Making Knowledge Visible:

Using Expert Yellow Pages to Map Capabilities in Professional Services Firms

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INTRODUCTION

Professional services firms rely on the skills and abilities of their staff to perform projects. As a result of working with many different clients the skills and capabilities of these firms continuously evolve in unpredictable and often divergent ways. Indeed, the projects themselves can be regarded as experiments (numbering thousands) across different organisations in specific circumstances, which provide opportunities to develop and deploy new knowledge. In order to enhance their project performance capabilities, professional services firms have invested heavily in knowledge management and knowledge management systems, including substantial investments in systems involving project databases, expert yellow pages, electronic communities of practice, searchable project repositories, etc. Despite these investments, the success of knowledge management has been mixed for many organisations. Although knowledge management systems help the firm to share and create knowledge among its staff and with its clients, much of the information stored in these systems is not tapped by the firm's senior managers, and these systems have been tools for supporting project delivery, rather than becoming enablers for strategic decision making about the firm's strategy and organisation. Despite the information that exists within their firms, senior managers in professional services firms seem to not to know what is going inside their firms - what skills and capabilities are being developed and deployed and how these skills and capabilities are evolving through interaction with clients. Increasing competition in the professional services market means that firms must constantly strive to better exploit their knowledge assets, and communicate the value of these assets both internally and externally. A change in the nature and usage of knowledge systems is long overdue – organisations need to move from use of static repositories to development of strategic tools to exploit existing knowledge to drive business growth.

In order to better understand the nature of knowledge inside professional services firms, working with Arup, one of the world's leading engineering consultancy organisations, we have developed a novel approach for mapping capabilities in professional services firms that combines social network and co-word analysis. This approach analyses the information in the firm's expertise location system/corporate yellow pages of skills and capabilities. It allows us to construct a bottom-up visualization of the knowledge within a professional services firm and to develop clusters of connections between different knowledge domains within the organisation. This bottom-up visualization enabled Arup to achieve an understanding of how its capabilities had evolved, and to reconsider not only its own internal knowledge management practices and tools, but also strategic decisions relating to capabilities and organisational structure.

The paper is organized as follows. Section 1 explores the nature of capabilities and project activity inside professional services organisations, focusing in particular on engineering consultancies. Section 2 outlines the study method, and briefly describes Arup and its unique development process, ways of working, and knowledge management activities. Section 3 reports the results. In Section 4, we discuss the findings in relation to decision-making within Arup, and to the general debate about the role of information technology (IT) in strategic decision-making.

THEORETICAL AND EMPIRICAL BACKGROUND

Professional services firms are driven by the requirements of both new and existing clients, and a series of discrete projects (Maister 1993). These projects often require hands-on interaction with clients and other organisations, leading to the co-production of new knowledge with clients and project partners (Bettencourt et al. 2002; Dougherty 2004; Gann et al. 2000; Miles 2000; Turner et al. 1999). Professional services firms rely on their human capital and the knowledge that resides in their staff for the performance of specialized and unique projects (Grant 1996; Hitt et al. 2001; Teece 2003). The ability to perform projects is also based on organisational knowledge and routines and professional services firms have developed extensive operating routines to support their project work, including project reviews, post-project reviews, team formation and assembly procedures, and knowledge management systems (Gann et al. 2000; Hansen et al. 1999; Lowendhal et al. 2001; Sarvary 1999; Suddaby et al. 2001). These operating routines allow these firms to offer a package of services that draw upon the experience and knowledge held within the firm (Ofek et al. 2001).

However, much of the knowledge that is held by professional service firms remains tacit, is embedded in uncodified routines, and rooted in the firm’s social context (Dougherty 2004; Morris 2001). In many professional services firms, particularly those focusing on innovation and creativity, it is the human capital assets that are invaluable and are the source of competitive advantage, because they are unique, rare and difficult for other firms to imitate (Barney 1991; Teece 2002b). These assets are experience based knowledge, gained through practising a craft skill over time, and in a variety of different situations (Scott et al. 1999). It is developed through ‘recursive practice’ and remains situated in the activities that people perform in order accomplish their work tasks (Constant 2000). In this respect, the practice of professional knowledge requires ‘artful competence’; learning how to applying the principles of the profession to unique situations, while making do with limited resources available

(Schon 1991; Werr et al. 2003). In such contexts, firms often rely on the ability of their employees to develop and nurture their own professional knowledge and networks (Dougherty 2004). Indeed, in many professional service firms, it is the closeness of the interactions between skilled, experienced staff and clients that allows the firm to build what Teece (2002b) calls ‘relational assets’.

Although professional service firms are increasingly recognised as central actors in modern economy, we still lack the tools in order map and understand the capabilities of these organisations (Drejer 2004; Miles 2000; Tether et al. 2002). As is the case with many other knowledge-intensive service firms, many of the traditional indicators of firm capabilities fail to capture the nature of activities inside these organisations (Metcalfe et al. 2005). For example, few firms in these industries use patents to protect their intellectual property and there are infrequent publishers of academic papers (Hipp et al. 2005).

An important type of professional service organisation is the engineering consultancy. Engineering consultancies offer a range of services to their clients, including feasibility studies, specialist technical inputs into projects, project management, etc. They are often involved in competitive bidding, during which they need to communicate their ability to deliver projects using the best knowledge and processes available. Engineering consultants tend to work in large, diverse project teams that span a variety of organisations. They work closely with upstream providers of architectural services and downstream contractors, developers and suppliers of components and materials (Gann et al. 2000; Gann 2000). Many of engineering consultancy firms work primarily for the construction industry, a sector characterized by its particular pattern of industrial activity. In construction projects, specialists from independent firms collaborate within a project team, which is usually disbanded at the end of the project. In addition, project team members and clients differ from one project to another, resulting in high risks of poor knowledge transfer and mistakes being repeated (Davies et al. 2000).

The project-based nature of their work, however, can make the activities of engineering consultancies appear highly episodic and ad hoc (Mintzberg et al. 1985). Project work involves highly differentiated and customized demand; clients negotiate the design of products and services to meet their special requirements. Thus, the knowledge and skills needed to perform some projects can be highly specific and localized. Other projects, however, may require more general knowledge that will be applicable across many different projects. The fundamental challenge for these consulting organisations is to translate project level learning into organisational capability (Davies et al. 2000; Davies et al. 2005; Davies et al. 2004; DeFillippi et al. 1998; Gann et al. 2000; Hobday 2000; Turner et al. 1999). The project-based nature of their activities means organisations working in the sector often struggle to learn from project to project (Prencipe et al. 2001); one project's key lessons are rarely fed back to the other areas of the organisation.

Engineering consultancies usually have a wide range of projects and skills operating at any one time. Arup, for example, performs up to 10,000 different projects every year, involving hundreds of different clients (Salter et al. 2003). Given this, it is difficult to grasp the range of activities that are undertaken by the firm, and the skills and knowledge that are being created within the firm as a result of these projects. In addition, as in many professional services firms, the control of the central or senior management over the organisation, is limited, and ties between project groups are often weak (Hansen 1999). Many project teams operate semi-autonomously and outside the boundaries of the firm (Gann et al. 1998; Maister 1993).

In order to help ameliorate some of these problems and to increase the effectiveness of their project performance, and knowledge sharing between projects, engineering consultancies have invested considerable resources in knowledge management (KM) and KM systems (Gault et al. 2003). Their approach to KM varies, with some organisations investing heavily in technology and knowledge capture through documentation and data, and others introducing cultural change initiatives to encourage knowledge sharing within the organisation (Argote et al. 2003; Cross et al. 2002; Davenport et al. 2000; Dixon 2000; Hansen et al. 1999; Nonaka et al. 1995; O'Dell et al. 1998; Sarvary 1999). Much of the initial interest in KM was in knowledge being structured into static databases and document management systems (Zack 1999). Whilst this is a critical component of an encompassing KM system, it was soon recognised that such a structured approach on its own was unlikely to fully address the needs of complex engineering design (Davenport et al. 2000; McDermott 1999). Document and data management may be acceptable KM strategies for clearly defined process based sectors, but for more complex design based activities, it is essential to understand the nature of knowledge in detail: to know what the organisation knows.

