstrator. A breakthrough in this area is essential to reduce knowledge authoring complications, which will consequently benefit the domain experts (who are no knowledge workers).

The immature speech recognition technology is the second aspect whose current stage is insufficient to enable automatic capturing of the contents of a face-to-face multi-participants meeting. There are a number of automatic speech recognition tools available as commercial software packages today. These off-the-shelf software packages are, however, satisfactory only for very well-defined applications such as dictation and medium vocabulary transaction processing tasks in relatively well controlled environments. These environments are different from the multi-participant face-to-face meeting. Listed below are some limitations generalised by the author to explain the insufficiency of the current speech recognition technology to perform automatic tacit knowledge acquisition from a face-to-face meeting:

1. Inefficient to support multi-speakers environment.
2. User is required to speak slowly and clearly.
3. Incapable of supporting ambiguous speech contents, this requires the user to structure his/her thoughts in order before the conversation starts. This requirement is apparently impractical in a multi-participant face-to-face meeting.
4. Unable to understand improvised discussion topics. Improvised discussion topics are the common phenomena of human-human interactions in face-to-face meetings.

5. Sensitive to the acoustic environment and the style of speech variations (AT&T presented their study results (Shahraray, 2002) on their baseline Switchboard Automatic Speech Recognition system with Word Error Rate of approximately 50%).

Synthesizing speech recognition technology with ontology-based information processing technique would be a good attempt to acquire the tacit knowledge transferred during socialisation on human-human interactions with minimum needs for human-computer interactions.

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ANNEX 5.A SCENARIO BASED QUESTIONS

Scenario 1

The objective of interview:

- To examine the approach used to capture requirements specified by the client.
- To study the collaboration methods implemented among the design team in this early phase.

Key actors: Architect, Client, Engineers
Scenario Description – Briefing stage:
A community center is in need in City B. Mr. Peter is in charge of this and he is an environmentally conscious businessman. He forms a team to start the design of a community center. The first meeting of the team started with Mr. Peter telling the other team members his requirements for the community center. Such kind of meeting is namely client briefing or requirement specification.

Concern: Briefing capture, collaboration (remote and face-face), communication language, interoperability (data model), and presentation of representation (model/etc.) to Peter, design intent capture and reuse.

Questions:

1. In accordance with the above scenario description, who are supposed to be the team members to join the client briefing?

Probes: To study if the interviewee(s) conduct(s) concurrent engineering practices, and/or the conventional ones.

2. Do all the mentioned team members (for example the three main groups of interest, i.e. client, architects and engineers) attend every meeting simultaneously?
    1. If no, how do they update each other if any of them does not manage to attend one of the meetings?
    2. If yes, what is the most bothersome subject (e.g. meeting time, meeting location, or etc.) that commonly arise while arranging the meeting time schedule?
3. What is your ambition to revolutionise the meeting mode from the conventional one to one that is more IT integrated?
4. The commonly used interaction mode in the client briefing session is probably brain storming, sketching, presentation and etc. In your opinion, what is the favourable interaction mode in that session?

Probes: How do you conduct the brain storming session?

5. What is the best way you can think of to present your sketchy ideas to the other team members?
6. A building project is always complicated, and the early stage plays an important role to reduce the probability of future errors. When several alternatives arise, how do you make fast and concise decision? What system (tool or system) do you use in assisting the decision making process at the client briefing stage, if any?
7. How do you document the ideas presented and being presented during the briefing stage?
8. Do you save such documents for future reuse? If yes, what system do you use for such purpose, please describe and show?
9. How satisfied are you with the approach currently used to perform your ideas?

Probes: Communicating ideas between individuals of a team in particular from different professional disciplines is not an easy task.

10. What is your experience in this concern? How do you justify that you are well understood by the others? How satisfied are you with the approach you currently use? What improvement can be thought of for the current approach you use?

11. There are several methods implemented to record the whole process of client briefing, which may range from note-taking to videotaping. In your opinion, how important it is to record the process?

Probes: What degree of detail you would like the record to be?

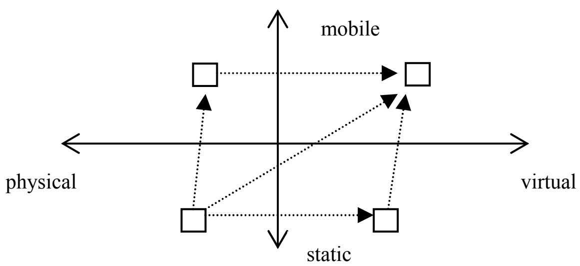
12. What mechanism do you use for this purpose? Do you use any special tools (such as software) to perform activity such as Web Camera Recording, Net Chat Archiving, etc? In what form will the context normally be, for example, text, sketches, drawings, 3D models?

13. If it is not your practice to record the process, why? Is it because of lack of skills/technologies or not necessary? If you do recording, how will you store such records? Can such records be searched and retrieved easily in the future? Please show your records storage.

14. Do you think that face-to-face meeting is the only way to conduct the client briefing session?

Probes: To your best knowledge, how do you like such working environment (workspace) as

- *Static and physical*
- *Static and virtual*
- *Mobile and virtual*
- *Mobile and physical*



15. What is your comment concerning the changing trend of workspace as illustrated in the above figure?

16. What is your personal experience in involving in the above-mentioned workspaces? Please describe how familiar are you with them. Please also elaborate your degree of satisfaction with the type of workspace that you are familiar with.

Scenario 2

The Objective of Interview:

- Study the mechanism used to assist the key actors in **making decision** during the conceptual design process.
- Analyse the flow of knowledge, range from the tacit to the explicit one such as in the form of documents among the team.
- Examine the necessity of knowledge store, search, reuse and create in the schematic design process.

Key Actor: Architect

Scenario Description – Design stage:

As an architect, you are assigned to design the community center; you are provided with data from the feasibility study and activities throughout the predesign and site analysis stages. You are now about to start the schematic design, which is also sometimes named as conceptual design. You have a lot to do and take concern to find a balance point between aesthetic, buildability, etc. Topics that are under consideration throughout the conceptual design phase including site plan preparation; showing building footprint and general landscape planning; paving and drainage; floorplan layouts that satisfy space requirements in the program; equipment and furniture layout; sections and elevations showing vertical dimensions; candidate materials and finishes; structural system types and building sections; solar design and conservation studies; mechanical equipment spaces and duct and chase spaces; fire protection requirements; electrical, fire, security, power and communication system requirements and types.

Questions:

1. Please describe briefly your roles and duties in this phase. Who else from the team will participate in this phase, and what are their associated roles and duties, respectively?
2. What is the very first step you will carry out when you are assigned to the task described in the above scenario?

Probes:

- Will you look for previous cases?
- Will you look for an example that you believe existed somewhere else in the world?

3. There are various practices to search for previous cases, such as consulting colleagues, searching files cabinets, etc. In accordance with all kinds of facilities provided by your company that are best suited for your knowledge and personal preferences, how do you look for previous cases?

Probes:

- Do you use any mechanism (for example catalog search) to help you in previous cases searching?

If yes, what mechanism is that? Please describe and show a demo.
If no, please explain why?

4. How important do you think previous cases are to help you in conceptual design, very important, important, and not important at all? What is your preference of the format of context presented by the previous case, for example 2D drawings without annotation, functional and technical specifications, 3d models, etc?
5. Does your company utilize any knowledge management system to manage the different type of information related to and/or generated from the project, such as documents produced in terms of letters, minutes of meeting, drawings, etc?
6. How do you derive the main system of the knowledge management system utilized by your company, if any?
7. Does the main system function mainly as best practice database that comprises information about quality defects, working methods, details, etc? Does the system support decision –making?
8. If you have been familiar with using a knowledge management system, what are the functional requirements that you expect to have for the knowledge management tools? If you have not used such a system before, what functional requirements do you think are likely to be expected? For example,

-- User group specified interfaces
-- User group customisable interfaces
-- Easy to use and maintain
-- Gives notice about new information
-- New suggestions are welcome…

9. Considerations from various perspectives influence your decision on a particular aspect during the design process. For example, reference to data from landscape planning associated with the relevant legislations and rules is necessary before putting any decision on the floorplan layouts, the type of structural system is closely related to space requirements and materials use, etc. Therefore, decisions made in any one aspect may influence the others. It is time-consuming to always carry out criss-cross study before any decision is made. What is your common practice to expedite the decision making process?

Probes:

- How do you access heterogeneous information sources?

10. Do you use any specific system in assisting you throughout the decision-making process? If yes, can you derive how such system functions? Please show some demo if it is possible. If no, please describe as detailed as possible your workflow in this aspect.
11. How satisfied are you with the current method used in this aspect, very satisfied, satisfied, not satisfied?
12. What improvement do you think is necessary for the current system, in particular in the aspect of time efficiency and conciseness?

Scenario 3

Objective:
To identify the vision of team members to an integrated workspace of IT based knowledge management system.

Key Actors: Architect, client, engineer

Scenario Description:
An engineer is involved in designing the structural system of the community center. He needs to do some calculation, but he is a novice. The following is his inquiry to the knowledge management system integrated in his IT based workspace, which is built on top of the internet. He logs on to his virtual workspace in which the knowledge management system is embedded, and connects to the appropriate information sources recommended by the system through internet.
(E): I need assistance
(System): Do you know the topic?
(E): Do you have any example of a structural system of a community center?
(System): I do not have a case that exactly matches your problem. But I have some other similar cases and the contacts of some people that might help.
(E): Yes, please show me such information.

The above conversation might appear in reality in the format of (a) form(s), or a dialogue with a graphical user interface, and some possible questions to the system.

Questions:
1. What is your opinion in regard to the system mentioned above? Are you using any system similar to that?
2. Project web has been a popular topic in this profession for many years. It has been claimed that the de facto project web sites serve as electronic document management systems while integrated with the great advantage of the internet. The well known features of a project web including
-- A team directory
-- Drawing directory
-- Drawings can be commented on online
-- Documents directory including photographs of work in progress
-- News and information
-- Social events
-- Training and induction programs
If you are requested to provide some opinions in setting up a project web, do you think the above-mentioned features are sufficient?

Probes:

3. Can you think of setting up some other system whose main functional system is similar to project web, but better than it?

4. What kind of features can you think of and propose to provide add-on value to the new system?

5. Disseminate knowledge gained from a project is important not only to the team members, but also to the future users. How do you conduct this task? In what context is the disseminated knowledge, text formed reports, 2D schematic drawings, 3D models, etc?

Probes:

-- Is 3D modeling necessary in this conceptual design phase?

-- How well will 3D modeling affect the collaboration effectiveness of a design team?

-- How does working in a 3D environment affect the communication of a team?

