Thinking about design experience: A semantic network approach

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Abstract

Social network analysis software has been used in this study to reveal individual and collective perceptions of space from different perspectives. The paper outlines how to analyse an ‘environment-response’ semantic network of a user group and that of the architect. The semantic network of the designer was found to be quite different from the users of their designs, a starting point from which to question how far designers of space are able to anticipate what impressions and reactions their designs elicit in users.

Determining what thematic clusters or topics emerge (called ‘metatopics’ in the study) from the networks is a primary aim. The networks usually contain 4-7 metatopics. A range of network analysis algorithms, calculating measures such as centrality and proportional strength of ties are applied to identify important constructs and help identify metatopics. These metatopics can also themselves be ranked and compared through network analysis indicators. Through these tools, new observations on the structure of collective mental representations of built environments are gathered.

Key words

Semantic networks, network analysis, perception, designed environments, interviews

The assumptions that designers make about the effect their designs have on end users is a vital part of the design process as well as a key part of the design. Social network analysis software ‘Pajek’ has been used in this study to visualize and analyse the mental constructs toward a particular environment. How people respond to a designed environment has not previously been explored as a network of thoughts, yet this could be a productive use of network analysis given that human relationships with the environment (natural and built) is gaining prominence as a research topic.

The paper discusses two ‘environment-response’ networks that were derived from a new workplace: one for the user group and the other for the architect. The network of the designer is quite different from that of the user group, thus calling into question in how far designers of space understand what effect their designs will have on users.

The paper firstly outlines why network analysis can be a useful and valid research tool in investigating human responses to the environment. The middle section describes the data used for deriving the networks. The final section, using a case study, discusses analysis of the environment-response user group (consensus) network before showing the designer’s environment-response network for brief comparison. Results of this method could be used contribute to discussions on how and why designers conceptualise space differently to users

(Cross 2006; Lawson 1997) and is an aim of the larger study. This paper refrains from making generalisations of theory in order to present one worked example of a new design research method. The intention is to indicate the utility that social network analysis offers to researchers interested in understanding the thought structure that individuals and groups of people have about a designed environment.

Theorising an environment-response network

This section of the paper provides an overview of key theories that provide a rationale for developing an environment-response network: environmental psychology confirms the existence of a human environmental response; the science of semantic networks explains that thoughts exist as a type of network; an overview of networks as an abstracted set of elements and connections that can be mathematically and algorithmically analysed and represented; and finally, the reasons for applying an environment-response network to a workplace setting.

Environmental psychology

Any environment has a psychological effect on users (Norberg-Schulz, 1980; Rasmussen 1964). Many researchers have attempted to understand what elements of the environment can enhance quality of life (Alexander, Ishikawa & Silverstein, 1977; Gifford, 2007; Zeisel, 1984). The hope is that designers armed with this knowledge could create environments that reduce stress, enhance mental acuity and emotional response and any other desirable outcomes. However, research in this area is generally inconclusive, based on intuition or small-scale studies and has not kept up with scientific advances in other fields.

This year Oxford University Press published *Brain Landscape: The Coexistence of Neuroscience and Architecture* to "challenge neuroscientists to study how architecture affects the brain" (Eberhard, 2009, p.xii). The emphasis the book presents to readers is that the brain, which controls behaviour, is influenced by the environment. Neuroscientists have found that connections between neurons in the brain to continuously 're-wire' to adapt to environmental stimuli all through our adult lives (Gordon, 2000, p.72). Architecture, it is supposed, can change our brains and our behaviour.

Semantic networks

Following on from studies on the network structure of neurons in the brain is a notion that thoughts would also follow a network-like structure. Thoughts about a subject or object (such as architecture), have been considered a type of network in order to "create abstract representations of the general features of input data" (Spitzer, 1999). Spitzer describes these 'semantic networks' as relating to associations between words as a form of knowledge representation. Semantic networks were first studied as a concept called *associationist psychology* (John Locke and David Hume) and later *free association* (Sigmund Freud, Sir Francis Galton and Carl-Gustav Jung). Later, it was theorised that words themselves are stored in a network like structure in the brain (Collins and Loftus, 1975). The use of semantic networks as a tool used to examine how thoughts occur has also been used in the context of developing artificial intelligence (Sowa and Borgida, 1991). Concepts underlying semantic networks are relevant to this research project, in which word-associations, extracted from interview transcripts, generate abstract semantic networks that represent respondents' concepts of architectural spaces. It takes as a starting point the notion that the abstract structural type of the network are tied closely to how subjective ideas about objects such as architectural environments are represented in the brain.

Network analysis

A network refers to any collection of interacting parts, which satisfies certain laws of form and organisation (Buchanan, 2002, p.18). The architecture of networks can be analysed meaningfully and patterns observed where previously none could be seen. To analyse a network its 'parts' are understood as a set of discrete elements (vertices) and connections (edges) between them. Extracting these features provides clarity to a question that would be impossible to answer, were all details to remain (Newman, Barabási & Watts, 2006, p.4). In addition to powerful visualisation capabilities of software, network analysis techniques allows for mathematically rigid measurement of the structure of the connectedness of a network independently of its content.

Sociologists and statisticians have been advancing the field of network analysis since the 1930s, but software for analysing networks really only began appearing in the 1990s when computer scientists became interested in modelling increasingly complex domains. Fields that use network analysis include information technology (including computer networks such as World Wide Web), biology, and the social sciences.

