Sieving Pebbles and Growing Profiles

Capitalising on knowledge embodied in design practice

Cristina Cerulli
School of Architecture, University of Sheffield, UK

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Abstract: This paper discusses tools and strategies to support the capturing and use of knowledge embodied in design practice. The tools described are part of a system conceived as a suite of modular tools, KMan, to be developed and adopted incrementally and independently, in the framework of a wider organizational knowledge management strategy. The concept of knowledge pebbles is introduced to describe collections of heterogeneous data formats to form a unit of potential knowledge In the final section of the paper an overview of all the tools part of the system is presented and some of the tools described and illustrated in more detail. In particular the Brief Management Tool, the Generic Search Tool and the Pebble Creation Tool are discussed.

1. RESEARCH FRAMEWORK AND APPROACH

This paper reports on some of the outcomes of ongoing research started with an EPSRC funded project on the issues of knowledge creation and management within construction industry projects (Cooper, Lawson et al. 1998; Cerulli, Peng et al. 2001; Cerulli, Peng et al. 2002; Cooper, Cerulli et al. 2005) and continued through a doctoral research, combined with architectural practice, looking at Knowledge Management tools for construction design practices (Cerulli 2004).

The research framework within which tools and strategies here discussed were designed and identified was fundamentally practice focused, although initially technology driven. Dealing with real construction project processes and complexities was at the core of the research approach and a significant number of leading architectural practices and construction organizations

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contributed to the study through hosting ethnographic field studies, and participating in interviews, workshops and advisory panels.

In terms of system design the approach adopted within this study has evolved from an effectively top-down approach, centred around the ADS prototype, to a bottom-up approach that culminated with the design of the KMan tool, discussed below. The ADS Project (Cooper, Lawson et al. 1998), was essentially technology driven: a set of technologies had become available, namely java and engineering components, and a tool was developed to explore the potential of those technologies within the construction industry, after identifying the problems that needed addressing within that domain.

Although every attention was paid to real practice through careful gathering of user requirements, this approach created an intrinsically top-down system. With a system like ADS a hierarchically structured organization would customise the system to reflect its practices and needs and the information and knowledge captured by the system would be structured according to the company's ethos and directives expressed by the company's executives. For this system to successfully work in practice there needs to be an alignment between the aspirations and intentions of executives, who have a larger input in the briefing, commissioning and funding of the system, and those of the non executive members of the organization, who will, potentially, populate and use the system. This alignment, although achievable, does not necessarily constitute the norm within large design organizations and therefore alternative approaches are required to facilitate the undertaking of knowledge management initiatives by architectural and engineering practices.

As the research progressed it became gradually apparent that Information Technology *per se* is not sufficient to address those problems of the construction industry that this research set out to provide solutions for and that an alternative, practice driven, approach was required. Rather than looking for suitable applications of the latest technology within the chosen domain, the practice driven approach, adopted for the KMan tool, aims to let the tools emerge from practice by providing a system structure that supports emergence. In this model, using collaborative filtering techniques, the organization's hierarchical structure loosens up and clusters of users emerge, based on user's affinities and interests and not on company roles. Similarly the information and knowledge stored into the system is gradually structured according to users' feedback and it becomes increasingly easier for users to find good quality material that is relevant to them.

The difference in approach between the ADS System and the KMan tool is epitomised by the techniques they use: while ADS makes use of taxonomies, structures that presuppose an organization from the top down, KMan uses recommender systems, typically bottom up structures.

2. WHAT KNOWLEDGE

The boundaries and definitions of information, knowledge and data can be subjective and change over time with circumstances. A collection of information does not necessarily constitute knowledge but has the potential to become such when the contextual information retrieved is used to infer and construct knowledge (Cerulli 2004).

