LESSONS LEARNT FROM EXPERTS IN DESIGN RATIONALE KNOWLEDGE CAPTURE

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Abstract

The focus of this paper is on the use of argumentation models and software tools to support knowledge capture in the design of long-life engineering products. The results of semi-structured interviews with a number of experts in the field are presented, exploring their collective experience of knowledge capture and eliciting guidelines for successful implementation of such models and tools. The results of this research may be used as the basis for the design of future tools and techniques for knowledge capture.

Keywords: Design rationale, Knowledge management, Argumentation, Information management, Technology

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1 INTRODUCTION

Knowledge is recognised as a valuable organisational resource from a strategic perspective and a foundation for competitive advantage in today's business environment (Ragab and Arisha, 2013) (James, 2004; Erden et al., 2008). The improvement in service support for long life products, for example in the aerospace industry, depends upon the implementation of effective knowledge management (KM) systems within dynamic learning environments. There is a need to capture information and knowledge related to the product as it is generated during both the design and manufacture stages, so that it can be re-used (Giess et al., 2008). Knowledge loss can lead to significant and widespread performance implications for an organisation (Daghfous et al., 2013). The results of a study show that strategies that target the retention of tacit knowledge and its inclusion in an organisation's routines are an effective means to mitigate knowledge loss (Daghfous et al., 2013). They suggest that a combination of standard operating procedures (SOPs) and strategies that enhance the capture of tacit knowledge should increase effectiveness of the organisation's KM efforts (Daghfous et al., 2013).

The focus of this paper is on the use of argumentation models and software tools to support knowledge capture in the design of such long-life products. After presenting the background to such approaches, the results of semi-structured interviews with a number of experts in the field are presented, exploring their experience with knowledge capture and eliciting guidelines for successful implementation and future development of such models and tools. Although the number of interviews is small, the deep expertise of the interviewees has allowed a rich picture of the issues in design rationale capture to be identified.

2 BACKGROUND

2.1 Argumentation Model

A key aspect of knowledge capture in engineering design is capture of the argumentation behind decisions taken during the design process - the 'design rationale'. A review of theoretical models of argumentation used to represent knowledge identified fourteen in total (Schneider et al., 2012). Seven of these are for capturing argument structure, whilst the remaining seven are linguistic approaches that deal with issues relevant to argument structure or detection. Both the Toulmin and Issue-Based Information System (IBIS) models follow the argument structure approach and may be used to address complex and wicked problems (Horst and Rittel, 1973). Although discussion of the range of models is not within the scope of this work, the IBIS model is popular because of its representational power, and therefore the selected model for this research. IBIS aims at supporting and recording decision-finding processes for problems which occur in design and planning (Scheuer, 2010). It is based on issues which take the form of questions (Rittel, 1970). It is particularly useful in supporting community and political decision-making and was designed as a documentation system, meant to organise discussion and allow subsequent understanding of the decision taken (Schneider et al., 2012). The benefits of using IBIS for addressing these types of complex problems are that (Conklin, 2006):

- It organises the debate by the questions from a high-level (general question) to a low-level (specific question), so it is easy to keep track of the questions' related ideas and arguments.
- It helps to exchange different answers in the collaborative environment by asking questions which also helps in the reasoning and cognitive thinking.
- It is a simple model to use.
- The notations have power in solving complex problems.

A simple example of an argumentation diagram using the IBIS model is illustrated in Figure 1, produced using the Compendium tool (Selvin et al., 2001), which shows an issue node, with two possible solution nodes and associated pro/con argument nodes.

2.2 Argumentation Tools

A review was conducted into 50 software tools that are built upon the argumentation models in the context of computer-supported collaborative learning (Scheuer, 2010). It considered both single-user and collaborative argumentation tools, since many single-user tools are often used collaboratively. The

tools were designed for various applications, ranging from constructing philosophical, legal and scientific arguments, to supporting group discussions, and included (Scheuer, 2010):

- **Single-user argumentation systems** – these are software modelling tools that help individuals structure their thoughts and/or prepare argument representations. Some systems provide only modelling facilities (e.g. Athena, Araucaria and Carneades), whilst others actively provide feedback (e.g. Convince Me, LARGO).
- **Small group argumentation systems** – these act as a software mediator between a relatively small number of participants and typically offer synchronous communication and/or collaborative modelling tools. Users may interact with both the system and other participants (e.g. Digalo, QuestMap, Belvedere and AcademicTalk).
- **Community argumentation systems** – these are similar to small group argumentation systems, but with support for a larger number of participants. Communication is typically asynchronous to avoid co-ordination problems (e.g. DebateGraph and Collaboratorium).