Organisations seeking to 'know what they know' have adopted many different approaches to analysing the skills and capabilities of their people. Some organisations use advanced profiling tools to mine email and other activities, while others rely on formally validated systems, which identify and sometimes rank individual skills (Davenport et al. 2000). In Arup, a 'personal profile' is a critical component, with individuals declaring topics or areas of interest they feel confident about, in order to identify both expertise and areas for future development.

The use and exploitation of KM systems such as those described above is itself a manifestation of a dynamic capability to capture and share knowledge (Eisenhardt et al. 2000; Pavitt 1998; Teece 2002a; Teece et al. 1994). It represents an important investment in that it allows the organisation to transform project-level learning into organisational learning. However, KM systems are also critical in providing information about the nature of the activities inside professional services firms. For some of these firms, this will be in form of demonstrating which project groups are drawing knowledge and experience from other groups through communities of practice. It can also highlight the development of new project level skills or even innovations, often initially codified in lessons learnt and other KM tools. These kinds of tools also provide considerable information about the nature and evolution of a firm's capabilities. In particular, they highlight the new capabilities that may be emerging in specialist groups, which may be operating largely independently within the firm, that are not widely known about by the organisation. To date, little attempt has been made by professional services firms to use this information for strategic decision-making or for understanding the evolution of capabilities inside firms. One reason for the lack of integration between the information held in KM systems and strategic decision-making in professional services firms is that there are available means of aggregating or summarizing this information in way that is accessible, understandable and relevant for decision-makers; it tends to be used in projects on a day-to-day basis. Thus, this information has tended to remain 'on the shelf', embedded in systems, and often ignored. In addition, in the past there was little need to understand skill combinations – engineering was characterized and problems resolved by discrete disciplines. However, the increasing complexity of engineering design is demanding cross-disciplinary problem solving (Stankiewicz 2000; Williams 2002). The ability to understand critical skill combinations has become a strategic imperative for those organisations seeking to compete on value rather than cost. Some mechanism is required to draw out knowledge from the information contained in KM systems about the nature of the capabilities inside firms in order to enable managers to see what knowledge is being developed, combined and utilized by staff in performing projects. Such a mechanism will allow these firms to pro-active harness potential complementarities between different areas of their organisations and provide new tool to map capabilities in professional service firms.

METHOD

Research Approach

Our approach involves working with our research partners to co-produce new knowledge (Huff 2000; Tranfield et al. 2004; Tranfield et al. 1998; Van Aken 2004; Van Aken 2005). To this end, we have taken problems from the real world of practice and attempted to apply the tools of social science to better understand the challenges, formulate new questions and resolve some of the problems. The research is premised on recognition of the mutual contributions of practitioners and academic researchers to research challenges and problem formulation. One of the challenges of this type of work is to find a common meaning and understanding across worlds of practice and academic research. To try to achieve this mutual understanding, we developed visual representations to create a space of meaning across different communities of practice.

The relationship between the research team and the partner organisation has been a long and close one. One member of the research team has conducted a number of different studies on the practices of Arup over the past five years, including its use of simulations, sources of ideas for engineering design, and management of technology. Another research team member is directly responsible for KM in Arup. In conducting this present research, we worked with Arup to develop the initial idea, the method and the analysis. First, discussions took place between the academic researchers and the engineering consultancy about some of the challenges faced by the organisation in trying understand the development of new skills and how new knowledge management tools could be used by it to better understand these skills. A key problem faced by the organisation was to develop a coherent picture of the bundles of skills, and the connections between different areas of the firm. We were interested, in particular, in developing a method that would allow us to use the information held by the firm to gain new insights into its evolving knowledge base and skills. By doing so, we hoped to influence strategic thinking inside the firm about what areas of these capabilities were central to the business, and how new areas and skills could be harnessed to produce new value for its clients.

In order to achieve this, we examined the skills descriptions in Arup's corporate yellow pages (expertise location system). These skills descriptions are self-declared and voluntary, although all Arup employees are encouraged to complete a text box in his/her personal profile, describing his/her expertise. and to update this every three months. The descriptions highlight their: areas of expertise; areas of interest; and relevant publications. There is no checking of the entries, and a high degree of trust exists that individuals will be honest and accurate – an approach that is typical of the culture and ethos of this organisation, but would not be appropriate for more formalized, structured firms. The result is that most

Arup staff have not only completed their profiles, but have also extra information about leisure and out of work interests and activities, which have proved to be a beneficial source of new skills for the organisation. Within Arup, the free text entered is analysed by a highly developed search engine to make sense of the largely unstructured text fields and give members of the firm access to relevant expertise.

We analysed these text excerpts from 'Arup People' using co-word analysis (Callon et al. 1991; Callon et al. 1986; Courtial et al. 1993; Law et al. 1992; Leydesdorff 2005; Leydesdorff et al. 2005). This is an established technique in bibliometric studies and has been employed to map the dynamic development of several research fields. Co-word analysis uses patterns of co-occurrence frequency of pairs of words in a corpus of texts (i.e. patent or paper titles, abstracts, keywords) to discover linkages between the subject areas of these texts, and to identify the evolution of a scientific field. The method is based on the idea that if pairs of words appear frequently, then they represent a close association between the topics to which they refer. If instead the co-occurrence is rare then it is assumed either that the topics in questions are not closely related, or that the relationship between them, although close, is relatively less important in the context under analysis (Law et al. 1992).

The first step in a co-word analysis involves identifying keywords from the body of texts in order to build the co-occurrence matrix. In this study, we used the most frequently occurring words in the skills descriptions as keywords. We constructed a co-occurrence matrix, which is a symmetric matrix with the same elements (i.e. keywords) in the rows and in the columns. Each cell in the matrix contains the number of times two keywords appeared together. However a simple counting of co-occurrences might be affected by the occurrence frequency of each keyword. Words that are used very frequently will have a higher probability of appearing together with other words than words that are used less often. We therefore normalized the co-occurrence frequency matrix by using Salton's (1983) cosine coefficient, where each word pair co-occurrence is defined as the ratio of their co-occurrence and the product of the square root of the respective occurrence frequencies (Leydesdorff 2005; Leydesdorff et al. 2005).[1]

We then visualized the normalized co-occurrence matrix and derived some other structural properties using social network analysis techniques. In this approach, each word is considered as a node connected by the relation of co-occurrence to another node. The size of the node is proportional to the number of times the word appears in the body of the texts

[1] Both the co-occurrence and normalized matrices were obtained using the software developed by Loet Leydesdorff (downloaded from the website: http://users.fmg.uva.nl/lleydesdorff/software/fulltext/index.htm).

being analysed. The thickness of the lines linking the two nodes is proportional to the normalized co-occurrence measure, that is, words that very frequently appear together will be connected by thicker lines. The visualization of the co-occurrence matrix allows a large complex information space to be organized and managed mentally. Unlike scientific visualizations, the knowledge maps are created from data that have no spatial reference. Specific graph layout algorithms are used to position the words in the map so that the geometric (Euclidean) distance between them is as close as possible to the graph-theoretic (path) distance between them.[2]

Following this procedure, we generated clusters of keywords from the normalized co-occurrence matrix, that is, we grouped together words that occur in a large number of skill descriptions. The underlying assumption is that such dense networks of co-occurrence may represent areas of expertise in Arup. We performed a cluster analysis using the Ward method (Ward 1963) with Manhattan distances. In this way, the relationships between nodes are transformed into relations between clusters. As before, the size of the nodes is proportional to the occurrence frequencies of the keywords in the cluster and the thickness of the lines between two clusters is proportional to the sum of the cosine measures between keywords in the clusters.

Using this approach, we were able to transform the raw, unedited text descriptions into a map reflecting the overall shape of the network of knowledge inside the organisation. This enabled us to present a new picture of the overall shape of skills inside the firm, based on bottom-up and non-trivial analysis of skills. We were also able to explore the specific relationships between the different skills areas. This approach allows us to explore potential interconnections between different skills areas and to highlight previous undetected overlaps and interdependencies between areas of engineering expertise that could be exploited to improve effectiveness.