In the KMan tool, knowledge is mainly inferred from contextual information made easily accessible and filterable; the tool aims to manage Data, Information and Knowledge, without trying to fit particular items into any of these categories. An item might be input into the system as Information at a point in time A and be retrieved later with other information to form knowledge at a point in time B. Or, alternatively, something that is pure data for an experienced designer X, for instance, the dimensions of standard steel members, can later become the basis for knowledge inferral for a novice user Y that might read this as a summary of steel construction solutions.

The KMan system aims to:

- Capture, manage and index for easy retrieval information already available. This functionality of the tool falls in what is widely accepted as information management but the author argues that effective information management and, hence, retrieval can be the basis for knowledge creation and design activities support.
- Provide a framework within which to gather knowledge by attaching metadata to existing documents to incorporate feedback on their quality or usefulness.
- Provide a place to record and share opinions, ideas and experiences by submitting them to the system.
- Support the emergence of communities of practice as defined by Lave and Wenger in their influential work "Situated Learning: Legitimate Peripheral Participation" (Lave and Wegner 1991).
- Support the creation of a shared repertoire of knowledge amongst users. Creating this type of shared knowledge warehouse for a design organization has the potential of:
    - Reducing time spent solving routine design problems. Part of the proposed shared repertoire could be a collection of successful details to be re-used in future projects. The re-use through adaptation of previous design solution does not necessarily hinder innovation as it is often argued (Grint,

Case et al. 1995; Willmott and Wray-Bliss 1995); on the contrary, it could even facilitate it by speeding up routine design tasks and, thus, freeing up time for ad-hoc inventive and pioneering design (Henderson and Clark 1990; Veshosky 1998).

- Allowing novice members of the organization to benefit from experts' knowledge. One way of doing this is, for instance, making available experts' personal lists of *favourites*, regarding exclusively their area of expertise. These *favourites* can be, for instance, internet bookmarks or a collection of documents that are considered very topical and of good quality.
- Fostering intra-project knowledge transfer and learning. Design problems and technical solutions developed for one project, as well as the performance feedback about those solutions, can be easily made available to the whole organization to potentially inform the design of other projects, contemporary or future.

Stenmark (Stenmark 1999; Stenmark 2001; Stenmark 2002), building on Polanyi's theories (Polanyi 1966), maintains that although we might not always be able to articulate explicitly what we are interested in, we intuitively know it when we see it and suggests that there is scope for KM systems that use recommender systems to make use of tacit knowledge without needing to make it explicit.

> "By identifying certain documents as interesting the user could tell an agent based retrieval system to maintain a dynamic profile that represents a certain limited perspective on the user's tacit knowledge without requiring explicitly defined keywords or manually updated records". (Stenmark 2001)

In the light of the results obtained by Stenmark's research at Volvo and given the quantity and diversity of information to be managed, captured and retrieved within a construction design process the KMan tool uses recommender system techniques to help users to:

- Overcome low signal to noise ratio and to sieve relevant information. As mentioned above in responding to the need of filtering relevant information the approach chosen for the KMan system is to avoid unnecessary formalization, and to opt for a strategy that is less demanding on the user in terms of cognitive overload such as the use of recommender systems.
- Capture and make use of some of the tacit knowledge embedded in people, without having to make it explicit.

3. PEBBLES OF KNOWLEDGE

Within the ADS system heterogeneous data formats were pulled together into the complex dataset *ADS Design Decision Record*, described elsewhere (Cerulli, Peng et al. 2001; Cerulli 2002; Cerulli, Peng et al. 2002; Cerulli 2005). The different types of data constituting the ADS Decision Record were: CIMM management attributes, ADS taxonomical attributes, CAD transaction data, natural language description of design intents/rationale, affected and pending design decisions and hyperlinks to other related documents.

The KMan set of tools keeps this notion of the collection of heterogeneous data formats to form a unit of *potential* knowledge. The term *potential* is used here because, as mentioned above the author endorses that a collection of information does not necessarily constitute knowledge but it has the potential to become such once it is retrieved by a user who will infer and construct knowledge from the provided contextual information (Gruber and Russell 1996).