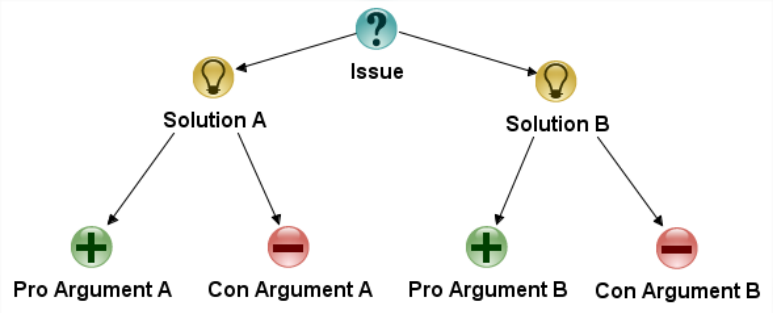

Figure 1. Simple IBIS Argumentation Diagram

Part of the review considered the gIBIS, QuestMap and Compendium tools that are based on the IBIS methodology. Researchers have also developed knowledge representation tools explicitly for design rationale capture which utilise the IBIS model (van Schaik, 2014). The principal graphical design rationale editors that represent the state of the art are Compendium and DRed (van Schaik, 2014). In addition, DesignVUE is an open source tool that is based on DRed, and Glyma is a more recent tool that has been made open source, so is also included within the tools described below which have been used in design rationale capture:

- **DRed (Decision Rationale editor)** – is a software tool which has been continuously developed since 2002. It is owned and its distribution controlled by Rolls-Royce plc, together with the EPSRC (Engineering and Physical Sciences Research Council). DRed maps are entirely composed from a fixed set of just 10 node types, each of which has one to five alternative statuses. Version three of DRed enables projects to be exported as a Microsoft Excel workbook, or as hyperlinked sets of .html or designVUE .vdk files. The success at Rolls-Royce has pushed DRed to the level of being one of the key design systems and tools together with more traditional design tools (Aurisicchio and Bracewell, 2013).
- **DesignVUE (Design Visual Understanding Environment)** – is a diagrammatic tool to generate information maps using the IBIS framework. It supports 'ideation' and decision-making for individual and collaborative design and planning practice. Maps have a bespoke file type (.vdk) and nodes can be bi-directionally hyperlinked to nodes in other maps (termed a wormhole). It was inspired by DRed, is open source and is developed at Imperial College London, supported by EPSRC. There are four IBIS nodes, namely, (i) issue (ii) answer (iii) pro argument, and (iv) con argument. Maps are usually composed of a three-level hierarchy, firstly an issue node, secondly one or more answer nodes, and thirdly, various argument nodes. Each node can also have a range of alternative statuses, for example, 'rejected answer', 'unlikely answer', 'accepted answer', 'rejected issue', etc. The tool has a lock feature that enables collaborative working on a shared file(s) (Aurisicchio et al., 2016).
- **Compendium** – is a software tool for mapping information, ideas and arguments. It was first developed in 1993 as an approach to aid cross-functional business process re-design (BPR) teams, and has been applied in many projects in both industry and academic settings. Compendium was described as being at the intersection of (i) collaborative modelling (ii) organisational memory (iii) computer-supported argumentation, and (iv) meeting facilitation (Selvin et al., 2001).

- **Glyma** – is an open source tool, similar to Compendium, but designed to enhance collaboration. Unlike the other tools, it has commercial roots and is built upon Microsoft SharePoint (Culmsee, 2015).

These design rationale knowledge representation tools are all designed to capture knowledge in a retrievable manner. Many of these and other similar tools have been designed and developed based on many collective years of research and experience. When looking forward to the future of such knowledge systems, it is important to understand the shared lessons learnt from this prior work, and that was the objective of the interviews conducted.