6. What approach do you use to deal with interoperability between team members?

7. Please give some comment on the use of IFC, if any.

8. Link to supplier will facilitate the design process when more information concerning a particular product is necessary. How do you link to the supplier chain? How satisfied are you with the conventional means of communication such as email, phone, faxes, with the supplier and team members?

Scenario 4

The objective of the interview:
-- To examine the approaches used to conduct conceptual design by the team members.
-- To study the collaboration mechanisms and communication flow involved in this phase.

-- To identify the specific needs of key actors to improve the implementing of a collaboration mechanism in the conceptual design phase.

Key actor: Architect, client, engineer

Scenario Description:
The team starts to work on the design with reference to the requirement specified by the client.

Questions:
1. Is collaboration with the other team members such as engineers and clients important at the conceptual design stage? How do you derive the collaboration activities conducted at this stage among the participating team members?

Probes:
2. What is your preferred communication mode when you collaborate with any of them?
3. What mechanism do you use, e-mails, telephone calls, faxes, post, etc?
4. According to your usual work practice, in what form usually is the collaboration context, for example, texts (e-mail, post, fax), conversation (telephone call, face-to-face meeting, etc.), etc?
5. How frequent do you collaborate with the other team members?
6. What is your experience in working with other team members at the conceptual design stage, particularly in terms of sharing of knowledge and design ideas? Do you have any unpleasant experience in this aspect, and how did you solve this problem that might arise from the difference in professional discipline?
7. Is a workspace different from the one you usually work in when collaborating with other team members? Please derive such workspace by making comparison with the ordinary one.
8. How satisfied are you with the collaboration mechanism that you are currently using? What is your ambition in improving such mechanism, from functions to user interface?
9. The use of collaborative tools has not been a new phenomenon in some other profession, such as e-business, distant learning, etc. Some of the collaborative tools with general purposes are easily available as freeware, for example NetMeeting, Yahoo Messenger, Groove, etc.

Probes:

-- What is your opinion about the contribution of such collaborative tool in the AEC profession, in particular in the conceptual design phase?

-- How do you share knowledge and experience with other interested parties, such as team members, suppliers, etc. in the conceptual design phase?

-- What is your experience in using collaborative tools in the conceptual design phase (as well as in client briefing)?

10. Besides the previously mentioned internet/network based collaborative tool, what other mechanism do you think can be categorised as a remote working method?

Probes:

-- What is your vision on an effective remote working method within a loosely coupled, project basis team structure? What can in your opinion to improve the currently implementing remote working method in the AEC profession?

-- What mechanism do you use to manipulate interoperability through data transfer across systems, as well as multi-team working and component sharing?

ANNEX 5.B DATA ANALYSIS OF CASE STUDY 2

Table 5.B.1: Sequence Model

Participant	Conversation	Activity	Intent
		Meeting started at 9.20 a.m. by Alice, the Project Manager	
Joe:	…We have three more weeks to submit our final design to the authority…	Joe briefed project schedule by referring to his log book	To refresh the memory of participants
Joe:	Chris, do we continue using the existing model?		
Chris	Yes, we mentioned the model proportion in our last meeting. The size of 1:100 is as big as the one used in the project of "Ma On San"…	Chris checks his logbook when he is asked about the model. Starts to describe the model by giving an example while using hand gestures.	Gave example to help visualize the model size
Shawn:	Can we reuse the base of the existing one? What is the proportion? I have to confirm if it is not too big to put in the meeting room.	Shawn flips her logbook to check the proportion of the existing model.	
Patrick Y	The model maker needs about 1 month to complete a model. Shawn, ESF has to decide on the model size as soon as possible. The promotion will be in the 1st or 2nd week of December.		To push Shaw to make decision.
Alice	So, the model should be ready within 3 weeks time from now. I think IDA may start to prepare a walkthrough presentation for promotion while waiting for ESF to decide on the model size.	Patrick Y makes notes in his logbook. Joe makes notes in his logbook.	To coordinate tasks.
Shawn	We need to know the price of different model sizes before any decision can be made. Can you check the price for model size 1:200 with new base and old base, and also one with the size of 1:100.	Patrick Y listens to Shawn's requests and makes notes on his log book.	To collaborate with each other.
Alice	IDA should email ESF the quotations as soon as possible. Now we have about 3 weeks' time before the promotion, can we get our three targets done? Can you (Chris) finish this in about a week?	Alice points at a document placed in front of Chris.	Trigger: to address concern.
Chris	I think it is ok, it is not impossible for us to get our targets done in 3 weeks. I can get this document issued even by tomorrow.	Chris looks at the document in front at which Alice pointed.	Reflection of own experiences
Patrick Y	If this document can be issued tomorrow, then we can fully utilize our 3 weeks' time. To handle this, we can divide the time, we deliver documents incrementally, but not all in one day to make our work load in a series.	Patrick Y points at the same document in front of Chris while talking.	To give suggestion
Alice	Yes, that's right		To agree with the suggestion given.
Joe	Any updates from the architects.?	After making notes of the discussion issues, Joe looks at Patrick Y while asking the question.	To coordinate the meeting by initiating the discussion session by session
Patrick Y	…updates on program… comments…	Patrick Y takes out a roll of drawings from his bag. He opens up and puts those drawings in the middle of the meeting table. He starts to report changes made on drawings in the last two weeks by pointing on the drawings.	To report work progress. To help meeting participants visualize the changes made on design by

			using 2D paper-based drawings.
Shawn	Can the architect show us some scheme layout drawings with updated cost?	Shawn pulls some drawings close to her and looks into them before asking the question	To enquire more detailed information.
Patrick Y	Yes, there will be new information put on the scheme layout drawings, but no additional drawings will be produced.		
Shawn	It will be better for us to have drawings with clear information about the cost.		To negotiate with the architect about the client's request
Patrick Y	Yes, of course, but I do not think you will want to see drawings with 1:1 scale…		To negotiate with the client.
Shawn:	Yes, of course not, but 1:50 is more than ok, but the drawings must include clear scope such as layout elevation, …we need the drawings to make decision.	Shawn writes down notes.	To make her request clear about how the drawings should be presented by giving explanation
Patrick Y	Ok.	Patrick Y makes notes in his logbook about Shawn's request.	The architect compromises on the client's request.
Patrick Y	Let's refer back to our program and the comments made on the landscape in previous meetings, …	He then unfolds the program and shows it to all meeting participants and starts to discuss the comments on landscape. He points at a drawing and starts to explain.	The architect presents his ideas of changes made on drawings
Shawn	Ok. Can you prepare the drawings about the necessary changes (e.g. main entrance accessibility, notion of the stairs, etc.) and let Chris have them checked?	Shawn makes notes in her logbook.	The client agrees with the ideas of changes described by the architect.
Chris & Patrick Y	Ok		To agree with the decision made by the client.
Joe	What about progress report?	Joes starts another question after jotting down notes.	To coordinate the meeting.
Patrick Y	Lack of some information, but can deliver by end of this week.		
Patrick Y	We have already provided DLO with a copy of the draft EVA license agreement. We have to get the license agreement reviewed as the prerequisite for GBP approval		To report on the progress made.
Chris	We might need to re-adjust our monetary estimation to get the approval.		To raise a potential consequence.
Shawn	Yes, please, as long as we get it approved.		To make an agreement on Chris's suggestion.
Joe	Any questions from the structural people?	Joes starts another question after he finished jotting down notes.	To coordinate the meeting.
Pat M	We (Maunsell) compared the layouts of the submitted GBP and the option 3. According to our calculation, in the new option, one level has been reduced from the building, we can shrink the column. We calculated the load and moment will impose on the structure of the roof top…	Refer to logbook while reporting the work progress in the last two weeks.	

	…we also found out from option 3 that we can reduce the slab thickness of the corridor if the length of it is reduced. In the old drawing, the corridor is 3 m long		
Alice	We have to be careful about the acoustic difference if the slab thickness is reduced, lots of noise will probably be created when students run on the corridor.		To raise the potential consequence
Pat M	What I mean is here. The thickness was 150 and we may reduce it to 125. But of course we also need to check the deflection and the acoustic difference.	Points at a specific part of the drawings while explaining with hand gestures.	To visualize his ideas.
Shawn	Henry can check the acoustic difference before we decide to reduce the thickness. How much can we save from the reduction?		To show her interest in the suggestion
Pat M	Approx 20% …		
Alice	But during the recess time, there will be a lot of students running up and down the corridor… 125 might be too thin…		
Pat M	Ok, yes, …then we may keep 150… Anyway, the corridor is not the critical part… the critical part is to know the column size… I need to know the height of all columns points from building roof to canopy to go through the calculation so that I can know how much space I can save by shrinking the column, then I can tell you the exact column sizes.	Pat M makes notes in his logbook with a pencil. He flipped the documents beside his logbook to look at the calculation result of the critical part.	To compromise with PM's concern.
Patrick Y	Ok, I will provide you with the detail on a drawing.	Patrick Y makes notes in his logbook.	To enable him to keep track of his assigned tasks.
Pat M	I also made some calculation on the roof…There are not many changes for the steel weight because only the geometry of the layout is changed… There was no beam member exceeding 9m in the previous model, but after the change, there is member of 12m… I need to conduct the deflection calculation upon the change…	Flip documents that are in front while reporting the result of simulation that has been done.	To provide structural advice to the architect as a way to enhance collaboration.
Lawrence	We JRP has been coordinating with IDA for the last 2 weeks…	Lawrence reports his works while referring to his logbook	Trigger: a discussion session about the task progress of the BS system.
Alice	Any progress with the canopy drainage?	Alice flips the drawings in front of her	
Patrick Y	Yes… JRP sent us a comparison report … We consider to make some changes here…	Patrick Y takes out another roll of drawings of A2 size from his bag. Points at the drawings while explaining	To provide visual aids to the participants
Pat M	…but it is good not to connect it with the main building drainage system, otherwise moments may occur and might damage the connection joints…	Pat M points at the specific part on the drawing that explained by Patrick Y. Pat M starts to explain his viewpoints with gestures.	To provide structural advice for the potential consequence.
Patrick Y	Ok, I will take this into consideration.	Patrick Y makes note in his log book.	
Lawrence	…ventilation system at the swimming pool…we assume that ventilation and heating are used in winter while there is natural ventilation and no heating in summer…	Look at his logbook.	Trigger: to continue reporting
Shawn	Oh no no… I think this is not a good	Shawn shakes her head to show that she	Trigger:

	assumption…users may prefer to use heating in summer too…we have a typical example of a pool in "Sha Tin"… it becomes wet in summer with only windows open, but with heating on…	disagrees with Lawrence's assumption.	Experience reflection by pointing out example in "Sha Tin".
Lawrence	But we think no heating is necessary in summer		To defend his own viewpoints
Alice	Different users have different habits… should consider what Shawn said that heating may still be used in summer…		To coordinate the decision made by the client with the engineer
Lawrence	Yeah, ok…	Lawrence writes down the consideration.	To compromise
Alice	…lighting system to the sports hall is directly under the pool, right? I am just thinking if there is a water leak, will this damage the light…	Referring to a sectional drawing while asking	Trigger of another discussing issue.
Chris	...	Pointing at a certain part of the sectional drawings to help Alice visualize the drawings.	To explain some part of the drawings to PM
Lawrence	We consider putting an insulation layer in between…	Start explanation with gestures.	To explain his ideas.
Alice	Didn't we have a design checklist about a year ago? Remember?	Alice thinks for a while before asking the question.	Trigger: the need of a system to coordinate the generated information.
Joe	I will upload the checklist again later	Write down in his logbook about the promise after all of the participants have been silent for a while.	
Alice	Yeah, I think we should all check the listed items. Please upload the list if we have any additional inputs now so that we can cross check during the detailed design stage.		To remind the maintenance of the system is everyone's duty.
Henry	We consider to putting on sound baffles along the roof structure to cut down the noise in the swimming pool…	Henry reads some notes in front of him while reporting his work progress.	Trigger: to report work progress.
Chris	Can the baffles support lights?		Trigger: to generate alternative for lights support
Patrick Y	I do not think so…		To eliminate alternative
Henry	The calculation will be finished by this week, more details can be known later…		
Alice	The music room is beside the plantroom…	Reading an A3 size drawing while starting her conversation.	Trigger: to search for potential problem from design
Henry	Yes, we (Patrick Y & I) have noticed about this and we use solid RC walls as an acoustic treatment…		To explain the alternative chosen
Alice	Will that influence the structural design?		To evaluate the alternative
Shawn	How about the sports hall?	Looks at a drawing put in front and writes down some notes in her logbook.	To address a potential problem
Henry	We have done something on the walls in the sports hall and gymnasium.		To generate the alternative
Shawn	How good is the acoustic material in sustaining impacts when there are ball		To discuss the alternative

	games?		
Henry	Our supplier provides us with two choices, fabric padding or rubber…		
Patrick Y	We (Henry & I) consider to choose fabric padding…		
Shawn	Is that good enough…? Can the supplier provide more advice?		To show the concern for a need of alternative evaluation.
Henry	Ok, I will check with them and get material samples…we can then discuss this again…		
Alice	Look at windows over here; it seems out of reach by human height… How do you (ESF) normally clean up windows & curtain walls?	Reads on sectional drawings then points on the windows part of the drawing at a specific section.	To raise a potential problem through searching facts.
Shawn	We normally subcontract to the cleaning company; one of our other schools… cleans up all windows once every 5 years.	Thinks for a while before giving the example.	To provide information through experience reflection.
Lawrence	Will you have a technician to take care of the control room and other stuff?		To provide a suggestion for generating an alternative.
Shawn	I do not think so, we will only have a caretaker. We bought a "cherry picker" which can be used for window cleaning …it can be transported from place to place, now it is with us at our ESP office.		To compare some ideas.
Chris	Cherry picker? Do you mean something like a forklift?		
Shawn	This was what the salesman said. Yes, something likes a forklift where you can stand in a compartment that can be lifted up. In some cases, scaffolding could be put up for this purpose too.		Idea analogy
Alice	Well, I think we should take this, particularly the maintenance of the BS system, into consideration especially in our design…		To make agreement on which action should be taken in the future.
		Meeting ended at 10:45pm	

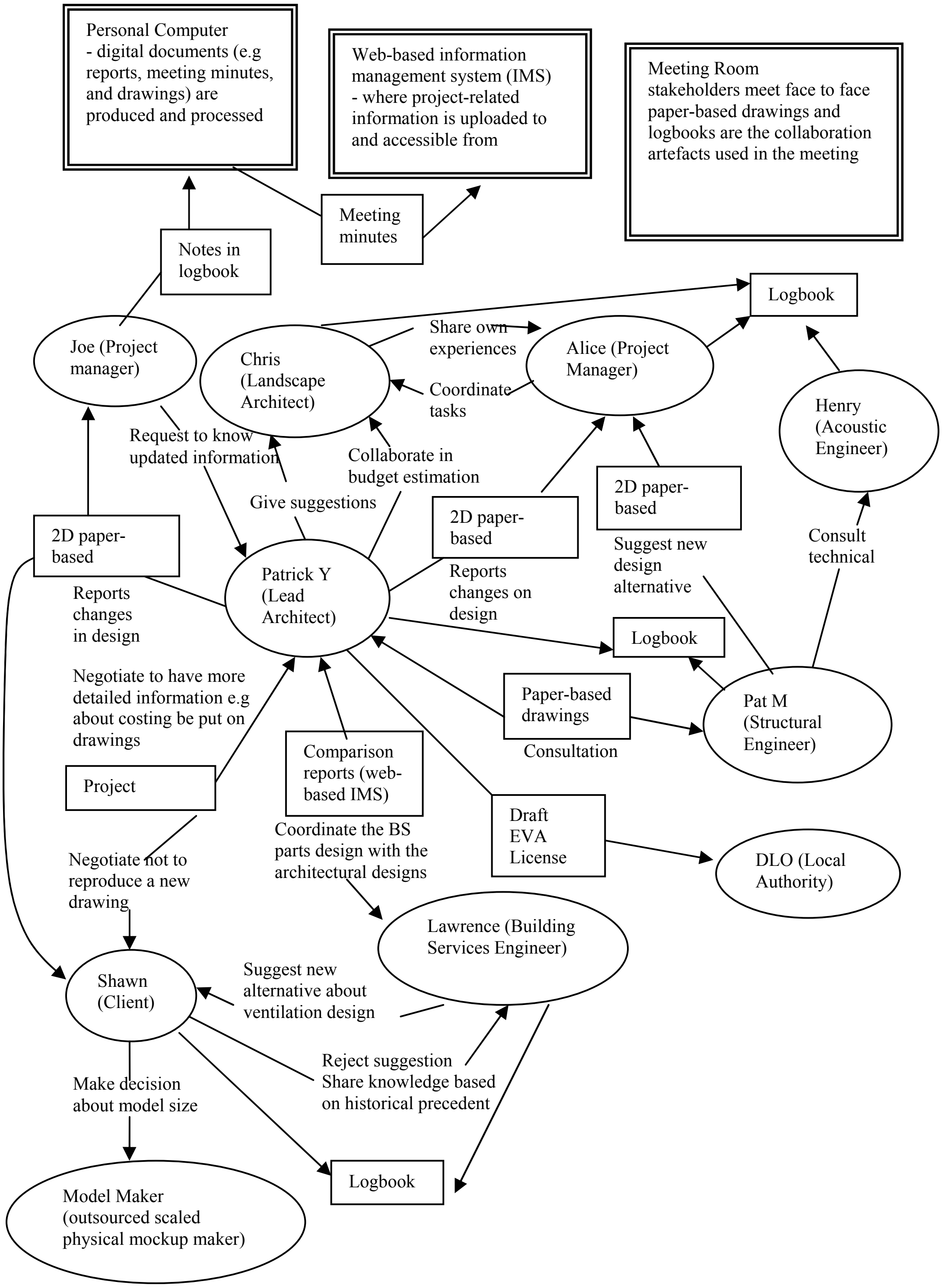


Figure 5.B.1. The workflow model is to illustrate the interactions undertaken by the multidisciplinary stakeholders for completing their respective tasks. Most of the stakeholders represented as bubbles in this figure met in the face-to-face meeting in which the observation was undertaken. The interaction with DLO represents a remote interaction that had been achieved before the meeting. In other words, DLO did not participate in the meeting. The interaction with the model maker was another remote interaction which was done outside the meeting.

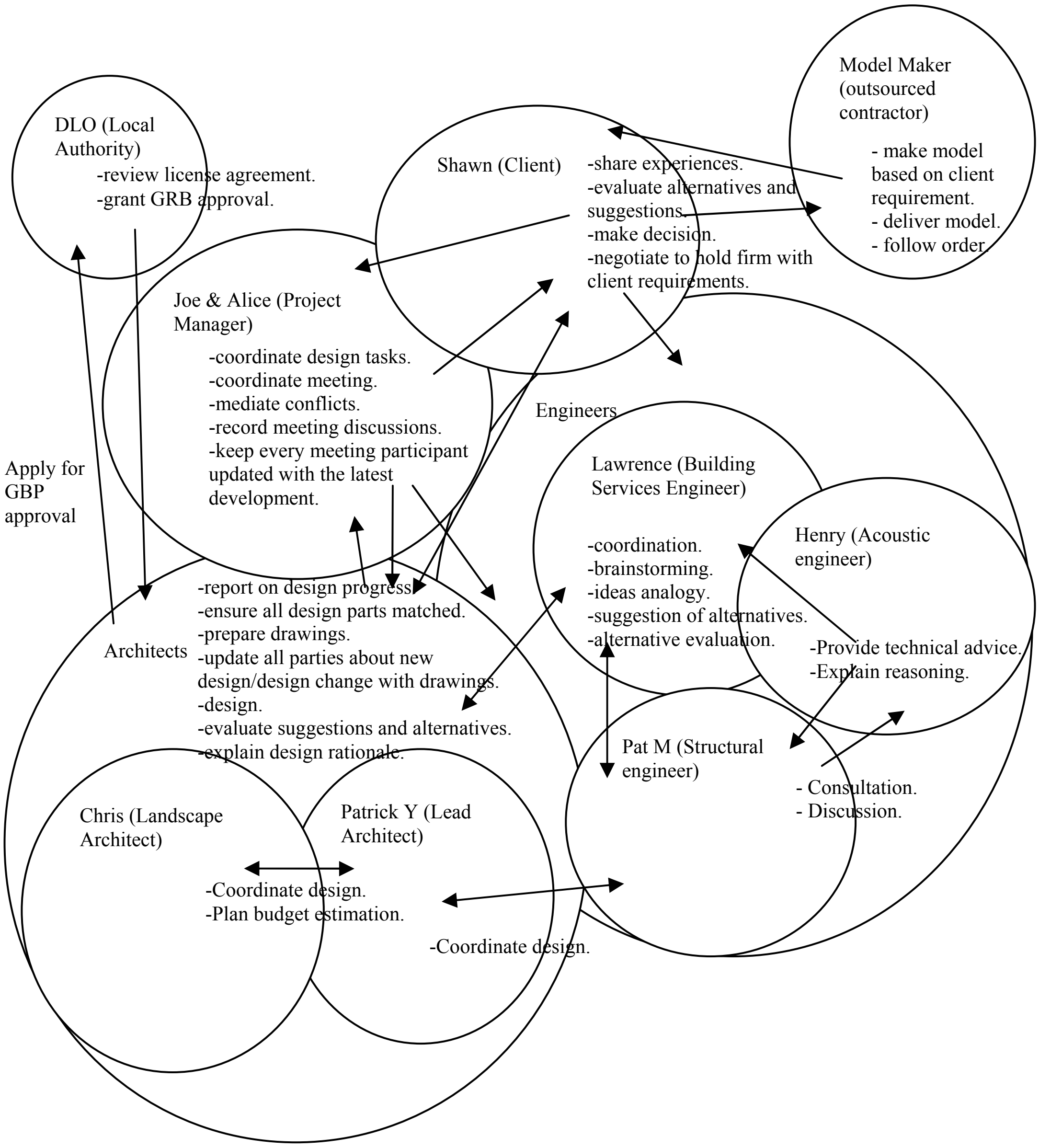


Figure 5.B.2. The culture model illustrates how the work culture of different parties who got involved in the project influenced one another to get their tasks done.