The Research Setting

Arup was founded in London in 1946 by Sir Ove Arup. It provides a range of design, engineering and associated services and currently has 71 offices across 50 countries, employing 6,500 staff. Arup is recognised for its concentration of technical and design knowledge. It has been involved in some of the greatest building projects of the 20th century, including the Sydney Opera House and the Pompidou Centre.

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[2] This algorithm assumes that each node is connected by springs to every other node in the network. The algorithm works by iterative optimization starting from the initial position of the nodes and their repositioning to minimize the overall 'energy' of the spring system, using a steepest descent procedure.

Arup works on several thousand projects simultaneously, providing specialist advice to a diverse client base. The growth in the firm has been almost entirely self-generated. The company started as a structural engineering firm; with successive new projects its capabilities expanded into a number of different areas. As the former Chairman of Arup, Bob Emmerson, stated: 'Gifted people take us in unexpected directions'. The firm now comprises over 50 specialist groups, ranging from environmental consultancy to acoustics, and its services are continuously moving in new directions through a combination of new business opportunities and market demand.

Arup sees its advantage over competitors as its ability to combine a wide variety of specialist skills on projects. Reflecting the aims of its founder, it aspires to be a total problem solver, through a weaving together of diverse skills. Many of its competitors are small, specialized design services firms, that have far fewer competencies, and encompass a narrower range of fields. Failure to share its knowledge and combine its skills effectively could leave Arup vulnerable to cheaper, more agile competitors in fast growth markets.

In some respects, Arup has found itself in a project-based virtuous cycle: the firm wins high profile projects because of its reputation for problem-solving, and highly skilled engineers are attracted to Arup because of its ability to win complex, exciting projects. As part of this project-based virtuous circle, as a senior manager in the firm suggested, Arup "gets problems that others don't get"; and Arup has gained a reputation for "delivering difficult projects", for "creativity in problem solving", and for working with the leaders in their fields.

As previously mentioned, the growth of Arup has been accompanied by an increase in the number of specialist groups within the firm. New groups have developed within existing teams based on the ability of project leaders to recognise new market opportunities, to develop specialist service offerings, and to spin out new teams. Central management acknowledges the *de facto* independence of these teams. Senior managers in Arup have adopted the 'let a thousand flowers bloom' attitude to the management of these groups, and the company is highly decentralized. There is a feeling that attempts to impose central control on these groups might weaken their development, and the company's senior management argues that groups should be left to get on with developing their own markets and skills. The management style adopted is similar to that found in many professional service firms employing highly creative people (McKenna et al. 2002).

KM at Arup has evolved as a response to this philosophy, based on a strategy initiated in 2000 and delivered and refined over succeeding years. The strategy focuses on people more than process, with systems that target support for the decision making process through a variety of voluntary actions rather than formal tools and mandatory. This strategic selection is in keeping with an organisation seeking to achieve innovation and creativity, rather than standardization in its designs (Hansen et al. 1999)

Arup has always had a strong knowledge sharing culture, and a willingness among employees to help one another. The imperative to preserve these behaviours strongly influenced the selection of technologies to support the KM strategy, with the development first of an expertise location system, followed by parallel systems to support the cultivation and delivery of communities of practice across the firm. Given the complexity of many of the projects undertaken by Arup, there is a frequent demand for new rather than standardised solutions. The solutions to client problems are rarely unique to one discipline or skills set, and generally demand the combination of different skills to create effective answers and add new value. This has had an influence on the approach to system development, with less emphasis on the skills that have been used in the past, and much more on finding new skills to cope with unpredictable and unexpected future problems.

RESULTS

We begin our analysis by exploring the content of the individual skills declarations available in Arup's expertise location system. In total, there are 3,857 expert yellow pages covering 15,730 different skills. Each employee on average has 3.7 skills, with 16 being the maximum number of declared skills. Textual descriptions are on average 316 characters long, but can up to 1,950 characters. The skills description are quite broad ("Underground Stations and Subways") or very detailed ("Automotive Industry manufacturing facilities generally from small scale tier 1 / tier 2 suppliers up to complete car assembly plants. Particular clients: Delphi, General Motors, Opel, VW, Toyota"). The range of expertise within Arup is very wide, and covers standard structural engineering competences such as bridge inspection and assessment, but also some unexpected skills such flying fox relocation; granite fountains; exhumation; film processing; and fund raising.

Using this raw information, we derived the 552 most frequently occurring words from the skills descriptions. to be used in the co-word analysis. We considered only those words that occurred with a frequency of more than 20 times.[3] We generated the co-word map based on the cosine normalized co-occurrence matrix using the procedure discussed in the previous section. The skill map, shown in Figure 1, offers a convenient graphic summary of the

[3] The words were corrected for the plural "s" and for some association, i.e. rail/railway; sustainable/sustainability; light/lighting; geotechnic/geotechnical; cable/cabling.

distribution of expertise in Arup. It is clear from the size of the nodes that the most frequently occurring words are ‘design’ (2,938 times), ‘project’ (1,904), ‘building’ (1,319); ‘system’ (1,181); ‘management’ (1,038); ‘engineering’ (973), ‘structure’ (706) and ‘structural’ (664), which it is not surprising given the nature of Arup’s business. These words also had the highest centrality scores in terms of numbers of links to other nodes in the network (degree centrality). It is significant that ‘design’ is identified as a key field, despite not appearing in Arup’s discipline list. Design is embedded in the firm as a core capability, but this capability is not always communicated widely within the firm.

Insert Figure 1 here

The map also shows that there is a special focus in the areas of ‘environment’ (505), ‘transport’ (493), ‘water’ (442), bridge (429), and ‘rail’ (354). The degree centrality index of environment, water, and rail is also very high. The map also depicts some obvious strong associations between ‘expert’-‘witness’, ‘forecasting’-‘demand’, ‘swimming-pool’, ‘due-diligence’, and ‘concert’-‘hall’, and also more interestingly, strong connections among ‘treatment’-‘water’-‘wastewater’, ‘noise’-‘vibration’, ‘solar’-‘energy’, and ‘retaining’-‘wall’-‘foundation’-‘pile’.

Some of Arup’s main areas of specialization are visible as clusters. For example, on the extreme left of the map in Figure 1, there is a cluster of geotechnic skills[4] and below this there is a cluster of words related to the water division (‘wastewater’; ‘treatment’; ‘water’; ‘pumping’; ‘utility’; ‘drainage’; ‘foul’; ‘surface’; ‘sewage’; ‘sewerage’; ‘stormwater’; ‘flood’; ‘river’; ‘defence’; ‘channel’; ‘hydraulic’; ‘SUD’). These words, together with others, form a very cohesive subgroup inside the network. The words in Figure 2 identify a very dense part of the network where each node has a cosine value sum equal to or higher than a certain threshold with other nodes of the subgroup, i.e. they form a valued core. This map shows that there are very strong linkages, not only among skills related to water and geotechnics, but also among expertise covering specialized areas such as microclimate, environment, electrical engineering, acoustics, façades, and automotive design, and broader areas such as structural engineering, project management, and commercial and residential buildings.

Insert Figure 2 here

To show the strength of the association between specific keywords and the rest of the network, we extracted two sub-graphs based on the focal keywords ‘fire’ and ‘healthcare’ –

[4] This cluster is formed by the following word: ‘geotechnic’; ‘soil’; ‘foundation’; ‘pile’; ‘retaining’; ‘wall’; ‘slope’; ‘stability’; ‘shallow’; ‘earth’; ‘bored’; ‘diaphragm’; ‘formation’; ‘instrumentation’; ‘soft’; ‘settlement’; ‘basement’; ‘deep’; ‘excavation’; ‘site’; ‘supervision’; ‘improvement’; ‘method; ‘specification’; ‘load’; ‘problem’; ‘movement’; ‘ground’; ‘investigation’; ‘reclamation’; ‘earthwork’; ‘embankment’; and ‘reuse’.

two of the current most successful business areas within Arup, and derived their ego-networks, which consist of a network of words connected to the ego either directly or indirectly. We chose these two particular keywords because these two divisions in Arup are very different. The fire division is a specialist group with its own business unit, whereas health care activities are spread across many different business units, which might lead to a more distributed knowledge network. The level of interest in fire-related topics is greater than that in healthcare: the two keywords appear respectively 443 and 73 times in the expert yellow pages. The analysis of the ego-networks reveals that both these research areas are spread across a whole range of different disciplines: the size of the fire ego-network (i.e. the number of nodes that are directly connected to the focal node) is 445, while the size for the healthcare ego-network is 295.[5] Given the occurrence presence of the two keywords this implies that experts in healthcare tend to be much more interdisciplinary than experts in fire related activities. This is reflected in practice – healthcare is a business area which calls for multiple skills from across the business, whilst fire is a specialist service involving a relatively small number of skills, and which is delivered into multiple business sectors.