3 METHOD

3.1 Research Method Selection

As part of a larger project aimed at developing new design decision capture tools, and to understand the collective lessons learnt from many years of experience in this field, a number of experts with direct experience in the development and use of design rationale capture tools were interviewed. Undertaking semi-structured interviews with these experts enabled specific research questions to be addressed directly, and provided the opportunity to gather primary data from the experts.

Qualitative interviewing is a flexible and powerful tool to capture the voices and the ways people make meaning of their experience (Rabionet, 2009), and there are several advantages in using a personal interview as the method for collecting data. It has the potential to overcome a poor response rate of a questionnaire survey (Barriball and While, 1994). The data collected is from a primary source. The interviewer is able to build a rapport with the participants and direct further questions based on previous responses. This form of data collection is particularly useful for the exploration of the perceptions and opinions of respondents, enabling probing for more information and clarification of answers (Barriball and While, 1994). It is also an effective means of gathering data from respondents where there is not a commonly shared vocabulary, which enables the interviewer to adapt the questions to the interviewee.

Four semi-structured interviews were undertaken with experts in the field and provided an opportunity to talk with these experts to allow them to reflect and talk about their experience. The experts had been intimately involved with the implementation and application of the design capture tools described in Section 2.2 and therefore had a richness of experience which it was wished to access.

3.2 Participant Selection

The interview participants, as noted, were selected due to their experience in the field of knowledge capture within the context of design, complex problem-solving and decision-making. Each of the participants had a major involvement with developing design rationale tools as shown in Section 2.2 (one interviewee for each of the four tools). Each participant brought many years of experience in capturing information and knowledge to the discussion, especially within group collaborative work, and each brings a unique perspective from their experience on working in the area on various projects both in academia and in industrial contexts.

3.3 Interview Design

The semi-structured nature of the interview enabled the same broad questions to be asked to each of the participants, but in a way that provided flexibility by allowing adaptation of each interview to the participants' different backgrounds and experience. All participants were asked a similar set of questions, but there was no rigid ordering of the questions. Participants were given open-ended questions and encouraged to talk about the views and experience related to this.

An interview protocol was developed to conduct the interviews. The interview protocol has two important components, namely (i) how the interviewer introduces him/herself (ii) the questions (Rabionet, 2009). It was firstly important to establish rapport with the participants. Since none of the participants were previously known to the interviewer, background reading was undertaken to understand the background of the participants and have understanding of their previous work. Since the researcher was positioned in both academia and industry, it was deemed necessary to clearly explain the role of the researcher, along with the motivations and goals. The introductory part of the interview involved a script pre-amble stating the purpose of the interview, the context, the interviewer's position within academia and industry, and finishing with presenting the opportunity for questions or any

clarifications. The second part of the semi-structured interview was based around the main questions in Table 1. A literature review highlighted the research gap that new methods and tools need to be developed to improve the situation. Subsequently, the following questions were derived to learn first-hand from the experiences of experts to build upon their work for future development.

Table 1. Semi-Structured Interview Questions

Question	**Purpose**
What experience have you had at meeting facilitation and group knowledge capture?	To clarify the background to the interviewee and their approach, and to build rapport.
What have you found is important to capture within this context? And how have you found that this is re-used, if at all? What are the parameters and trade-offs to capturing this information and knowledge for re-use, if any?	To identify what information and knowledge is important to capture, and what lessons have been learnt from past experience. To understand the factors that need to be considered when capturing knowledge and the nature of their relationships.
What methods or tools have you used to capture knowledge in this context? And how effective would you say that they are, in terms of strengths and limitations?	To understand the interviewee's evaluation of the effectiveness of previous and current methods used for capture.
Do you have any facilitation guidelines, documents, examples of best practice, or lessons learnt to share?	To identify any potential gaps in the literature search, e.g. new work emerging, non-academic work, work from other related communities/domains, etc. And to allow the interviewee to discuss any points that they think are relevant.