These *units* of potential knowledge are likened to pebbles on a beach: each pebble is an individual unit and has its individual colour and properties, nevertheless the collection of a large number of pebbles can be read as a portion of beach, just as a collection of information and data can, when interpreted, be read as knowledge or used to construct it.

Moreover if equipped with the right sieve, or filtering tool, one could filter out unwanted pebbles or keep only the desired ones. One, for instance, could decide to filter the whole beach and get rid of all blue pebbles or to keep just the yellow ones that are bigger than one millimetre; similarly one could filter the whole information stored in the system to eliminate decisions prior to a certain milestone or to highlight only the scheduled actions that have not been attended to.

What is a *pebble*? It can be any piece of information to which someone attaches some sort of interpretation, semantic, comment or link. Examples of a pebble could be a folder containing site pictures, a research report on shading techniques, an informative e-mail or a CAD intelligent engineering component.

Once *pebbles* are created their rating will start evolving on the basis of user's feedback. Users will be encouraged to flag out particularly good pieces of information, to provide feedback on the individual *pebbles* and to make links between various *pebbles*. At any time users can flag out pebbles that they consider particularly good and useful. The introduction of a ranking system will also allow accommodating negative feedback, so that poor quality material can be filtered out. The overall pebble rating displayed for each pebble, when retrieved, should be the average of all the rating provided by the different users, but the individual comments should also be made available for reading, if desired.

As knowledge is dynamic and contextual each pebble should be able to evolve over time by being modified and edited. This requires a versioning system to keep a record of the evolution of the pebble over time.

Users can also link several pebbles by defining dependencies and relationships. Regarding the way these links are defined, one possibility is to use structured link-types that could be, for instance, similar to IBIS categories. This strategy would call for an undesired action of formalization (Shipman and Marshall 1999) which would essentially bring on board the limitations of the argumentation approach to design rationale capturing (Shipman 1993; Shipman and McCall 1997). The other possibility is to refrain from defining the nature of these links and simply indicate the presence of a generic link between items. These generic links would be unstructured but they could be indexed by date or author to make them searchable. For KMan tool the latter possibility was considered more adequate because, while still providing a pointer whose nature can be inferred when required, it is less demanding on users, thus avoiding a *cognitive overload* (Shipman and Marshall 1999).

The system also enables the links between pebbles as well as their rating/feedback to evolve over time.

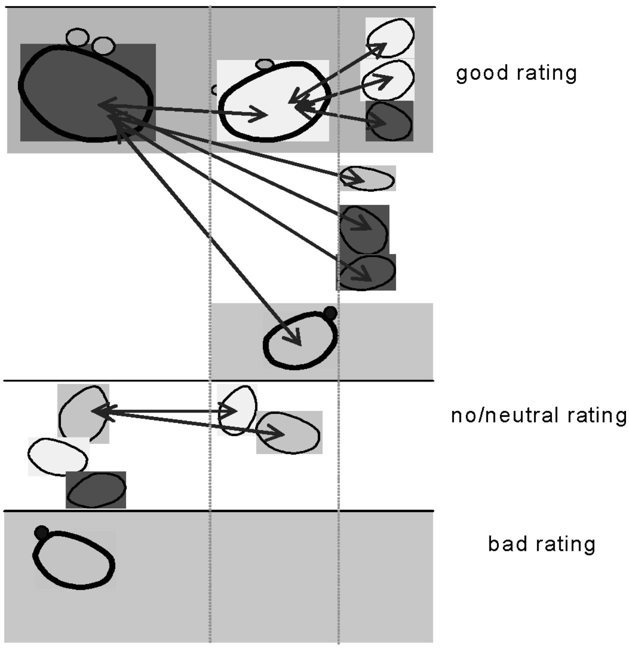

Figure 1. Retrieved pebbles are displayed according to their rating.