Insert Figure 3 here

Figures 3 and 4 show these two ego-networks where, for the sake of clarity, the links among the nodes directly connected to the focal node have been removed. We also removed the nodes less often associated with the focal node. Thus, the maps in these figures illustrate the strongest connections between the fire and healthcare related activities with other skills. As shown in Figure 3, healthcare issues are very strongly integrated with interests in hospitals, medical departments more generally, and long term public finance contracts, but also with work related to the education and retail sectors, to leisure centres, to law courts, and to refurbishment activities. This reflects the multidisciplinary nature of the skills involved. Expertise in fire appear to be very strongly connected with issues related to smoke, egress, alarm, safety, protection, emergency, risk, codes and regulations, but also with CFD (computational fluid dynamics), modelling, system, analysis, engineering, and buildings. We also found that airports, stations, residential buildings, and shopping centres were connecting, indicating that these types of projects are associated with the movement of people in extreme events. This is a particularly strong example of how the technique can support the development of capabilities in areas where their application could not have been predicted – in this case the need for expertise in extreme events mitigation post 9/11.

[5] On average the size of the ego-networks in the co-word map is 281 nodes, with a minimum of 71 nodes and maximum of 552 nodes.

Insert Figure 4 here

Although informative about the overall skills in Arup, the co-word map is too complex to be analysed in greater detail. We therefore generated clusters of keywords from the normalized co-occurrence matrix, using the method described in the previous section. We found 20 clusters which are reported in Table 1.[6] This clustering allows us to identify potential synergies among activities in different skills areas. The clusters were named to reflect the existing business areas in Arup, and were validated by senior managers in the company. Some interesting findings emerge from the grouping of the skills reported in Table 1. Expertise in fire, microclimate and wind appear to share some common interests which can be related to the analysis of fluid dynamics and simulation. Similarly, structural engineering, seismic engineering, and automotive design all have similar methods for the analysis of vibration (non-linear element analysis and dynamic analysis) and software (Nastran) in common. It also appears that engineers with expertise in acoustics use visualization tools, which are also employed by engineers working on Information and Communication Technology (ICT)-related issues. These connections point to some complementarities or synergies among different business areas that could be reviewed and potentially exploited to seed the development of communities of practice and also to drive business growth – for example, the fire, microclimate and wind communities.

Insert Table 1 here

This analysis helps reveal the structure of relationships between different areas of Arup's knowledge. It shows that the underlying skills of the organisation have strong overlaps with each other, beyond what was previously considered inside the organisation. It also shows that these overlaps may be a source of competitive advantage for the firm as it finds ways to bundle previously distinct areas of activities into cohesive solutions for its clients.

In order to extend the analysis, we conducted another analysis using the text describing the interests of staff in Arup People. Exploring the interests of Arup staff allowed us some insight into areas of potential new expertise in the firm. In total, 2,768 employees entered information in this field, declaring a total of 8,283 interests, with an average of around 3 per staff member. As in the case of the skill descriptions, some descriptions of interests were very broad: 'industrial ventilation and steam systems'; and some were very detailed: 'A

[6] Because of the sample size, we could not report neither the dendogram of the cluster analysis or a list of the words forming the different clusters. However, both are available upon request from the authors. We report here the clustering of the most often occurring words. 'Design' and 'engineering' are in the 'Rail & Civil Engineering' cluster; 'system' is in the 'Control & Commissioning' cluster; 'project' and 'management' are in the 'Risk & Project Management' cluster; and 'building' is in the 'Airports & Public Buildings' cluster.

keen interest in landscape/urban design and sustainability with a particular interest in desert areas and water harvesting and management and planting strategies. A particular interest in landscape/townscape and visual assessment and the furthering methodologies of townscape and skyline assessment with "tall" buildings'.

Insert Figure 5 here

We extracted 247 keywords from these descriptions using a cut-off value of 15 occurrences to account for the smaller number of bodies of text being analysed. We then derived the normalized co-occurrence matrix which we map in Figure 5. The results suggest a strong degree of overlap between interests and skills. For example, words such as 'design', 'project', 'management', 'building', 'system', 'engineering' occur very frequently in both the descriptions of interests and of skills. More interesting though, was the focus on sustainability and renewable sources of energy. The word 'sustainable' appears 425 times in these descriptions. while it appeared only 236 times in the skill descriptions, while 'renewable' occurs twice as frequently in the descriptions of employees' interests (72 times) than in the descriptions of skills. The importance of these topics is also confirmed by the very high value of the degree centrality index of the words 'sustainable' and 'energy'. We also found a new focus on innovative, alternative, intelligent and efficient solutions. Words such as 'efficiency' (51), 'alternative' (38), 'innovative' (21), and 'intelligent' (22) are keywords that do not appear in the analysis of skills. There are also cohesive subgroups of interests that show up when we extract from the network the value core reported in Figure 6. Wireless technology, risk assessment and materials ('composite', 'fibre', 'reinforced', 'concrete') are cohesive areas of interests that did not figure in the dense core of skills.

Insert Figure 6 here

To continue the contrast between skills and interests, we re-ran the analysis of the fire and healthcare ego-network to identify interest themes among these two groups. We map the healthcare and fire ego-networks in Figures 7 and 8. The most interesting finding here is the emphasis within the fire group on the structural behaviour of steel and concrete infrastructures, evacuation and human behaviour in case of fire – these interests are again related to an increase in Arup's engineering work associated with extreme events that occurred after 9/11. In general, the health care interest map overlaps with the skills map.

Insert Figure 7 here

Insert Figure 8 here

DISCUSSION

At present, many of the tools used for analysing capabilities in manufacturing firms cannot be applied to professional service firms (Eisenhardt et al. 2000; Henderson et al. 1994). Few of these firms' patent; nor do they have hard, physical products that can be used to build a picture of their underlying capabilities. Indeed, given the range of projects undertaken in different markets, professional services firms are noisy, messy environments in which to develop strategy, and develop a profile of firm's capabilities. Much of the knowledge inside these firms is not uncovered by the conventional tools of measure and management. Yet an understanding these capabilities is vital for these firms as market pressures demand that they search for new sources of value. As competitiveness between professional services firms increases, companies such as Arup will have to continually explore how best to analyse their skill set and also to communicate to clients why they should come to a firm employing 7,000 rather than a firm offering a similar list of skills with 700 employees. The value of larger organisations is the breadth and depth of services that can be mobilized and accessed if needed – which is difficult to convey in a summary of top level skills. The technique developed in this paper allows an honest, but far richer picture of an organisation's knowledge to be developed, creating an opportunity for larger firms both to understand their true capabilities, and to communicate the potential value of these capabilities to clients. The healthcare map is a good example of the breadth of services available from Arup as opposed to the narrow range of services available from smaller competitors.

Utilizing a tool that is common in professional services firms - the corporate yellow pages or expertise location system - it has been possible to develop a map of capabilities, and to explore the relationships between different capabilities. We have exploited a tool that was designed to enable knowledge sharing inside the firm, and to explore the knowledge that underlies effective performance in a professional service firm. In this respect, we have attempted to find the 'combinatorial capabilities' that underpin different project activities in professional service firms (Kogut et al. 1992). The method used in this paper could have wide generalizability across a range of professional service firms and could help managers to gain a better understanding of their firms'project skills, the skills of individual staff members, and how these skills can be translated into organisational capability.