The development of the questions was based upon a literature search to understand the subject matter in sufficient detail to talk with experts in the field. In order to enhance the quality of the questions and interview protocol, the researcher used the material and knowledge from a training course in interview techniques to supplement the reading. This planning stage was key to ensure quality in the process. The concluding remarks at the end of the interview were to explain to the interviewee the process and the next steps for the research. There was an opportunity provided at the end of the interview to allow the interviewee to express any concerns, or ask any questions. It was not deemed necessary to conduct a pilot interview, since the interviews were loosely structured and discussion-based. However, the questions were reviewed and developed iteratively in parallel with the literature review. The interviews were conducted remotely using a telephone or voice-over-IP software, depending on the preference of the interviewee. This choice of format for interviews was chosen given the circumstances. When the interviewee's responses were unclear, the interviewer asked for clarification. In certain situations, the interviewer also probed for more detail to ensure completeness and accuracy in the response. When it was necessary, the interviewer re-phrased questions to ensure that the participant understood what was being asked.

3.4 Data Analysis

Participants' accounts of their experiences were the primary source of data. Each interview lasted between 35 and 100 minutes, and was recorded in audio format to reduce the likelihood for interviewer error. The interviews were transcribed from these audio recordings by the researcher, to allow the researcher to become totally immersed in the discussions. An intelligent verbatim (Anon., n.d.) transcript was manually produced by the interviewer which omitted all housekeeping issues, including filler phrases and meaningless utterances. Brief notes of important points were also made during the interview for reference.

The data was analysed to identify key themes. The issue with such a data reduction approach is that there is a risk of missing relevant points and losing the sense of meaning. This was addressed by having more than one researcher undertake the analysis and also using the audio recording in addition to the textual transcription to review the interviews. A coding technique was used to make sense of the interview data using the software, NVivo. Key phrases were coded within the transcript that were linked to the initial question themes. This coded data was then organised into categories corresponding to these

themes. The key points and patterns were then identified from the data. This was an iterative approach, whereby additional themes emerged throughout the review process with multiple researchers.

3.5 Confidentiality

Each of the participants was asked verbally if they would be willing to participate in the research and signed a permission form. After the interview, participants were also provided with a transcription and invited to make any corrections or comments.

4 RESULTS AND DISCUSSION

There were several key themes that emerged from analysing the interviews. These are discussed in the following sections.

4.1 Adding Value

A key message from the experts was that in order to capture knowledge effectively, it needs to be a value-adding exercise both at the time of capture and later on. Participant one (P1) claimed, "*I think it needs to be part of the process*". P2 explained this point further, stating that "*if your value is simply capturing stuff that someone may use in the future, that's not really an awful lot of use to the people who are actually doing their work now*". P2 went on to explain this as a known problem in collaborative systems where there is the need to "*support the work that your colleagues are trying to do now, as well as any future promised pay-off"*. If this is not done, then effort is spent on intensive documentation that no-one will care about because "*…it's for some unknown person, in an unknown future, who needs that information for some unknown purpose...which is a tough value proposition*". So the key lesson learnt is the need "*…to add value to them in the short-term and ideally you want as a by-product that something is going to drop out which is also more useful than just bunch of photos or flipcharts or a few notes in a Word document, or a discussion thread in some internal system"*. P2 elaborated on this point further, by explaining the issue with not taking this approach, "*You're not going to be able to sell it just on the basis that this will just help people maintain the system in the future. In the end people will do it if they have to, but you're trying to constrict people into something that seems to have poor return for their time and energy*". This challenge has been an issue for 20 years in Design Rationale research, explained P2. Whilst supporting maintenance of the engineering product in the future is useful, P2 reflects that this alone is a hard sell- "*So the key breakthrough was understanding how to tie this to adding value right there and then, or close to there and then. Possibly as a result of having a very focused discussion, you generate documentation out of that that everybody in the room values because it helps us move on*". A key lesson learnt here suggests that the knowledge capture should be as much of a supporting tool as it is capture for later re-use. P2 states, "*when things get busy, the first thing that goes is documentation, and there's still the sense that it benefits somebody else*", reinforcing the need to add value up-front. P3 shared this view, stating that "*they (the producer of the record) have to benefit themselves*", before going on to describe their experience with the approach that they took. P3 claimed that their approach was produced with the aim of capturing rationale for future use. However, they were surprised to find that it wasn't only future use that was important, it was useful at the time too. In the context of a meeting addressing a difficult problem, P3 explained, "*we found that when people captured the structure of the discussion, we could keep track of the problem-solving process much better. So the meeting got captured for future use as well, but people were doing it because it was helping at the time in addressing their immediate problem*". P2 described a similar experience explaining, "*We had a mantra...'value now and value later', but if you've got no value now, it's going to be a tough sell*".