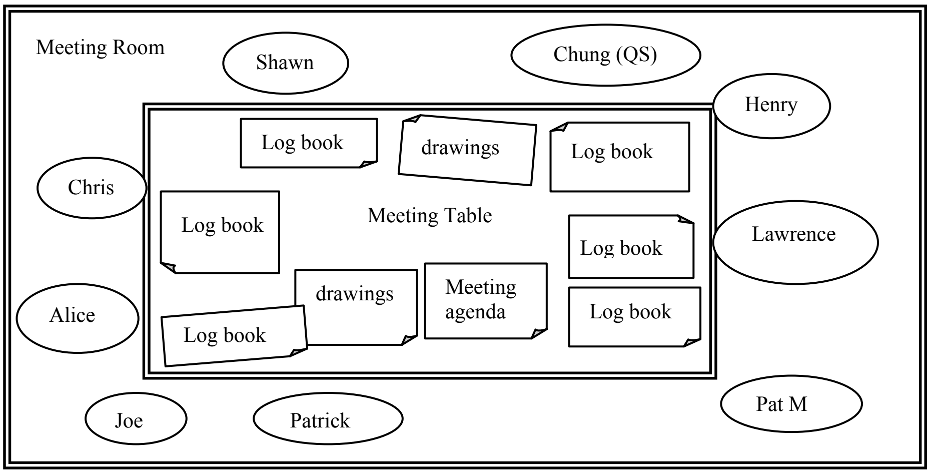
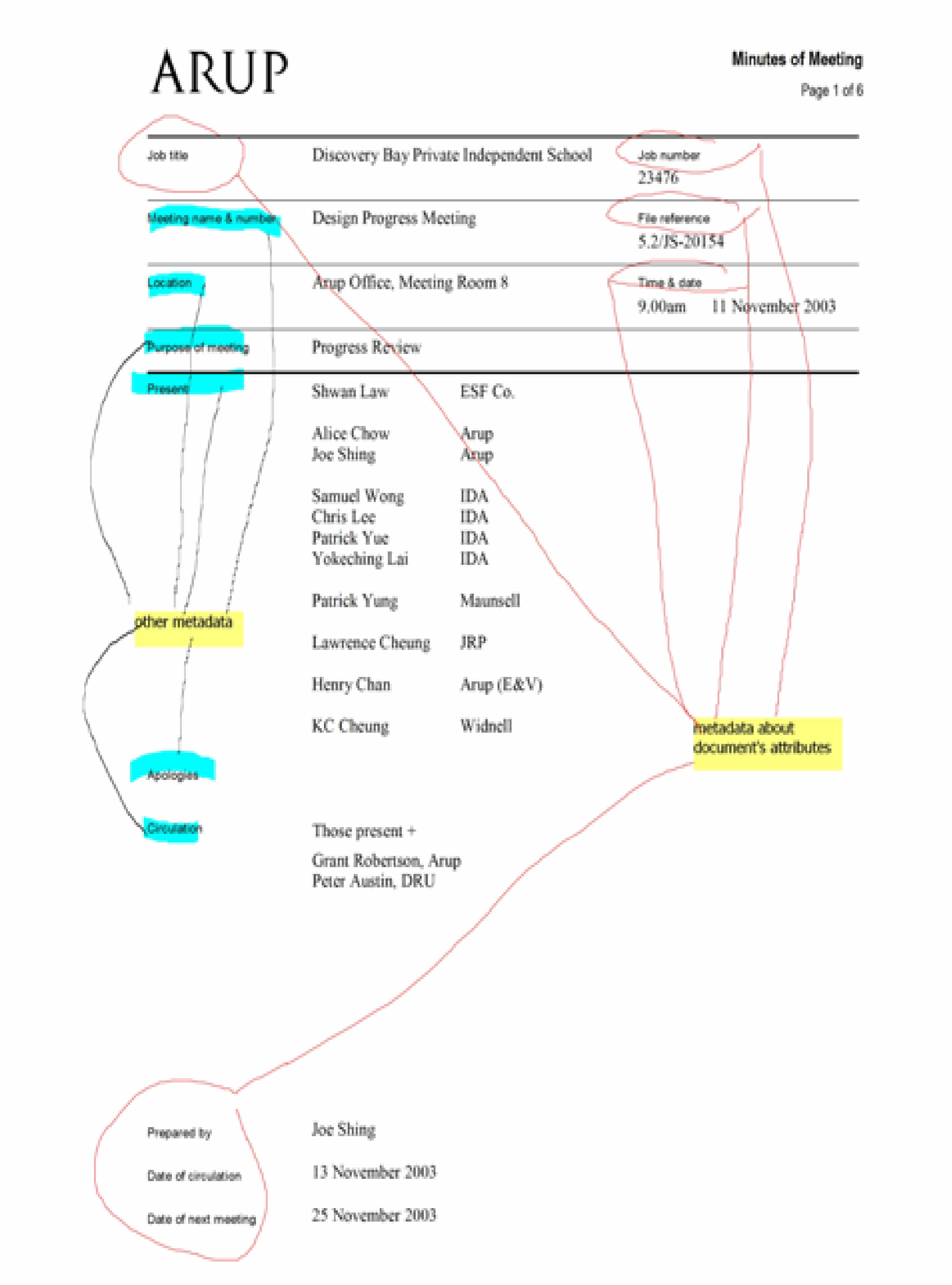


Figure 5.B.3. The physical model illustrates the physical environment of the meeting room in which the observation was made. Small bubbles represent the meeting participants.


ARUP

Minutes of Meeting

Page 1 of 6

Job title	Discovery Bay Private Independent School	Job number	23476
Meeting name & number	Design Progress Meeting	File reference	5.2/JS-20154
Location	Arup Office, Meeting Room 8	Time & date	9.00am 11 November 2003
Purpose of meeting	Progress Review		

Present	Shwan Law	ESF Co.
	Alice Chow	Arup
	Joe Shing	Arup
	Samuel Wong	IDA
	Chris Lee	IDA
	Patrick Yue	IDA
	Yokeching Lai	IDA
	Patrick Yung	Maunsell
	Lawrence Cheung	JRP
	Henry Chan	Arup (E&V)
	KC Cheung	Widnell
Apologies		
Circulation	Those present +	
	Grant Robertson, Arup	
	Peter Austin, DRU	

Prepared by	Joe Shing
Date of circulation	13 November 2003
Date of next meeting	25 November 2003

Job title	Job number	Date of Meeting	Action
Discovery Bay Private Independent School	23476	11 November 2003	

Project Manager's Overview (28 to 11 November 2003)

The Project Manager stated that the detail design workshop held with the Client on 4 November 2003 concluded discussions on room arrangements for the option 3 scheme. The Architect is now preparing the layout freeze plans for co-ordination with other designers and aim to present the cost of the design to the Client by the end of November. Once the Client endorses the scheme, the consultant will commence their respective detailed designs.

The PM advised the following initial quotations for the new presentation model to coincide with the option 3 scheme:

1:200 Model (Reuse the Base of the Existing Model)	HK$33,000
1:200 Model (New Base)	HK$40,000
1:100 Model	HK$60,000

alternatives

The Architect stated that the model maker will take about a month to complete the model therefore the Client has to decide as soon as possible to meet their promotion activities in the first or second week of December. The PM advised the Architect to start preparing a walkthrough presentation of the design for the promotion activities.

The following items are targeted to complete in the next two weeks:

- Issue Request for Quotation for the ETFE Canopy Consultancy
- Preparation of scheme layout drawings with updated cost for presenting to Client in early December 2003
- Preparation of General Building Plans for submission at the beginning of December 2003

(Post meeting note: ESF Co. has confirmed to build the new model with a new base at HK$40,000 on 13 November 2003. Arup advised IDA to contact the model maker to start making the model immediately. The date of the promotion activity has still to be confirmed by ESF Co. in due course.)

Job title	Job number	Date of Meeting	Action
Discovery Bay Private Independent School	23476	11 November 2003	

Amendment to last minutes of meeting:
NONE

Architectural

1. **Request for Quotation for ETFE Consultancy**

Maunsell stated that it is important for them to have the information obtained by the ETFE consultancy early as it may affect their foundation design. IDA advised that they aim to issue request for quotation documents for the ETFE consultancy by Wednesday, 12 November 2003. ESF Co. and Arup advised IDA that they should ask all the suppliers for their interest in submitting the quotation before issuing the document. — IDA

The schedule tentatively agreed in the meeting area is as follows:

Issue request for quotation document	12 November 2003
Quotation return	19 November 2003
Complete Assessment and recommendation	21 November 2003
ESF Co. approval	25 November 2003
Award Consultancy	28 November 2003
Complete Consultancy	19 December 2003

Maunsell worries that the scheduled 3 weeks for the consultancy may not meet with their foundation submission in end of December 2003. Maunsell suggested having the ETFE consultant to provide information such as loading can be used for design as early as possible.

2. **Co-ordination Programme**

IDA advised that they are at present incorporating comments from all parties to the co-ordination programme. Arup advised that time should be allowed for incorporating comments items such as the review of the draft tender drawings and documents. — IDA

IDA advised that the 90% of the tender drawings would be submitted to Arup/ESF review in mid February 2003. ESF Co. accepts this if all general layouts and elevation would be available.