Two quite separate aspects of this study have allowed a model of emergent skills development to be created: the volunteered, free text database used for expertise location by

Arup, and the analysis technique used. This approach is particularly appropriate for Arup, where the knowledge profiles of people are volunteered rather than structured, and where there is a strong tradition of professional autonomy. Arup is likely in future to combine a declaration of skills with some inference of skills through the nature of the work being carried out. Either way, bottom-up evolution of the skills clusters is far more likely to identify skills emerging in response to the needs of the market than a top-down classification of skills. In the case of more structured skills databases, the analysis technique would be analysing a narrow perception of an organisation's skill set, and would be unlikely to develop such rich pictures of potential business growth. There is still potential in such environments to explore links between existing business areas, but to generate greater value, the structured database would need to be supplemented by a more intuitive profiling of people's skills and interests – either through surveys or more direct profiling techniques – before the analysis is carried out.

Given the increased competitiveness in many of the traditional core engineering consulting markets, there is a need to continually re-evaluate and reinvent the knowledge base (Grant 1996; Kogut 1996; Kogut et al. 1992). These organisations need to constantly move between competitive markets to unique sources of value where higher rates can be justified – a move that can only be encompassed with confidence if there is a true picture and understanding of capabilities. This study of skills and expertise offers a structured technique for identifying value of knowledge assets. The framework in this paper offers a far more instinctive model – linking clusters of knowledge and allowing the organisation to see both the current level of activity (e.g. from profitability within each cluster) and the potential benefits of combining clusters.

FUTURE RESEARCH AND LIMITATIONS

This study opens up a range of new research questions and highlights the potential for corporate yellow pages/expertise location systems and other KM systems to be used to gain new insights into the nature of capabilities in professional services firms. KM systems represent a considerable information resource on managerial behaviour, which, to date, has not been fully exploited in innovation research. In fact, the information contained in KM systems constitutes unique and powerful lens through which to view what is taking place within the firm, and how knowledge is being created and shared among different actors. The use of this information may enable managers and researchers to better understand the evolution of capabilities and the role of knowledge in creating competitive advantage, especially in environments knowledge often resides in skilled individuals.

In order to gain insight into the performance implications of the use of knowledge inside the firm, it would be useful to link the acknowledged capabilities using our analysis with the financial performance of different groups and individuals within the firm. In the future, it might be possible to explore which bundles of skills are responsible for the growth of new businesses, or the profitability of individuals and teams. This knowledge could lead professional services firms to proactively seek to harness these complementarities between skills to realize new value. In addition, using our approach, it is possible to map skills across different offices to find which offices rely on which combinations of skills and to identify the knowledge interdependencies in different offices. In a large, decentralized multinational, such as Arup, this information may provide a mechanism to bring together new combinations of the skills in different offices that are geographically separated or fall within different business divisions. Using other data held by our partner organisation, it would be possible to explore the changing profiles of skills inside the firm among different age cohorts of staff. This analysis could highlight areas of potential growth. It could also highlight key staff that may span skill boundaries.

Although we have used a large, unique dataset and powerful set of analytical tools, our study is limited to one period and, therefore, we can make no assumption about changes in capabilities over time. In addition, our analysis focuses on the most common words and therefore misses many of the unique or less frequently occurring combinations that may be emerging in different parts of the organisation. Therefore, this does not capture all the seeds of potential future growth. The mapping of capabilities by means of co-word identification, and social network analysis is especially useful for professional services firms, but it may be inadequate for other types of firms that rely on the use of capital equipment or more physical technologies. Also, our approach equates word clusters with capabilities, with word combinations representing clusters of skills of individuals. However, the skills of an individual in a professional service firm are often bound to the nature of work and the types of teams in which the individual usually operates. At present, we are only able to map individual skills, and these individuals may be embedded in project teams with a range of different skills. The different skills within a team may complement each other and interact in the performance of a project in ways that our analysis is unable to capture. With the use of information from knowledge management systems, combined with other data sources, it may be possible to explore many of these theoretical and empirical challenges about the nature of capabilities and knowledge work in professional services firms in greater detail.

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Figure 1. Arup Knowledge Map, Cosine normalised co-word map of 552 keywords (words connected at the threshold level of cosine >0.15)

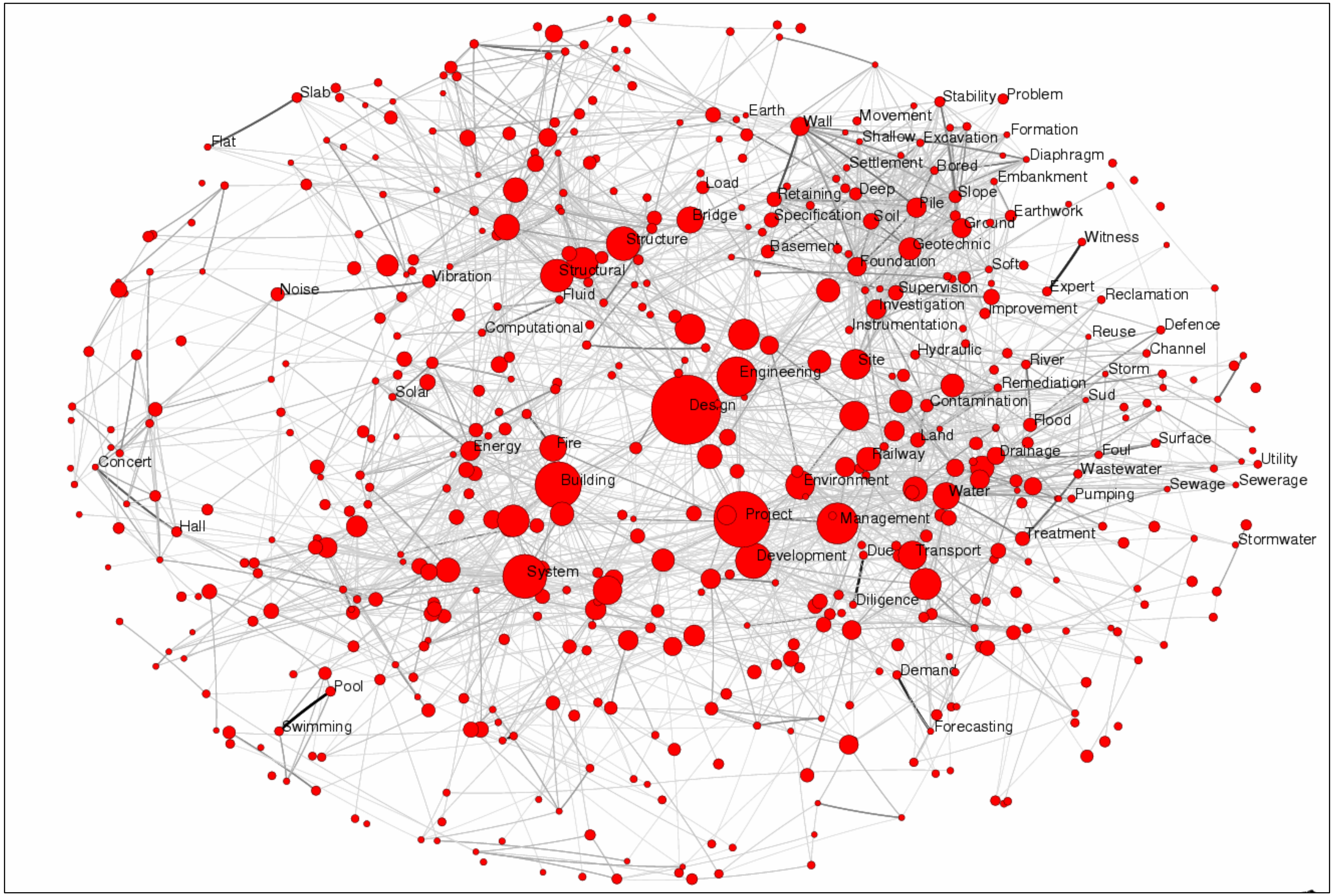

Figure 2. Arup Knowledge Map, Valued core (threshold level of cosine >1.15)