4.2 Parameters and Trade-offs

A key theme to be discussed was that of the trade-offs that are necessary when capturing knowledge from groups. P2 discussed the trade-off between who does the work and who gets the benefit. P2 identified the issue of where, when and by whom the effort is put into the process in terms of 'overhead', and the trade-off that is required. Discussing meetings in particular, P2 states, "*There are many approaches to meeting capture, including machines starting to make sense of audio and video records. Which have got a very low overhead for the human initially, but potentially could mine the transcript...speech-to-text technology, etc. So there is a whole space of trade-offs going on here as to who is carrying what effort and when in order to perform what kinds of tasks*". P2 went on to discuss

this trade-off in terms of the return provided and the challenges- "*So the only principle that I could declare with confidence is you're going to have to negotiate the cost-benefit trade-off somehow. You either incur up-front, which gives you a higher return, or you try and minimise the capture costs, but then you're potentially creating harder re-use costs later on. Or if you minimise the capture costs and just press record on some device, how is that going to help people actually in their job, right here and now, without either a smart human or smart agent going through that and trying to extract stuff of value?*"

4.3 Important Information to Capture

The topic was discussed as to what is important to capture in the context of engineering design meetings, workshops and synchronous collaborative working. A key message was that the importance of what should be captured is very much context dependent. P3 explained- "*It depends so much on what knowledge you're trying to capture in the workshop. For a start there is quite a difference between a workshop that is trying to elicit group knowledge about something....how a system works or what the structure is of a system, what problems there are in a system...and then a workshop that's trying to get a group of people to use their knowledge to solve a problem. (there is) a fundamental divide between those two types of workshop*". With a similar view, P2 said- "*It's a little hard to answer (what is important to capture) because there are so many different contexts. The answer is always going to be dependent on what are you trying to do, or what's needed to move people forward*". P1 stated the need in this context to capture actions and the advantages/disadvantages of alternative options. P1 also highlighted the importance of aspects that were agreed not to progress with, in addition to what is not required- "*We found that it was useful to capture what has been agreed as a proposal to go forward, as much as what has been agreed not to go forward. And also the reasons in favour and against these alternative options that are being considered*". P1 went on to add, "*I think with rationale models what I imagine that you don't capture the obvious. There are many things that are obvious, and they could easily make argument for example that you captured. But they are not useful to anyone. So you only focus on things that are really critical for what you are thinking about. So this often is very much dependent on the expertise of the people involved, because depending on how much you know about a specific domain, some arguments can be more or less obvious*."

P3 discussed the need to capture what participants feel is important for their role and the essence of what was said- "*You capture what the participants feel is important in what they are saying. When somebody makes an important point, what they think is an important point, in a technical discussion, they want to see that the crux of what they said in their field is there in the graphical map*". P3 went on to describe how the importance of what to capture should be linked to the final engineering product- "*What people think is important is anything that they can see that will significantly impact the quality of their performance doing their job. Will it impact the quality of the final product? Will it impact the time or the cost of producing? It's engineers. Engineers know what's important in doing their engineering, and they will aim to capture anything that's in their head that will have a significant bearing on those quality parameters*". Acknowledging that people's understanding will vary, P3 notes that "*The important thing about capturing rationale is that if there are misconceptions, those misconceptions are captured...that when in the future the truth is discovered, you can go back and annotate the record as to why these things are wrong and we now know that they are wrong...don't make the same mistake again*".

4.4 Facilitation

It is evident that there are a range of approaches that have been adopted amongst the experts in terms of co-ordinating the elicitation of knowledge. These range from eliciting knowledge from a group of participants in a workshop by a skilled facilitator, to having no facilitation at all, through training participants to work and think in a certain way.