Users will be able to define within the search tool what type of pebbles they would like to filter: they could decide, for instance to search for all items related to *photovoltaic* with a positive rating of three and above. In the case of un-filtered search the system will first show the pebbles with good rating, in descending order, together with all their related pebbles, including those with negative rating; secondly pebbles with no or neutral rating will be displayed and, finally, those with negative rating.

The company Intranet was chosen as software environment to host the Information and Knowledge Management functionalities because of its widely spread use in UK construction design practices (Carrillo, Robinson et al. 2002) and for the flexibility that Intranets offer by allowing to easily integrate information from various sources and in heterogeneous formats.

4. THE KMAN SUITE OF TOOLS

In line with the practice based nature of this research the proposed tool was devised using a real architectural practice as target user while, at the same time, every attempt was made to keep the system generic enough to be valid for other organizations within the construction industry domain. The practice chosen this exercise is Reid Architecture (RA hereafter). RA was chosen because of its high interest in knowledge related issues applied to architectural design practice and because the author had the opportunity to work for that organization both as an architect and as adviser for the company's KM development programme.

RA was at the time working to implement a system that, building on and integrating other systems in use within the practice, would assist and facilitate IT support to knowledge creation and management. This study contributed to the specification of that system.

The KMan suite comprises several tools, summarised in *Table 2* below. In terms of System Architecture each tool could be an independant application and seamless integration could be achieved through the Intranet.

Some of the applications could be developed by partially reusing software created for other research projects or customising software available off the shelf.

In the sections below the Briefing Management, the Pebble Creation and Generic Search Tools are described in more detail, with a focus on the Graphical User Interface (GUI).

Table 1. Synoptic Table of knowledge capturing tools integrated in KMan.

KNOWLEDGE CAPTURING TOOLS	
Tool	**Function**
Profile Keeping Tool	To capture user preferences as a by-product of their tacit knowledge and, via a recommender system, make that knowledge available to others
Pebble Creation Tool	To flag out and attach DR information to any type of information. Heterogeneous
Brief Management Tool	To record and track the requirements' development and their corresponding elements of the solution
Document Archival Tool (Qdoc+)	Improved Qdoc Interface to provide opportunity to add comments, links or pictures when saving documents
Design Review Recording Tool	To capture the information and knowledge made explicit in a semi-structured way during design reviews
Meeting Minutes Generator Tool	To facilitate production of meeting minutes and gathering contextual information
Project DB	To contain standard information about projects
Thematic Homepages	To allow quick compiling of mini-sites featuring specific topics
Feedback Bar	Provides user with opportunities to express their feedback on the system recommendations and on the quality of documents

Table 2. Synoptic Table of knowledge retrieving tools integrated in KMan.

KNOWLEDGE RETRIEVING TOOLS	
Tool	**Function**
Generic Information Search Tool	The Generic Search Tool is conceived to be the starting point of any search. Quick and Advanced search.
Easy Qdoc Retrieval	To improve the retrieval of documents archived using the Qdoc software.
Project Homepages	An intranet site where pointers to all the information concerning one specific project are provided and tools to navigate and view that information can be launched.
Project Directory	a subset that a Contacts Database containing the contacts for a specific project team.
Drawing Management Tool	drawing browsing and searching facility with preview and drawing history management.
Project History tool	To build and navigate historical project information from the desired perspectives.

4.1 Pebble Creation Tool

In section 3 the notion of pebbles as units of potential knowledge was introduced. This notion is very generic and can assume several formats; in other words a pebble can be any piece of information to which some Design Rational like information is attached. A pebble can therefore be, for instance, an idea for a marketing event, a proposal for an exhibition in the office gallery space, a folder containing good examples of factory buildings or a record of a design decision. Meeting minutes and design review records are pebbles too, but, given their recurrence and importance, an ad hoc tool has been created to generate them.