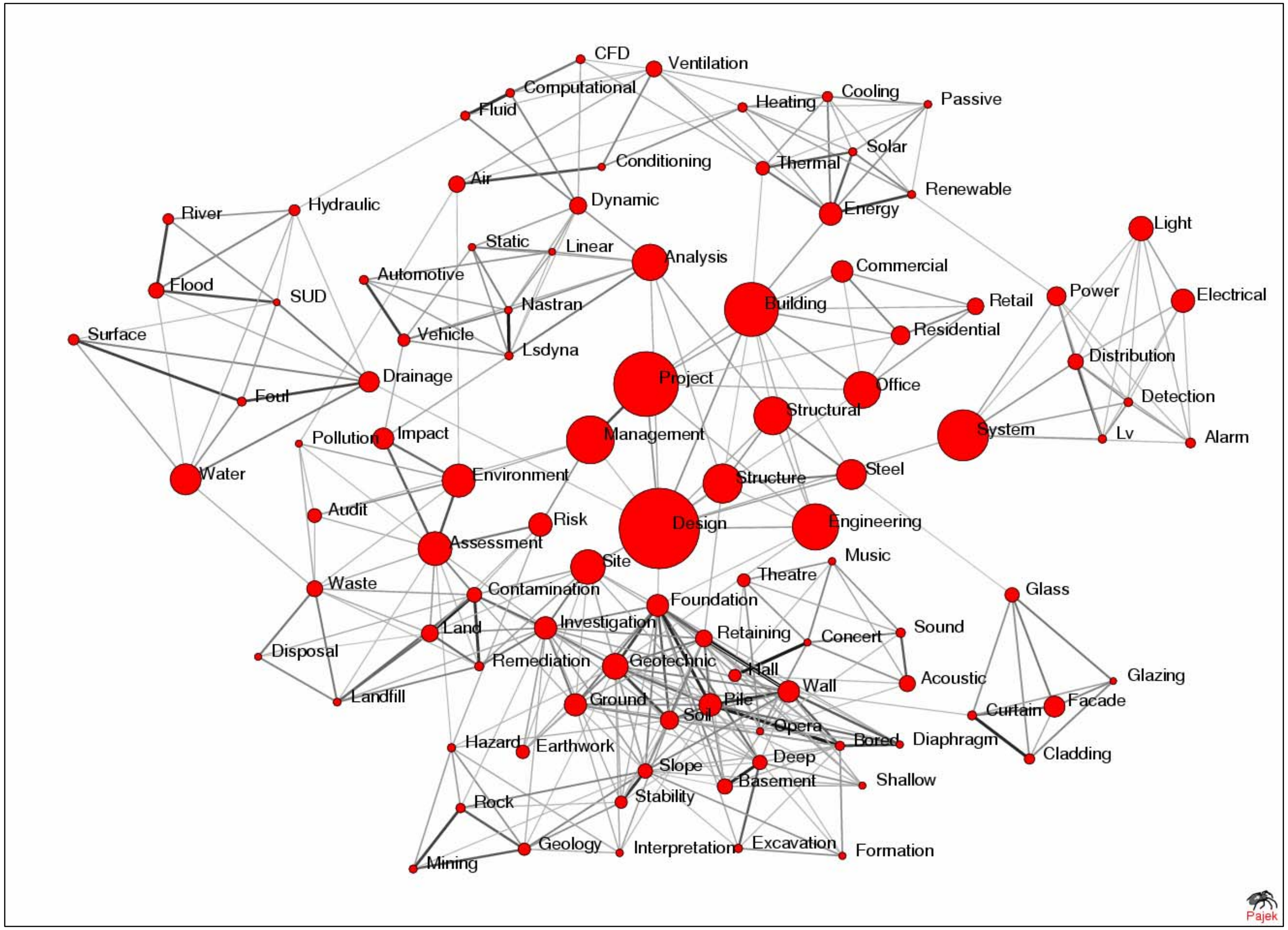

Figure 3. Arup Knowledge Map, Health care ego-network (words connected at the threshold level of cosine >0.05)

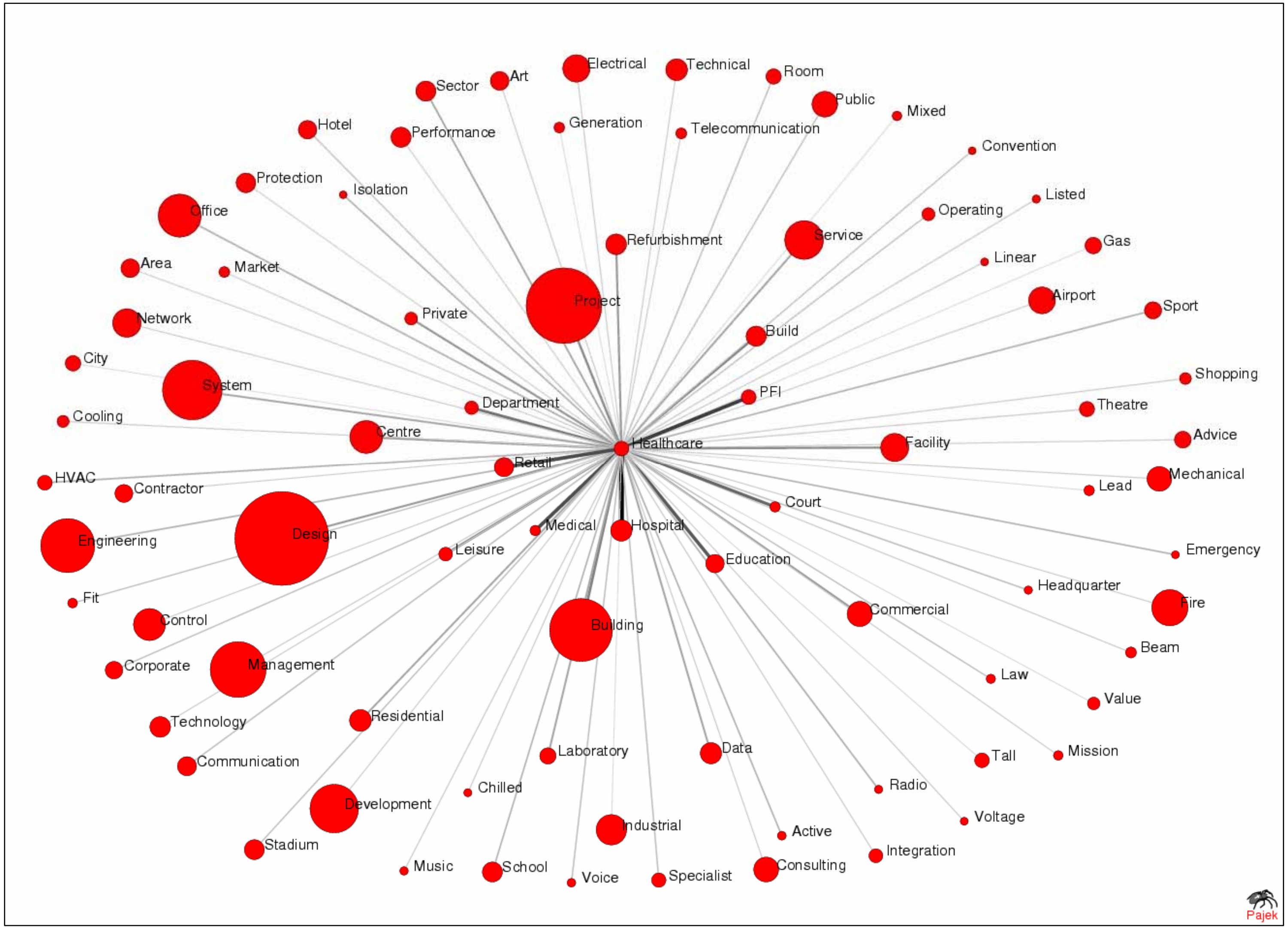

Figure 4 Arup Knowledge Map, Fire ego-network (words connected at the threshold level of cosine >0.05)