The Glyma approach, described in Section 2.2, is derived from the practice of dialogue-mapping (Conklin, 2005), whereby a skilled facilitator guides a group to build-up argumentation documentation, to identify and evaluate various decision options. This form of capture tends to be aimed toward socio-technical and wicked problems. Contrastingly, the approach taken by DRed and DesignVUE involves no appointed facilitator and relies upon individual participants building up a graphical representation of argumentation, design and evaluation themselves. This approach requires the participants to have been trained in thinking and working in a certain way, and is designed to work in both synchronous and asynchronous collaborative contexts. The approach for Compendium appears to be fairly adaptable,

allowing argumentation to be constructed and knowledge captured either with or without a facilitator. Compendium as a tool lends itself to both approaches, but appears to lean toward using a facilitator for knowledge capture.

When addressing the role that facilitation has to play in such knowledge capture activities with the experts, P2 discussed the particular qualities and skills that a facilitator needs. He described his experience of facilitating using such an argumentation tool explaining that a good mapper "*keeps up with what's going on, and adds value to the meeting and comes up with something coherent at the end and everybody feels that they own the decision and they made progress*". P2 went on to distinguish the difference between dialogue mapping and conversational modelling in this context, explaining that conversational modelling uses a model such as IBIS that requires answers to questions- *"Any model is simply a framework to manage attention. It says these are the important things to pay attention to at a particular moment in the design process". P2 went on to introduce the use of metadata tags to generate richer datasets- "That was the key development that they made with conversational modelling was to tie it to a framework or model that actually the people in the room might well be familiar with anyway".*

Elaborating on their experience and knowledge of how to facilitate groups for knowledge capture, P2 explains that "*you've got to be fluent with whatever representational tool you're using, whether that's a pen or (software tool) or something else. You're going to have to hopefully understand where the team is coming from and where they're trying to get to. You're going to have to have improvisational skills. You're going to actually be making some ethical decisions, because you have to decide whether to intervene in the conversation here and steer it in any direction? What am I going to record?...what am I not going to record? So those actually start to take you into sort of ethical decisions because you're choosing to capture some stuff and throw some other stuff away. Or should I perhaps not record what was just said there because that wouldn't be appropriate? So there's an awful lot going on*".

In contrast to this facilitation approach, P1 and P3 explain how they have experienced engineers who are trained without the need for a facilitator. P1 explains- "*...the view that I was trying to put forward is that people can be trained into capturing rationale and make independent design rationale capture. So people can achieve that without the need of some support and a kind of external knowledge elicitator…So our view in the research has always been to try and teach users to read and write design rationale maps independently*". P1 explained that they had no experience in taking a facilitation approach, but noted a benefit in terms of contribution- *"...my assumption is that when you have a facilitator, the people that are participating into a meeting are only able to read a design rationale map, for example. Whereas, if you don't have a facilitator, everyone should be able to do both tasks of writing and reading*". P1 notes that whilst this approach requires no facilitator, he points out the need for the knowledge representation to be co-ordinated in some way- "*So we did see that there needs to be someone that essentially keeps a record of the knowledge structures that are created, and essentially co-ordinate the rationale that is captured. So in that sense, that person can be seen as a co-ordinator. But we also trialled situations in which essentially the output of the software are kept on shared drives, and can be accessed and edited by multiple people*". P3 also clarified that they had limited experience in facilitation, but explained the approach that they took- "*the received wisdom was this works if you've got an expert facilitator in the IBIS method and only in that situation. You need to take your group of experts, bring in your expert facilitator and do your workshop and you'll get a decent result...the experience of (software tool) was quite contrary to this. We found that the design teams could facilitate these things themselves...they could capture rationale and what they were doing whether in individual situations or asynchronously collaborative groups and if they wanted to review that in a workshop situation, they could bring the materials along, they could do their own facilitation, review, annotate, and capture the rationale for the decisions being made...accepting and rejecting things. Very fluidly they'd go between their individual work, asynchronous group work, using the same tool and the same documents*".

In stark contrast to the approach of P1 and P3, the work of P4 is based around having a facilitator to elicit the group knowledge. P4 described his experience as a practitioner working in various industry and academic settings using a dialogue-mapping approach. He explained how to learn to become a good facilitator- "*Facilitation, basically it's a craft skill. You've just got to do it the hard way and learn. I learned from watching others and it was the hardest bit for me to master...and I still haven't mastered it, but I'm better at it than I used to be*". P4 broke this down into three stages, "*In terms of dialogue mapping proficiency, it really is three stages. Stage one, you get to the point where you can do the IBIS notation…(stage) two, you've then got to be reasonably savvy on the (software tool) software (step three) then I just learned to facilitate by just doing it*".