3. **Revised Schedule of Accommodation**

IDA advised that the revised SoA would be made available by end of this week. Subsequently to this, IDA will notify HKR of the revised GFA figure by early next week. — IDA

4. **Monthly Progress Report**

IDA advised that they would submit the design progress report by the end of this week. — IDA

tree structure hierarchy for organising the document's contents

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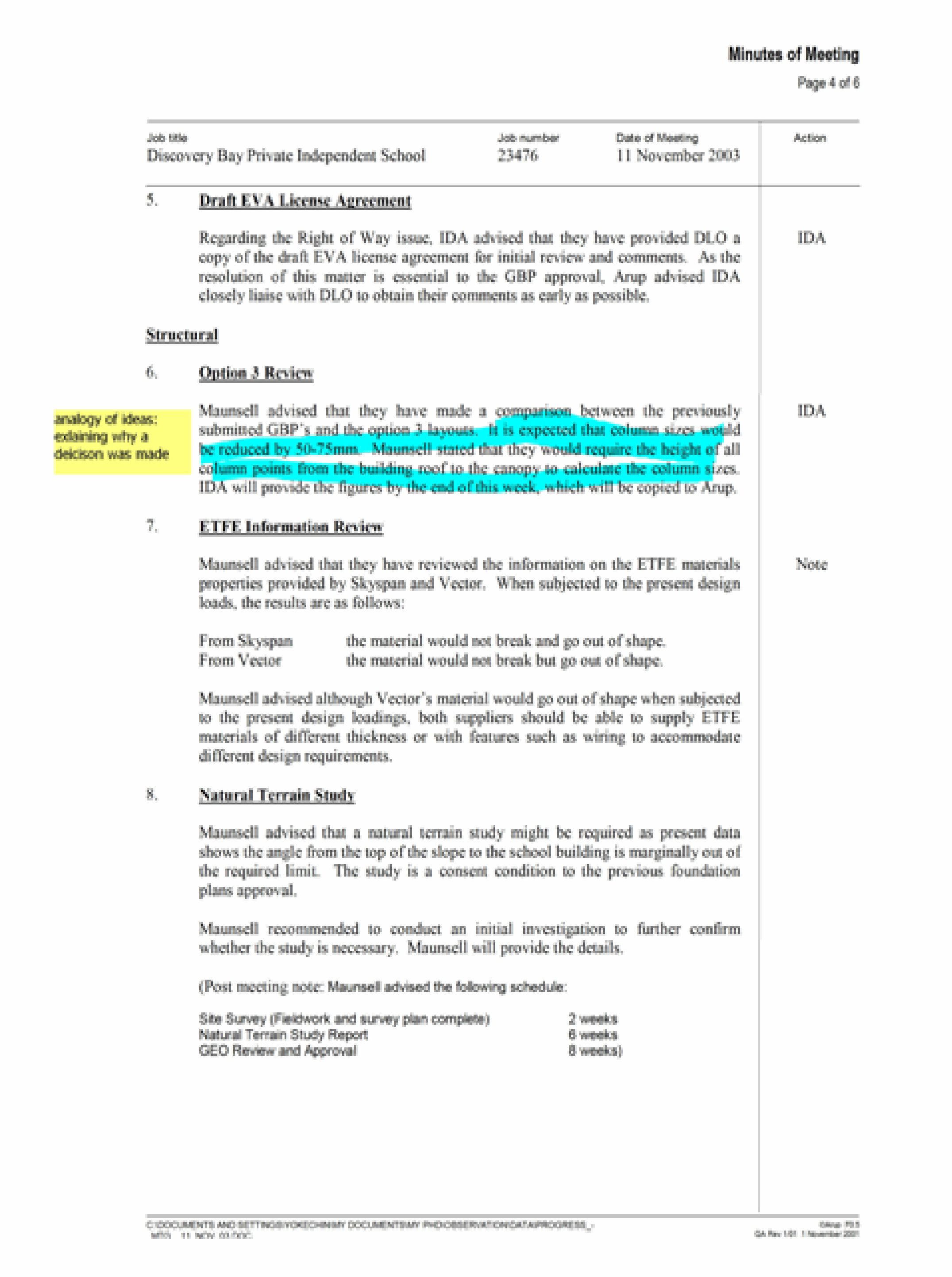


Minutes of Meeting

Page 4 of 6

Job title	Job number	Date of Meeting	Action
Discovery Bay Private Independent School	23476	11 November 2003	

5. **Draft EVA License Agreement**

Regarding the Right of Way issue, IDA advised that they have provided DLO a copy of the draft EVA license agreement for initial review and comments. As the resolution of this matter is essential to the GBP approval, Arup advised IDA closely liaise with DLO to obtain their comments as early as possible. — IDA

Structural

6. **Option 3 Review**

Maunsell advised that they have made a comparison between the previously submitted GBP's and the option 3 layouts. It is expected that column sizes would be reduced by 50-75mm. Maunsell stated that they would require the height of all column points from the building roof to the canopy to calculate the column sizes. IDA will provide the figures by the end of this week, which will be copied to Arup. — IDA

7. **ETFE Information Review**

Maunsell advised that they have reviewed the information on the ETFE materials properties provided by Skyspan and Vector. When subjected to the present design loads, the results are as follows: — Note

From Skyspan	the material would not break and go out of shape.
From Vector	the material would not break but go out of shape.

Maunsell advised although Vector's material would go out of shape when subjected to the present design loadings, both suppliers should be able to supply ETFE materials of different thickness or with features such as wiring to accommodate different design requirements.

8. **Natural Terrain Study**

Maunsell advised that a natural terrain study might be required as present data shows the angle from the top of the slope to the school building is marginally out of the required limit. The study is a consent condition to the previous foundation plans approval.

Maunsell recommended to conduct an initial investigation to further confirm whether the study is necessary. Maunsell will provide the details.

(Post meeting note: Maunsell advised the following schedule:

Site Survey (Fieldwork and survey plan complete)	2 weeks
Natural Terrain Study Report	6 weeks
GEO Review and Approval	8 weeks)

Figure 5.B.4. The Artefact Model: An example of meeting minutes. The model was analysed in several aspects including the document structure, the document content and how discussion contents were formulated in natural language texts to portray analogy of ideas, decision reasoning and design rationale. The analysis was annotated in (yellow) boxes shown in the figure.

ANNEX 5.C DATA ANALYSIS OF CASE STUDY 3

Table 5.C.1: The Sequence Model

Participant	Conversation	Activity	Intent
		Meeting started at 10 am. Before the meeting was started, hand sketches made by Kin were put up on the partition wall before he started to present his design ideas.	
Kin	I checked with them last Friday about both the reviewed and proposed coordination drawings. It seems to be ok.		To review what has been done in the past weeks.
Winston	Have you checked if the proposed one can fit in our design?		
Kin	No, I did not have these drawings until last Thursday. I will check if any coordination can be done later. I could not find the file mentioned by them in our archive system which only has records until 2002. But I will give them a call to have it done...	Kin was holding some A0 size drawings that Winston brought into the meeting room.	To explain his situation.
Winston	Ok		
Joachen	How does this affect the conceptual coordination?	Unrolls the A0 size drawings, and points at the centre of the drawings.	Trigger: to enquire further explanation
Winston	The original building has different roof profile… this coordination has changed the roof profile at a different angle…the eaves line and slab line are required to be checked with building regulation again for this coordination…	Points at the drawings and makes gestures while explaining.	To explain by giving comparisons between the current design and the previous one.
Joachen	Will this not affect the glass envelope?		To externalize the potential consequences.
Winston	Yes, the glass envelope will need to be raised in this case.		
Kin	Shall we start to talk about the sectional design of the landscape?	Stands in front of his design sketches to present his ideas of sectional details of landscape design	Trigger: to draw attention from participants.
Winston	Yes…		
Kin	I have made two choices here. The first one, let us take a look at the site boundary… the red line is the site boundary, which is the datum of the boundary…	Holds a pencil and points at a sketch on wall with the pencil.	to present design ideas (images)
Winston	In the meeting with client's consultant last week, a skew red line was decided on… the retaining wall will be in a wider angle…	Points at sketches and makes gestures in the air.	To update the meeting participants on the agreement made with another party of the project who may influence the design decision.
Kin	So, the coordination of the site boundary and the red line must be kept, …ok?...		To reflect his understanding
Winston	Yes…		
Kin	…I came out with an idea to create a line of steps…one can look down to our garden and create the feeling of more spacious…this feeling can be shown in	Kin points on a plan view sketch while explaining the idea of steps. He points at a sectional sketch (west side) to expand his explanation.	To give explanation on the alternative he generated.

	my model later…steps are very good to give the inviting feeling, when you see the steps you will follow the steps to move up…		
Kin	I have done the scenarios of the pocket spaces. With the steps here, people can go up and then come down… I do not go further with this approach because I come out with another approach…At the moment, I have 7 steps here… when I come down to the basement, I have a parapet…In the second approach, when I come down, I can have pocket spaces where I can put some chairs for people to sit…	Points at the sectional sketches of both west and south view.	To present the generated concepts.
Kin	I need to find something for better treatment of the pocket space, let's talk about that in our next meeting…		
Kin	Over here, the parapet of the library, I thought of doing some treatment on it to make people feel safe psychologically…it is scary when people look down from here, quite deep draw…	Points at another sectional view sketch	
Kin	I show you this example, this for me is not just the treatment of the handrail…but if I make use the design features and the verandah I can achieve that kind of feeling…the verandah can enhance the space relationship…	Kin walks to his desk to get a book. He looks for a page that shows a design of a spacious verandah. He holds the book in front of him to show the picture to all meeting participants. Chris's view is blocked, so he walks towards Kin to get the book and reads on the pictures shown. Winston opens up his notebook and jots down some notes.	Trigger: Use external sources to help meeting participants visualize his internal visions.
Winston	We need to look into the elevation of the wall…it looks strange with this design…I think you may deal with the parapet so you can define the height of the parapet wall so that it could be lower than the street level…	Winston stands up from his seat and walks to the wall to points on the sectional view sketches. Winston starts to draw his ideas on Kin's sketches while explaining his ideas.	To criticize the design concepts by externalizing own visions with sketches.
Winston	How is the lowest balcony interface with the bridge?...treatment of handrail still needs to be looked into again…I think handrail may not necessary…it does not look nice from the street level…	Winston points at the elevation sketch of the south view.	
Kin	…but Winston, my handrail is over here, it may not be so obvious from street level		To negotiate the alternatives generated
Joachen	What is that for?		
Kin	It is just a psychological barrier…		
Joachen	At the street level, when people move around the cages, or whatever, they will notice there are steps…handrail may not be necessary…		To eliminate the alternative with a personal viewpoint.
Joachen	What is that, in fact over there?		
Kin	Where?		
Joachen	Here…	Joachen moves forward to point at the sketch.	Trigger: to visualise the question.
Kin	I use plant, there are planter cages…	Kin uses his pencil to mark on the sketch at which Joachen pointed.	
Winston	Yes, more than 20% of the total building area must be a green area according to the government regulation…	Winston uses external sources (governmental regulation) as reference to help making a decision.	To organize cognitive activities by referring to a certain information source.
Winston	Don't forget about what the light can do…		To propose suggestions

Winston	To retain the subsoil, can you not use a beam?	Makes gestures in the air to point at the position where the subsoil needs to be reinforced.	Trigger: to refuse the design concept generated by Kin at a particular part.
Kin	I need to reinforce the subsoil at this section… I will divide them like this…	Kin draws on his sketch on the wall with his pencil. He draws six squares to explain his ideas.	To negotiate
Winston	I still think you should not use beam, otherwise the whole street will full of beams…		To confront concepts with explanation
Chris	If we don't use beam, are we going to have a beam across here?	Chris walks towards the sketch and moves his finger across the sketch to show the spot that he meant.	
Winston	We may probably think of lower the beam 1m below…		To suggest new design probability.
Chris	Think about the 3D zone, once you lowering the beam, the soil treatment here might be different…	Chris draws on Kin's sketch of elevation view with his pencil.	To visualise the potential problem of the suggested design problem.
Kin	This will be the next thing to look into…		To show the need for back tracking the current design concepts.
Winston	You might need to take this into consideration when preparing the construction drawings…		To remind the additional relevant/subsequent workloads.
Winston	You may need to lower the garden over here…	Winston draws on one of Kin's sketches in elevation view.	
Winston	The law requires you to have 3m here…therefore the parapet walls might need to be extended.	Explains with continuously sketching on Kin's sketch on the wall.	To reflect knowledge regarding regulation on his explanation
Kin	Ok, I still have 3m here. It is always good to have thorough discussion to get more ideas…		Agreement has been made to lower the garden.
		Another discussion session starts. Kin takes down all his sketches so that Peter can put his on.	To prepare for next discussion session.
Peter	I tried another option about how one could move down from the corridor…	The discussion on Peter's work about the sky garden and its relevant parts continues.	Trigger: to review his design idea.