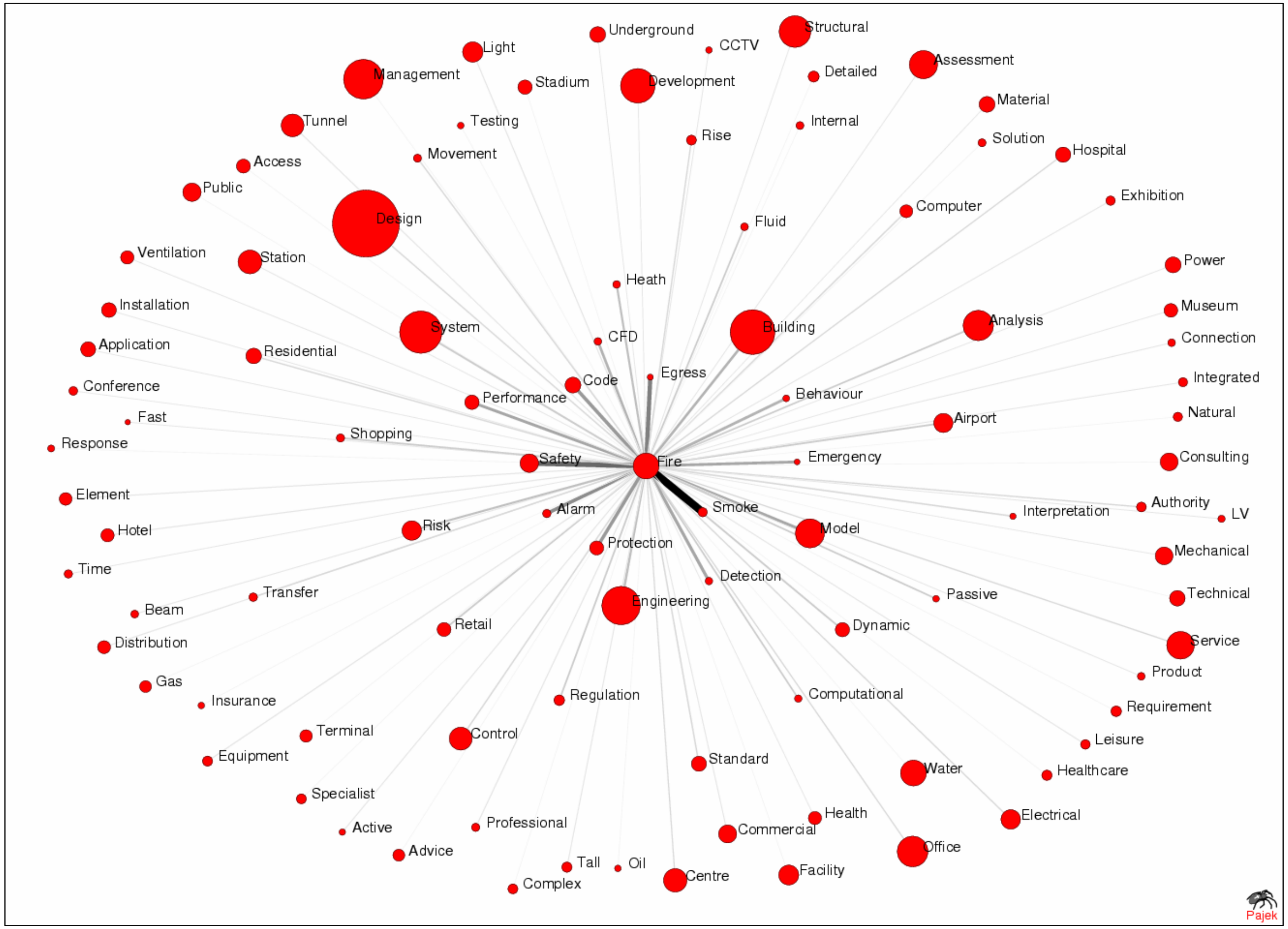

Table 1 Key clusters within Arup's Knowledge Map

Airports & Public Buildings
Acoustics, Visualisation Software & ICT
Risk & Project Management
Architecture & Refurbishment
Lighting, Electrical Engineering & Telecommunication
Automotive Design, Structural & Seismic Engineering
Environment, Urban & Transport Planning
Water & Pollution
Process Management
Offshore Engineering & Maritime
Geotechnics & Geology
Bridges & Tracks
Contract Management
Fire, Microclimate & Wind Engineering
Rail & Civil Engineering
Control & Commissioning
Manufacturing & Logistics
Healthcare & Education
Regulation, Materials & R&D
Industrial Engineering

Figure 5. Arup Interests Map, Cosine normalised co-word map of 247 keywords (words connected at the threshold level of cosine >0.04)

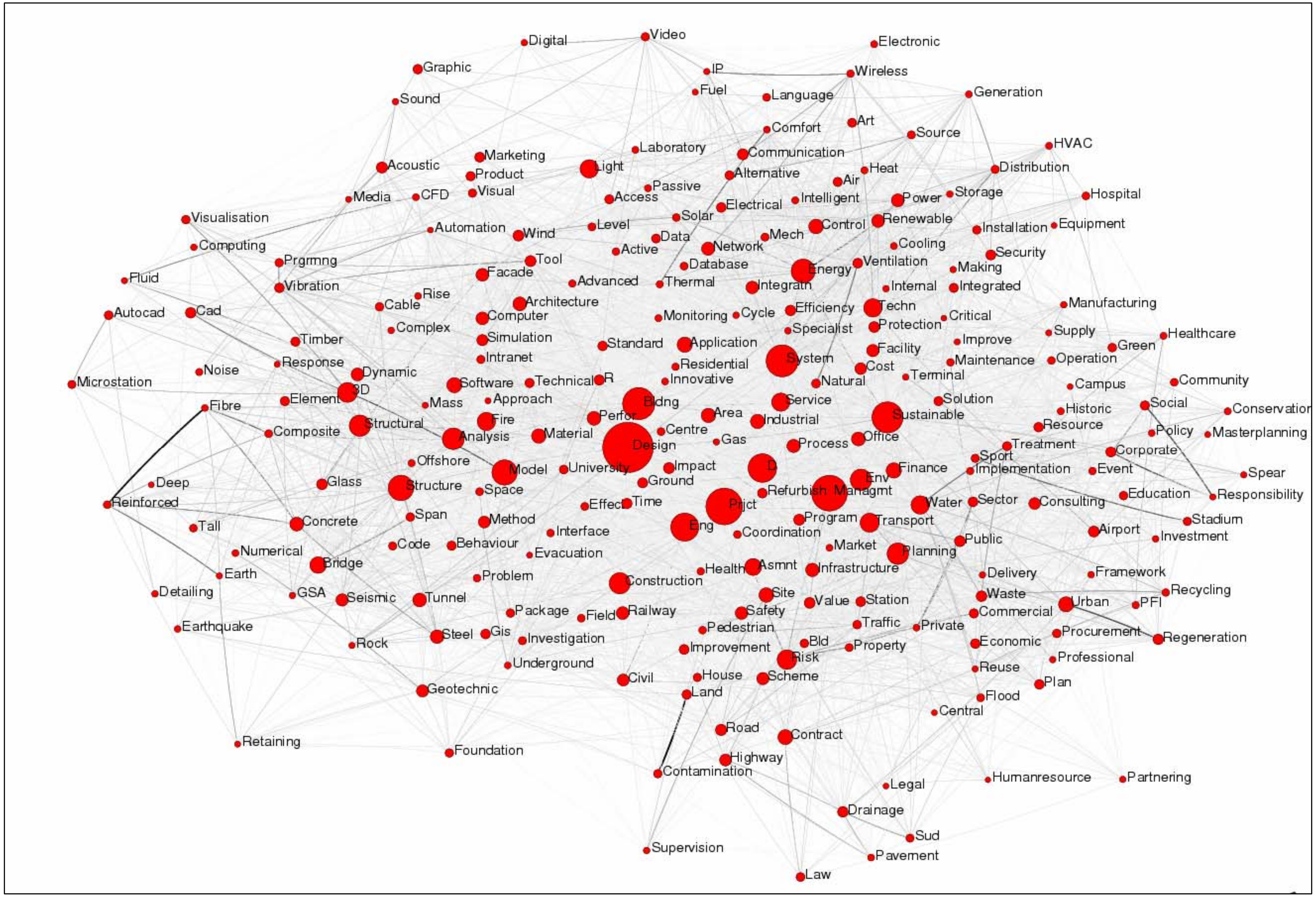

Figure 6. Arup Interests Map, Valued core (threshold level cosine >1.15)