It is clear that the adopted approaches and the development of the tools with respect to facilitation differ greatly. However, even in the case of no facilitation, the need for a form of co-ordination is recognised. Where a facilitator is needed, it is apparent that this role is challenging and requires considerable practice to become effective. The tools have been designed to be used in very different ways, but all are aimed at supporting the design work, not merely acting as a design rationale documenter. Whether used to support the facilitation of a group workshop synchronously, or to support the co-ordination of group design work asynchronously, the IBIS model can be used is a variety of ways.

4.5 Knowledge Structure and Representation

Each of the experts has experience with using various methods of capturing information and knowledge, but they are all experienced in using a graphical representation of knowledge, such as with the IBIS framework or similar. P2 and P3 covered this issue as part of the discussion. P3 highlighted an important issue related to the structure and representation - "*The important thing is that the graphical representation that you're trying to capture, what's spoken, or what's sketched in the workshop...the structure of the diagram has got to match closely the structure of the knowledge*". P3 also identified a challenge related to managing multiple representations and how they are linked- "*Another important thing is if the task requires more than one representation, how are you going to manage that? For example, if you want to have a workshop that analyses the functionality of a product, finds the bad aspects of what's going on and how it's working, and tries to resolve to find solutions to those bad aspects, then you might want to use a functional analysis diagram to capture the shared knowledge of how it works. An IBIS diagram for each of the individual harmful effects regard that as an issue...how can we remediate this harmful affect? How can we avoid it? And then propose answers for each of those issues. You certainly want to link the issues that are the root of the IBIS for proposing solutions to the harmful effects that have been captured in the functional analysis diagram. It is one integrated information space that you need ways of linking elements between the two diagrams. And that is the whole basis of (software tool) – bi-directional linking...you want to be able to create links, but any link that you create it needs to work both ways, because when you come to it in future, you don't know which way your reasoning is going to be forward or backwards. You need to be able to follow the link in both directions*".

P2 discussed the need to understand how the various aspects are structured and are represented together, "*Basically, you've got a particular, what I call the ontology, which is building blocks of the language. Whether that's IBIS or QOC or some other representational scheme. You've got the representational technology that you're using, whether that's a flipchart or a mapping tool, or any other of a number of representational tools that might be in play...it could be a CAD tool, or Google maps, it could be a simulation, it could be a predictive model...you've got all these different tools to present stuff with. So you've got to understand how it all weaves together into the flow of the conversation.*"

5 SUMMARY AND CONCLUSION

From the interviews the key lessons learnt from the experts for adding value in developing effective future knowledge capture methods are as follows:

- The capture should ideally be part of the design process itself and support the design and decision-making.
- Value should be added 'now and later', i.e. in the short-term at the time of generation of the argumentation models with capture of knowledge for later access as a by-product of this.
- The producers of the record should benefit themselves in addressing their immediate problem, providing an incentive to document.
- A trade-off needs to be made between where the effort is put within the process and by whom, and this needs either an explicit or implicit cost-benefit analysis.
- What is important to be captured is context dependent.
- The following information is important to capture in the context of design-related collaborative working: actions; alternative options considered; advantages and disadvantages of alternative options considered; agreements; rationale (e.g. Design Rationale); an important discussion point that is linked to the final product in some way, along with the crux of the dialogue/argument.

- The adopted approaches and tools differ greatly with respect to facilitation. However, even where no facilitation is used, the need for co-ordination is recognised. Where a facilitator is used, it requires considerable practice to develop the skillset.
- The tools have been designed to be used in very different ways, but all are aimed at supporting the design work, not merely acting as a design rationale documenter.
- The structure of the knowledge representation should closely match the structure of the knowledge itself. And this structure needs to be linked to other knowledge structures and information sources which can be searched and navigated.

In conclusion, this work has compiled the experience and lessons learnt from knowledge capture experts. This synthesises provides guidelines for current best practice, but may also be used as the foundation to address the design of future tools and techniques for knowledge capture.

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