The interface of the Pebble Creation Tool as proposed contains the following components:

- author and date, transparently captured by the system;
- List of Participants. Participants' names can be selected by ticking the project directory list.
- Circulation. As for the Participants, names can be easily selected from the project directory. By ticking them from a comprehensive list.
- Category list. Users can choose from a drop down menu a category applicable to the pebble that is being created. Examples of these categories are: product information, interesting building, event, suggestions. Should users feel that none of the categories provided are suitable for the pebble they are creating, by selecting OTHER they will be given the option to define a new category.
- Brief Description [Title]. Text box with limited number of characters. This is where the user will summarise the content of the pebble by giving it a sort of heading. This field is compulsory and it is the minimum requirement of textual input needed to create a pebble.
- Explanation [Design Rationale]. Free text box for text of unlimited length. Here is where users that are willing to do so can provide detailed unstructured explanations on the object of the pebble.
- Linked files. User can provide links to contextual information related to a pebble. As mentioned in Chapter 5 Gruber and Russell found that rationale explanations are more often constructed by interpreting stored information available than by retrieving exhaustive explanations (Gruber and Russell 1996, 330). Access to hyperlinks to relevant items will help inferring design rationale and knowledge, thus reducing the amount of contextual information that need to be input at the time of the pebble creation.
- Related images. This functionality allows including illustrative images to the heterogeneous data set that constitutes a pebble.

- Qdoc Save. This button allows saving the Pebble. By clicking this button the user is presented with two options: one is to save and commit to the system and the other is to save in a draft folder for future editing.
- Create Report. This button creates a printer friendly report of the Pebble created.

It is possible to envisage that after a test period during which users confront themselves with the structure of the generic pebble creation tool, user feedback would lead to an evolution of the interface for this tool in which data input forms become category specific. For instance by selecting the category "interesting building", some fields specific to that type will appear in the pebble creation interface such as "architect", "date", "location", "area", "cost" etcetera.

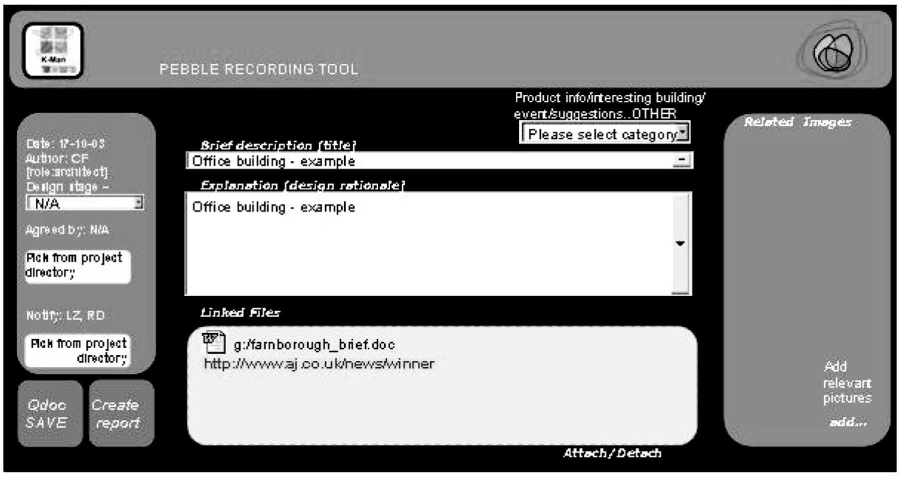

Figure 2. Pebble Recording Tool Interface.

4.2 Brief Management Tool

The Brief Management Tool (BMT) proposed in the KMan suite is a device to record and track the development of requirements, elements of the problem space, and their corresponding components of the solution.

BMT has both knowledge capturing and retrieving capabilities. This tool, by allowing all actors involved in a project to view how requirements map onto solutions, at least partially, and vice versa, has a substantial potential to improve current practice (Figure 3).

Clients could, for instance, understand that their request for a *flexible building* was addressed by the design team by choosing a s*teel structure with easily replaceable composite panels* and by choosing a *building footprint* that, although sub-optimal for the first phase of the project, will offer optimum land use for the future phases of project development.