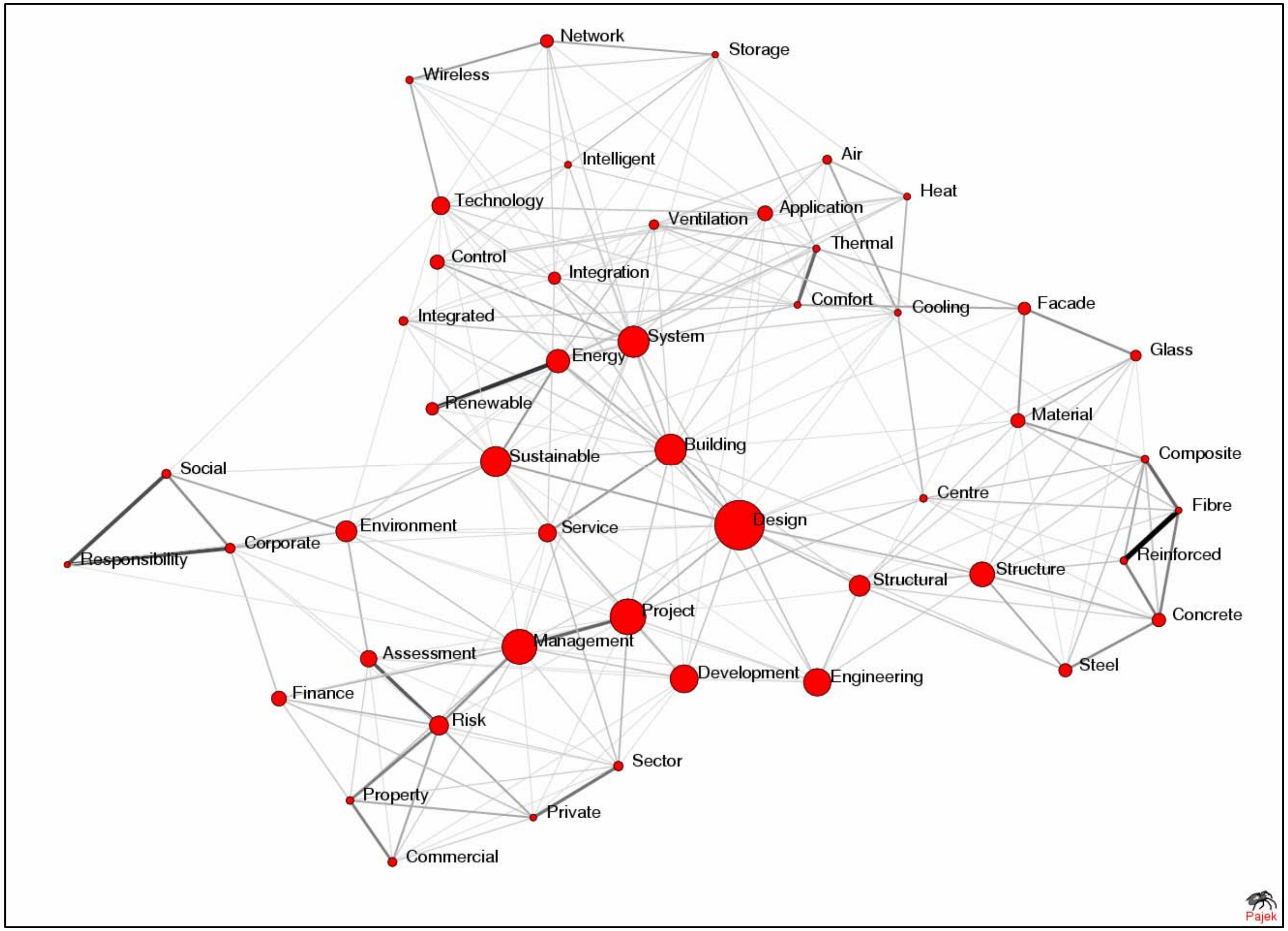

Figure 7. Arup Interests Map, Healthcare ego-network (words connected at the threshold level of cosine >0.02)

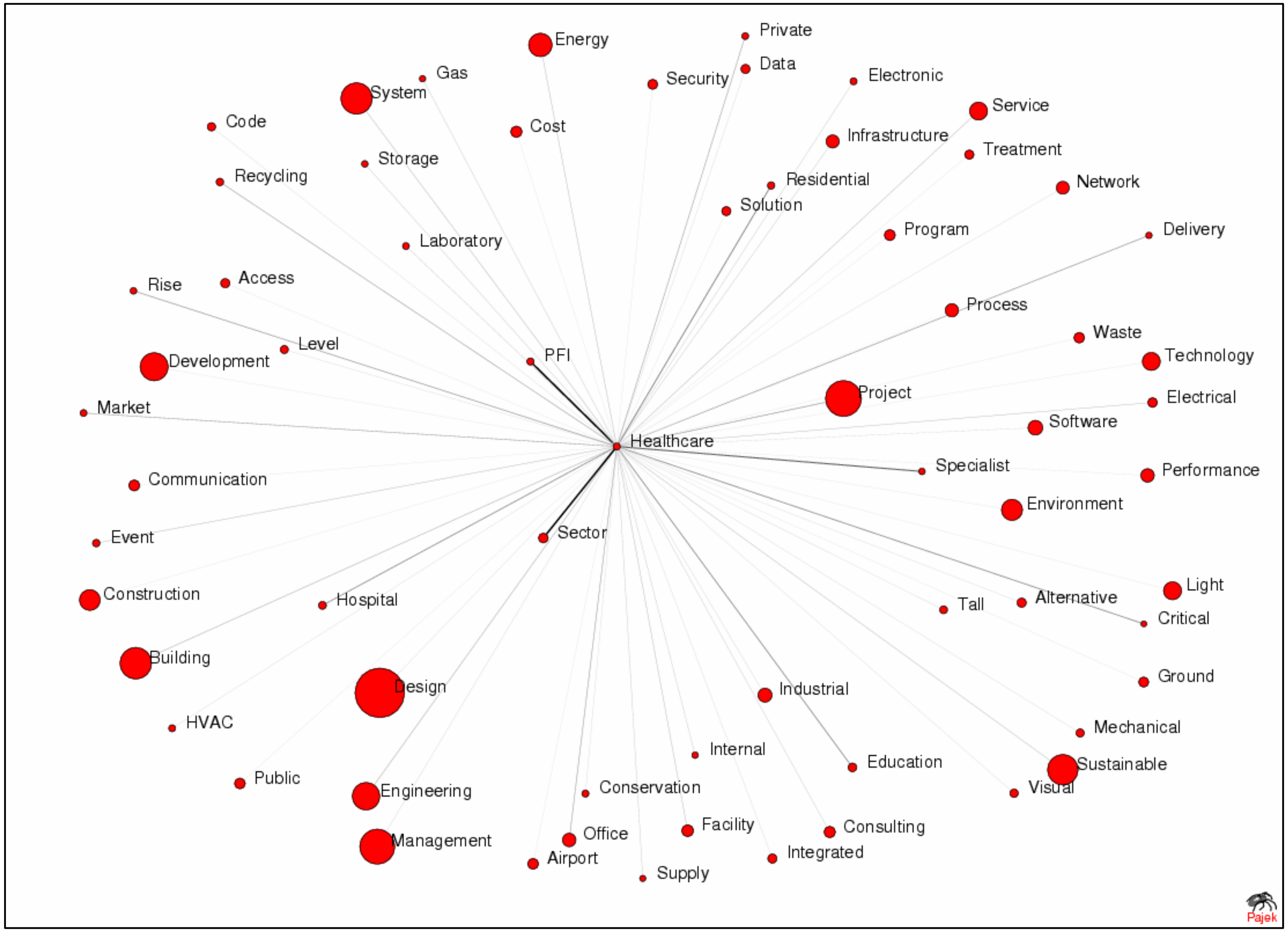

Figure 8. Arup Interests Map, Fire ego-network (words connected at the threshold level of cosine >0.02)