Consolidated Sequence Model

Main Activity	Intent	Abstract Steps
Review tasks assigned in the previous meeting	Disclose meeting history. Provide quick introduction of the meeting scope. Coordinate assignments.	Trigger: Start the meeting by referring to the meeting minutes of the previous meeting as the current meeting agenda - someone speaks out the review.
Start discussion session	Keep team member notified of the updated information. Define problem, if any. Generate the alternative solutions for the problem - compare the alternatives.	Trigger: Interpret problem. Describe problem orally. Use tools/aids to describe the problem to help other participants get a grip on the problem. Decide what the main areas of choice are. Find what are the different solutions

		in the area (consult experienced supervisor, use social connection, access to relevant archive, etc). Assess solutions feasibility (based on experiences, advices or use special tool). Compare the alternative solutions by assessing their respective nature. Make comparison from multiple perspectives (based on experiences and relevant knowledge with and/or without using special tool). Decide on a set of comparisons and preferences as a basis for a choice (based on compromise and collaboration between the affected parties).
End discussion session	Choose one alternative as the solution, which needs to be tested later on (in the next meeting). Make a decision for the next action.	Estimate the impact of the decision made. Decide if the decision can be made now. Decide on the next following step that either directly or indirectly correlates to the action taken.
Summarise meeting contents	To check if the meeting follows the agenda (or meeting minutes of the previous meeting). Decide if any additional topic should be covered. Allow the meeting participants to know their respective duties.	Check the meeting agenda to ensure all topics have been covered (e.g. read the circulated agenda that is either paper-based of softcopy). Conclude the meeting.
Record the assignments/tasks to be achieved before the next meeting	To refresh memory when it is necessary.	Record the reasoning behind the decision made on a certain action (e.g. someone prepares meeting minutes during or after the meeting).

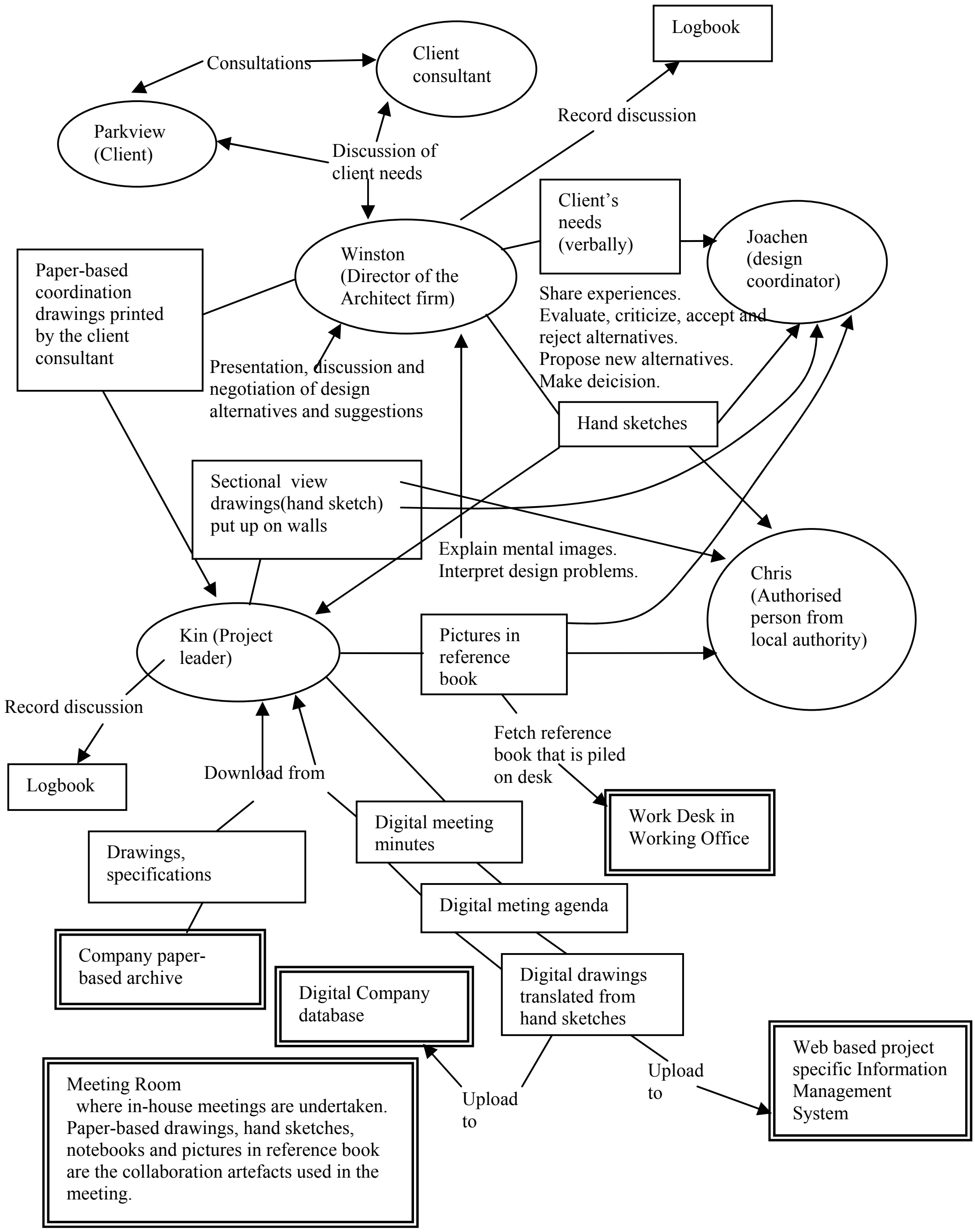


Figure 5.C.1. The workflow model illustrates the interactions undertaken by the multidisciplinary stakeholders for completing their respective tasks. Most of the stakeholders represented as bubbles in this figure met in the face-to-face meeting in which the observation was made. The interaction with the Client and the Client's Consultant represents a remote interaction that had been achieved before the meeting. In other words, the Client and his consultant did not participate the meeting under observation.

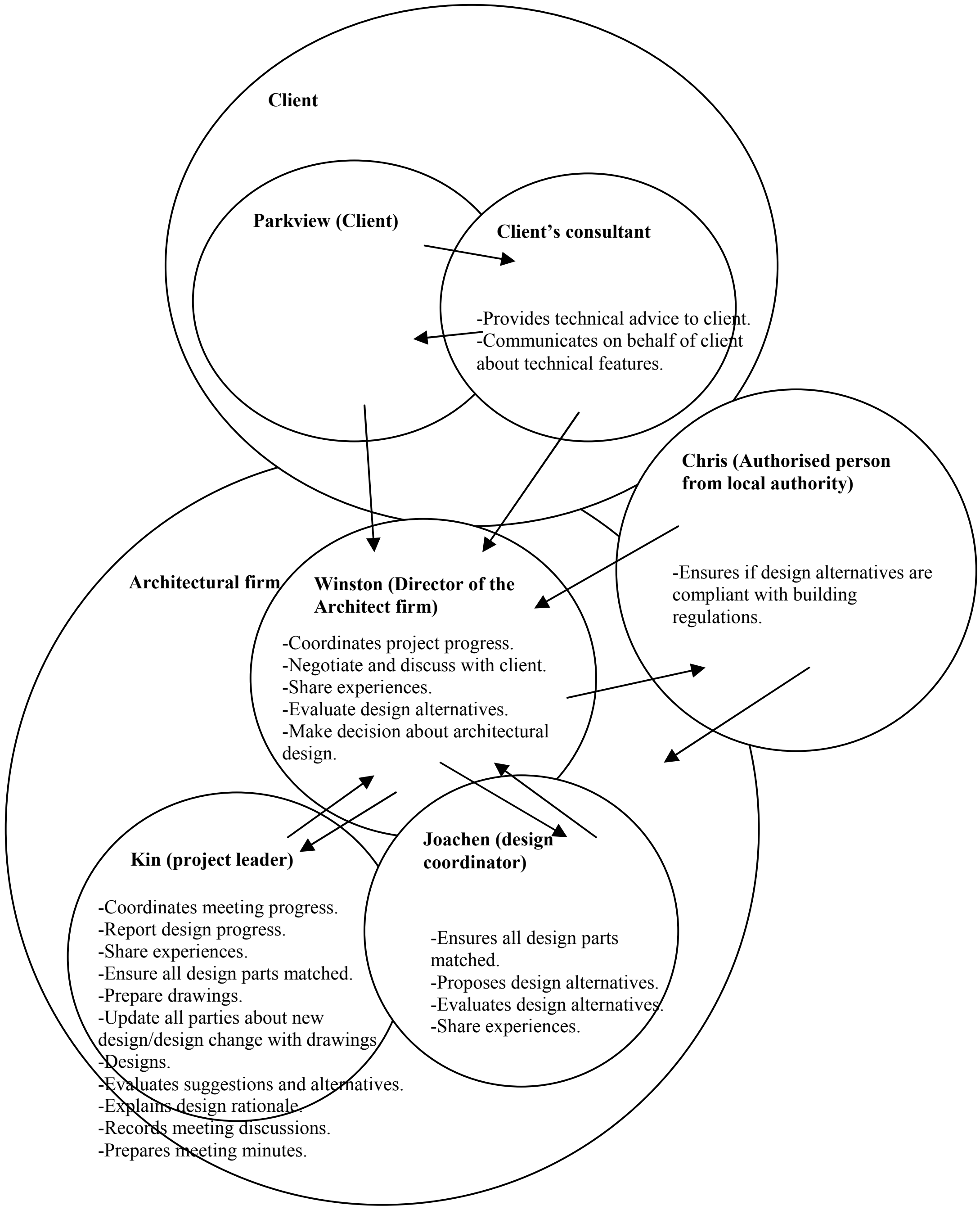


Figure 5.C.2. The culture model illustrates how the work culture of different parties who got involved in the project influenced one another to get their tasks done.