Similarly the BMT tool could allow a new member of the design team that was not part of the initial design process, to find out that the reasons for choosing composite panels were the client's request for flexibility, the fire ratings requirements and the design team desire for an *industrial slick aesthetic*.

The interface of the BMT Tool as pictured in Figure 3 contains the following components:

- author and date, transparently captured by the system;
- Requested by list, names can be picked by selecting them from the project directory list.
- Notify. This function will send an automated notification to all the actors that the author names as interested or affected by that item. As for the Requested by names can be easily selected from project directory.
- Notify author of changed status. This function sends a notification to the author of an item each time the item is modified.
- New Requirement text input box. Here is where the user can input a new requirement into the briefing database using free text to describe it.
- Add new requirement. Once the item description is complete by clicking Add the item will be added to the requirements list displayed in the central part of the screen.
- Browse Requirements List. In the central part of the BMT interface the requirements submitted to the system can be viewed and browsed. Users can Edit/move up/move down and add new versions for each item and view the whole list using a scroll bar.
- Requirements Summary. In this section on the right hand side of the BMT is displayed all the information regarding the requirement item selected in the requirement browser section, on the left hand side. This summary is has four components:
    1. *generic information* about the requirement such as when it was last modified, by whom, who was notified of the changes and what is the current status of the requirement (e.g. ongoing, addressed, to be addressed etc.).
    2. *full textual description* of the selected requirement. Users can edit this description and view previous versions of the same item.

3. *linked files.* Where files linked to that item can be define and viewed to provide contextual information for the selected requirement.
4. *list of elements of the solution.* In this section all the elements of the solution that satisfy the selected requirement are listed. By selecting one of these elements, a list of all the requirements that that specific component will appear.

- Create Report. This button creates a printer friendly report of the BMT.
- Qdoc Save. This button allows saving the content of the briefing database. As every Qdoc save operation it is possible to save and archive or save in a draft folder.
- Toggle REQUIREMENT/SOLUTIONS view. This button allows switching from a requirement centred interface to a solution-focused interface. The BMT interface to navigate the components of the solution space has the same structure and features of the requirements interface.
- Items from meeting minutes that are labelled as Design Brief will by automatically added by the system to the requirements/solutions database.

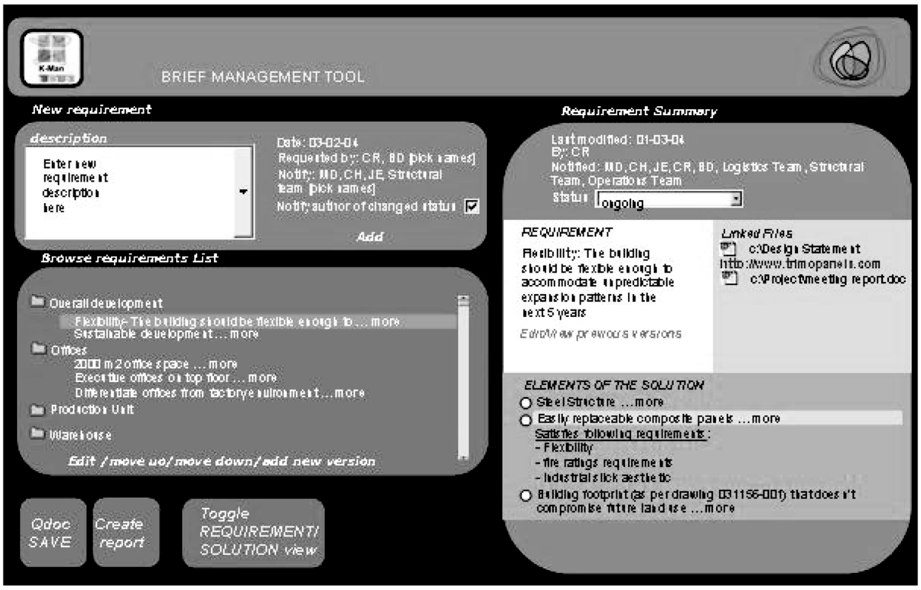

Figure 3. Brief Management Tool Interface.