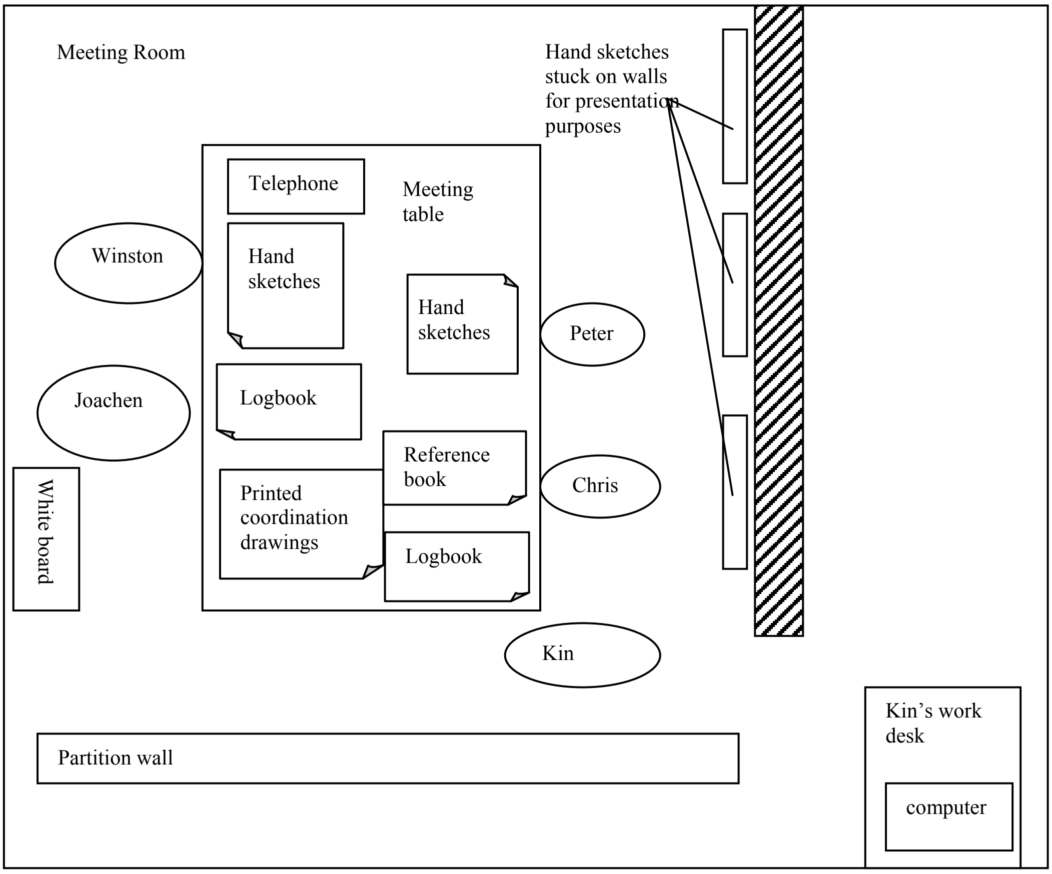
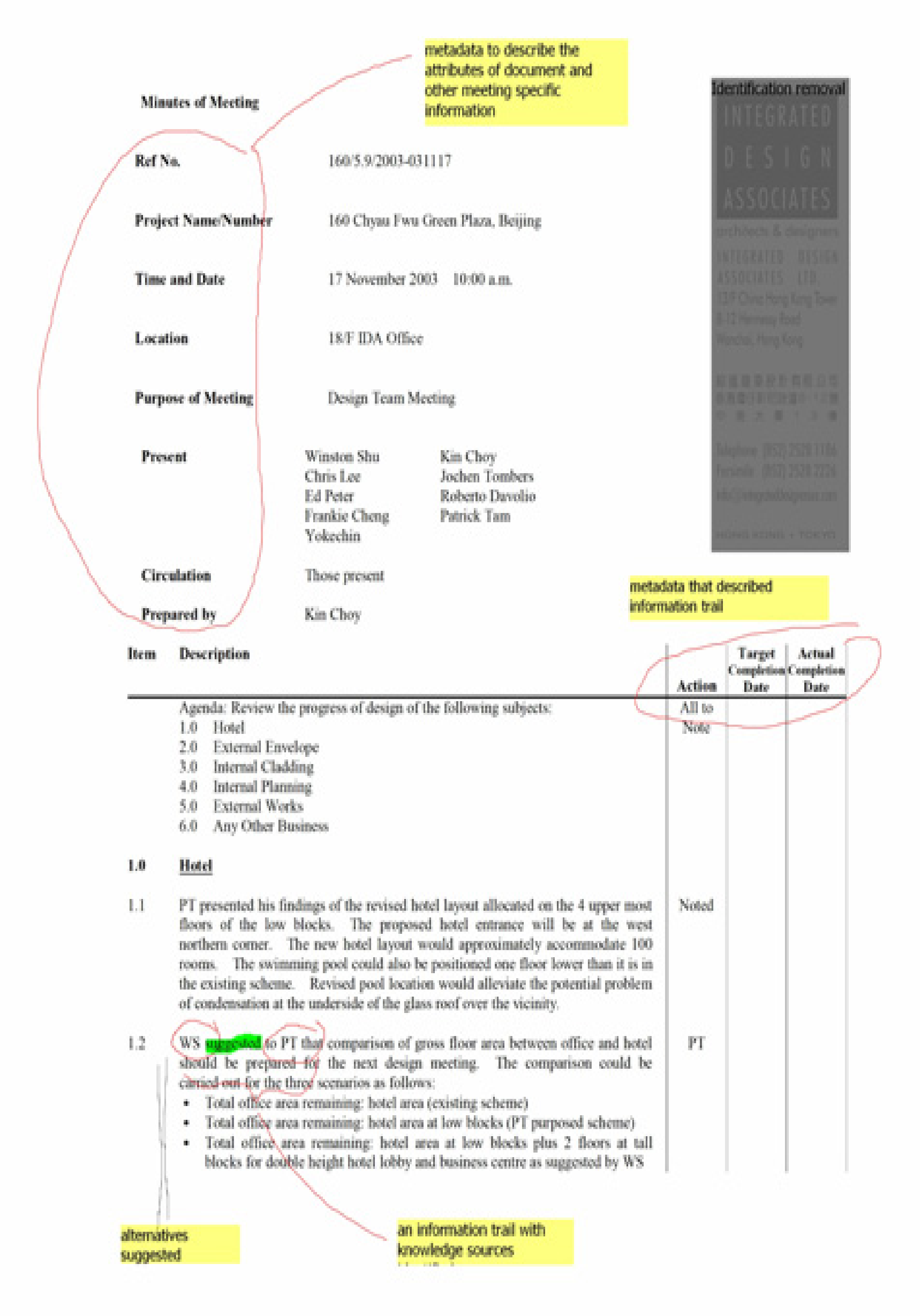


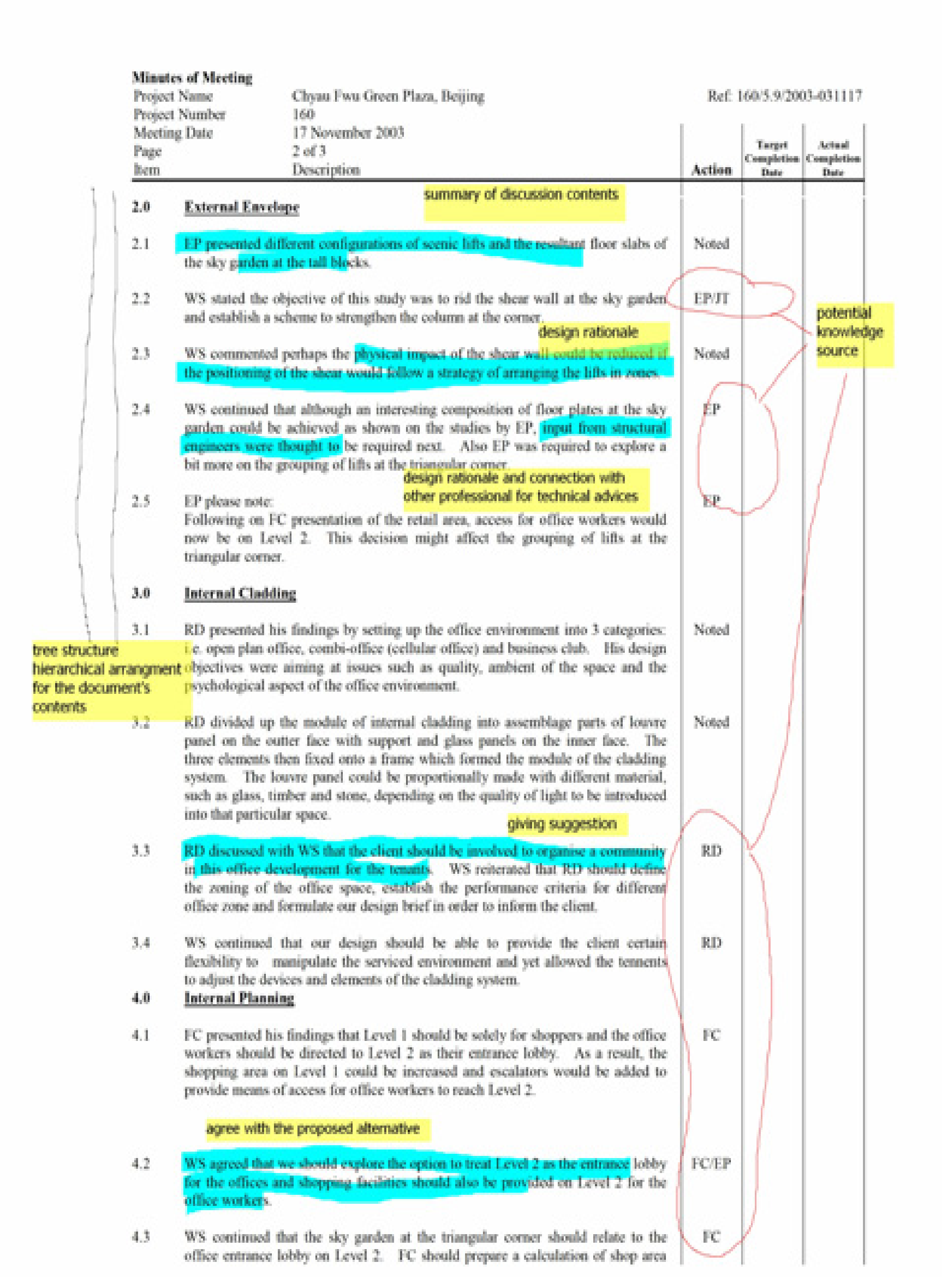
Figure 5.C.3. The physical model illustrates the physical environment of the meeting room in which the observation was made. Small bubbles represent the meeting participants.



Minutes of Meeting

Ref No.	160/5.9/2003-031117
Project Name/Number	160 Chyau Fwu Green Plaza, Beijing
Time and Date	17 November 2003 10:00 a.m.
Location	18/F IDA Office
Purpose of Meeting	Design Team Meeting
Present	Winston Shu, Chris Lee, Ed Peter, Frankie Cheng, Yokechin, Kin Choy, Jochen Tombers, Roberto Davolio, Patrick Tam
Circulation	Those present
Prepared by	Kin Choy

Item	Description	Action	Target Completion Date	Actual Completion Date
	Agenda: Review the progress of design of the following subjects: 1.0 Hotel 2.0 External Envelope 3.0 Internal Cladding 4.0 Internal Planning 5.0 External Works 6.0 Any Other Business	All to Note		
1.0	**Hotel**			
1.1	PT presented his findings of the revised hotel layout allocated on the 4 upper most floors of the low blocks. The proposed hotel entrance will be at the west northern corner. The new hotel layout would approximately accommodate 100 rooms. The swimming pool could also be positioned one floor lower than it is in the existing scheme. Revised pool location would alleviate the potential problem of condensation at the underside of the glass roof over the vicinity.	Noted		
1.2	WS suggested to PT that comparison of gross floor area between office and hotel should be prepared for the next design meeting. The comparison could be carried out for the three scenarios as follows: • Total office area remaining: hotel area (existing scheme) • Total office area remaining: hotel area at low blocks (PT purposed scheme) • Total office area remaining: hotel area at low blocks plus 2 floors at tall blocks for double height hotel lobby and business centre as suggested by WS	PT		



Minutes of Meeting

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Item	Description	Action	Target Completion Date	Actual Completion Date
2.0	**External Envelope**			
2.1	EP presented different configurations of scenic lifts and the resultant floor slabs of the sky garden at the tall blocks.	Noted		
2.2	WS stated the objective of this study was to rid the shear wall at the sky garden and establish a scheme to strengthen the column at the corner.	EP/JT		
2.3	WS commented perhaps the physical impact of the shear wall could be reduced if the positioning of the shear would follow a strategy of arranging the lifts in zones.	Noted		
2.4	WS continued that although an interesting composition of floor plates at the sky garden could be achieved as shown on the studies by EP, input from structural engineers were thought to be required next. Also EP was required to explore a bit more on the grouping of lifts at the triangular corner.	EP		
2.5	EP please note: Following on FC presentation of the retail area, access for office workers would now be on Level 2. This decision might affect the grouping of lifts at the triangular corner.	EP		
3.0	**Internal Cladding**			
3.1	RD presented his findings by setting up the office environment into 3 categories: i.e. open plan office, combi-office (cellular office) and business club. His design objectives were aiming at issues such as quality, ambient of the space and the psychological aspect of the office environment.	Noted		
3.2	RD divided up the module of internal cladding into assemblage parts of louvre panel on the outter face with support and glass panels on the inner face. The three elements then fixed onto a frame which formed the module of the cladding system. The louvre panel could be proportionally made with different material, such as glass, timber and stone, depending on the quality of light to be introduced into that particular space.	Noted		
3.3	RD discussed with WS that the client should be involved to organise a community in this office development for the tenants. WS reiterated that RD should define the zoning of the office space, establish the performance criteria for different office zone and formulate our design brief in order to inform the client.	RD		
3.4	WS continued that our design should be able to provide the client certain flexibility to manipulate the serviced environment and yet allowed the tennents to adjust the devices and elements of the cladding system.	RD		
4.0	**Internal Planning**			
4.1	FC presented his findings that Level 1 should be solely for shoppers and the office workers should be directed to Level 2 as their entrance lobby. As a result, the shopping area on Level 1 could be increased and escalators would be added to provide means of access for office workers to reach Level 2.	FC		
4.2	WS agreed that we should explore the option to treat Level 2 as the entrance lobby for the offices and shopping facilities should also be provided on Level 2 for the office workers.	FC/EP		
4.3	WS continued that the sky garden at the triangular corner should relate to the office entrance lobby on Level 2. FC should prepare a calculation of shop area	FC		

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	against circulation area for our information.			
5.0	**External Works** (explained the reasoning behind design)			
5.1	KC presented sectional details of two different approach to the landscape design at the 3m zone around the perimeter of the site. KC explained the site boundary should be defined with the outter most hard edges of the planter boxes and the approach to these landscaped "pocket" of spaces could either be going up flight of steps or down flight of steps.	Noted		
5.2	KC proposed that the approach of going down the landscaped pocket of spaces was more spatial and the objective of providing a resting place to appreciate the building seemed more relevant. (gave proposal for a design based on analogy of ideas)	Noted		
5.3	WS highlighted issues such as the treatment of handrail, the integration of the planter cages with the fire escape stairs, ventilation openings, external lighting and follies of different theme could be further explored. Also the treatment to the wall below the parapet, the positioning of the ring beam at the retaining wall and the horizontal concrete prop thereof, the constructional details of the EVA route and the 3m deep soil required at the perimeter were also discussed.	KC		
5.4	WS continued that elevational studies of the parapet walls extending to the B2 level sunken garden were required. Overall coherent of the design should be achieved. (made decision and plan for next)	KC		
6.0	**AOB**			
	KC informed the meeting that the building above ground was required to be repositioned back to its co-ordinates as defined in the concept design stage and approved by the Beijing Authority.			

Meeting ended at 4p.m.

Kin/kc

19 November 2003

Figure 5.C.4. The Artefact Model: An example of meeting minutes. The model was analysed in several aspects including the document structure, the document contents and how discussion contents were formulated in natural language texts to portray analogy of ideas, decision reasoning and design rationale. The analysis was annotated in (yellow) boxes shown in the figure.

ANNEX 7.A TEST SCENARIOS FOR THE NEW SYSTEM DESIGN (including the futuristic scenarios of a virtual collaboration workspace)

Bob is a representative from Company A, who is assigned to set up a team with the responsibility for designing a new residential area. Company A is a housing developing company. To set up a design team, Bob wants to know who the team members of the previous projects of Company A were. Bob sits in front of his desktop to search previous cases from the virtual workspace (IT-CODE). He inputs the name of a previous project to the query. A graphical information representation pops up in his computer screen to show the list of stakeholders identified with their roles of the specified project associated with their respective personal particulars such as name and contact information. Relevant information such as the affiliated company, some other participating projects, previous teammates, can all be traced by further browsing the displayed graphical representation.

Bob wants to know who all the engineers involved in Project C are. Very quickly he just inputs the name of Project C to access to the ontologies (RDF schema) built. A list of properties that are defined in the RDF schema of Project C is then displayed in the drop-down list box to assist Bob to search the information of interest. By choosing the property named "has-role" and filling in the provided dialog boxes to construct a simple query for narrowing down the search scope. The graphical result is then displayed to Bob. The result consists of the names of all involved engineers, and their profiles.

Now Bob wants to find, say, all documents in regard to space planning that finished before 29/3/2001 of Project B, the stakeholders who contributed in the planning and where are they respectively stored. Bob needs to choose the project-specific ontology by inputting the project name, Project B. The next step he needs to do is to construct a query by following the user-friendly on-screen instruction. After inputting such information as "Search documents and authors from documents with keyword of space-planning and cut-off date of 29/3/2001" into the appropriate dialog boxes, the demanded answers are displayed associated with the respective URIs of the documents in a graphical representation.

Since the last coordination meeting conducted three weeks ago, a forthcoming one for Project D will be between Bob and the design team tomorrow afternoon. Bob is responsible for three more projects, which run in parallel with Project D. In the last meeting, a discussion in regard to the design of a wall was carried out. Conflicts of interest between the architect and the structural engineer occurred in the design. Both parties compromised and decided to make some appropriate changes. Before the next meeting, Bob needs to know what changes have been made and, therefore, he wants the latest version of the design drawing. Bobs logs into the virtual workspace of Project D and uses the Semantic Search function. He starts his search by choosing the right ontology (RDF schema) and constructing a query by inputting the appropriate parameters (information) into the displayed dialog boxes.

Will is the famous architect in the city. It is necessary for Bob to do some research before deciding to choose tender offered by Will. Bob wants to know more about Will besides all those glamorous comments. The best thing Bob can do is to consult opinions from companies that previously collaborated with Will. In order to conduct a careful research, Bob has the idea to look for all companies that store (d) sketches by Will, with the assumption that only companies that correlated with Will store (d) his sketches. Bob activates the Semantic Search engine and fills up the query form. The input information is likely as "Search all companies that store sketches of architect whose name is Will". After a few seconds, searched results with names of companies associated with the respective URIs are displayed on Bob's computer screen. With this information, Bob can make further moves such as to contact the relevant personnel of the corresponding companies.

Example of Query Search

Example of basic query search: "Search all documents which are about Will".

Enhanced Query:
"Search all documents which (are about: Will or
are about: any subclass of Will or
are about: any group related to Will)
and have keywords: Will, architect, design, comment
and do not have keywords: advertisement
and are between dates: 2002-01-02 and 2002-05-05
and are submitted by Alan or Joe"

Comments: To date, the query search performed above is only available for structured databases but not for the unstructured and semi-structured web-based heterogeneous information sources (containers). By using the semantic web based IT-CODE, such a complicated query search can be performed by the Semantic Search engine.

Scenario of collaborative design in a virtual workspace:

A coordination meeting will be started five minutes later. Bob is sitting at his office and reviewing the meeting minutes of the last meeting and the meeting agenda of this meeting. He does all this just with his desktop computer log on to the internet-based virtual workspace. He is suddenly alerted by a bell ringing sound from his desktop computer, and a small window with the notice of "John has just log in" blinking at the same time. He knows it is the architect, John, ready to start the meeting. Very soon, more team members log on to the conference room of the virtual workspace. They are now all ready to start the meeting. John, the architect, wants to present to Bob, the client's representative, his latest space planning after responding to the advice from the structural engineer.

All conversation in the meeting is recorded. Approximately five minutes before the meeting session ends, John activates the RDF editor of IT-CODE to create a simple meta-model, which semantically represents the information generated in the meeting, to facilitate future reference and reuse.

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