4.3 Generic Search Tool

The *Generic Search Tool* is conceived to be the starting point of any search and it consists of a *quick search* functionality and an *advanced search* one. The search results are displayed taking into account the quality score of the various items and system recommendations for the specific user based on his profile.

After selecting the appropriate search strategy and parameters the user can click on the "search" button and the results of the search are displayed in a new window (Figure 4). The search results are split into three tiers:

- Projects. A list of relevant projects carried out within the practice is displayed in the first tier. In the scenario illustrated in Figure 4, displaying the results of a search for the word "Airport" the projects listed are Heathrow Terminal 1, Gatwick South Terminal, Edinburgh Air Traffic Control Tower and Farnborough Airport Competition. By selecting one item from this list, say Farnborough Airport, on the right hand side a preview summary of the project is displayed containing an image and information like project name, date, client, cost and construction materials. By clicking on the "open" button another window will be open the project homepage with a bottom frame for feedback on accuracy of the recommendations.
- Related Pebbles. Items are displayed in descending order of ranking. Again by selecting one item a preview/summary is displayed on the right hand side. Even without opening any of the items users can express interest in specific items and by doing so will cultivate their profile. If the item is opened, like for the projects, the item is displayed in a separate window with a bottom bar to provide feedback on the quality of the recommendations.
- Contacts, with a list of the people in the practice involved in the area object of the search. Beside each name a list of the major projects they took part in for the area in question.

5. CONCLUSIONS

This paper gave a partial account of the research that led to the design and specification of the KMan suite of tools. In particular the concept of pebbles of knowledge, implicit in the KMan system, was introduced and some of the individual tools that compose KMan were described in more detail.

KMan was designed to address the problems related to the knowledge management and transfer within construction projects. Although designed for flexibility and incremental implementation, it is relatively development-intensive and therefore expensive and not affordable for small to medium practices. Further research is now being carried out into creating similar tools and functionalities to those of KMan, using freely or cheaply available software, like, for instance wikis.

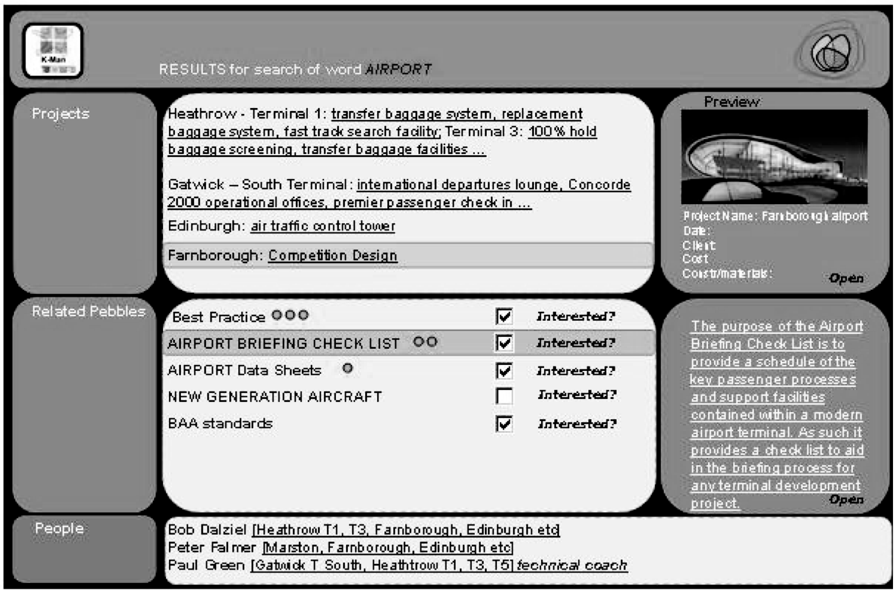

Figure 4. Search Results Interface.

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