Why look at workplace settings

Many people spend a significant part of their lives at a workplace. Robert Gifford, eminent environmental psychologist, says that "the physical environment at work is crucial to employees' performance, satisfaction, social relations and health" (Gifford, 2007, p.372). Research into people's response to workplace settings focuses on employee productivity and satisfaction (Brill, 1984; Becker & Steele, 1995), but other important areas are to be investigated, especially in an increasingly knowledge-based work environment: collaboration, interaction, social behaviour, being part of a team, control over environment, flexibility, comfort and health (Worthington, 2006). To map out the human response to the workplace environment, Gifford (2007) draws on extensive research to find that five variables of workplace settings primarily contribute to behavioural response: 1) sound, noise, and music, 2) indoor climate, 3) air, 4) light, colour and windows and 5) density and arrangement of space.[1] John Eberhard, author of *Brain Landscape*, also devotes a chapter to workplace design (2009, pp. 135-153). His purpose is to identify areas for further research. It can be concluded that this architectural setting has elicited limited empirical research on the user response, yet is an important architectural type to investigate in terms of its psychological impact on society.

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[1] These variables can be observed in the environment-response network, but so do other features, such as technological devices that enable free and easy movement as shown in the later graphs. The usefulness of an environment-response network is that it captures variables in total, so that their relative importance can also be examined.

Fig 1. An atrium inside case study *workplace x*. The environment-response network will reflect the thoughts and feelings of employees that use the space, positively and negatively. (Photo: author)

Data in the environment-response networks

The data was collected from interviews, coded into spreadsheets then transformed into a Pajek readable file.

Data Collection

Data was gathered from in-depth interviews at a series of workplaces (this paper focuses on one, *workplace x*, as an example). Nine to fifteen employees at each case study workplace were asked to talk about their experience of their physical surrounds using metaphors. Metaphors involve understanding one thing in terms of another and are assumed to shape new thoughts (Gibbs, 1992). This technique has been used in the field of psychotherapy to help patients make unconscious experiences more conscious and communicable (Kopp, 1994) and in consumer market research (Zaltman & Coulter, 1995). The use of metaphors is stimulated by a range of images provided to interviewees to help illustrate their thoughts. This technique was used to collect data for the environment-response network as it offers a way to go beyond the interviewee's conscious self-perception of their response to their workplace environment. Once a metaphor, thought or feeling has been stated by a participant they were then asked to elaborate on it and to connect it to an aspect of the workplace that most strongly gave them that response.

Coding the data

Data in the interview transcripts are coded in environment-response pairs, response-response pairs and occasionally, environment-environment pairs. When a thought or feeling is mentioned, its link to the workplace environment or other thoughts or feelings is recorded. Between 40 and 80 pairs are identified for each respondent.

Linguistic research in syntax, the study of the rules of language and sentence structure, is beginning to examine the basis of language as links between words and actions when they share an object of reference. Richard Solé uses this notion to turn linguistic constructs into networks: “two words are linked if they have been syntactically combined in a collection of sentences. Different languages share the same scale-free structure, with most words having few syntactic links and a few of them being connected to many others” (2005). While linguistic theories are being developed, there is not much literature on research methods that translate speech into a network model. What has been done in this study is to assemble networks from meaningful constructs that are connected by association within in a related set of sentences.

Structure of the network data

Each analysed network of a user group has approximately around 100-120 vertices representing meaningful constructs and 600-1000 edges (comprised of 40-80 edge pairs from each individual interviewee). Vertices are either thoughts or feelings about an environment (shown as circles in the network) or workplace environment features (shown as squares). The number of duplicate connections (connections made by several individuals) provides a weighting to an edge. In the visualisations the vertices are sized according to the number of participants mentioning the corresponding construct. The graphs are also undirected as the directions of connections between constructs in interviews are not able to be coded with certainty due to language syntax complexities.

In the consensus network one-off responses are removed so that it only reflects connections about which there is a certain consensus within the respondent group. This consensus data, displayed as a network, provides visual information about the pattern of perception and emotional response to space for the group.

A key feature of the environment-response network is that it demonstrates links between workplace environment features and thoughts and feelings. This allows tracing of how particular responses were generated. While the networks have been abstracted, they demonstrate that responses to any given environment are complex and interrelate with many different parts of the environment. Social network analysis tools enable unpacking and interpreting of that complexity. In reading the networks, caution must be exercised towards the generalisation that certain features will, if installed in a different environment, lead to similar responses. The aim of this paper is instead to demonstrate the potential of analysing the overall environment-response network to observe perspectives on the one environment by different involved groups of people.

Analysing environment-response networks

Analysis of environment-response networks takes, using social network analysis (SNA) terminology, a ‘sociocentric approach’, in which the structure of the entire network is analysed as opposed to focusing on the position of one of the constructs of the network, or an ‘ego-centered’ approach, although this can be done on a case-by-case basis when much more information specific about a case is desired. In addition to the visualisation capabilities of network analysis software, the network analysis operations used for the environment-response network are proportional strength of ties, removal of edges, centrality measures (degree centrality and closeness centrality), cut points and bi-components.

To analyse the environment-response network it was first considered what analysis was desired from the network. Determining what thematic clusters or topics emerge (which we've called 'metatopics') from the networks is a primary finding. The first step is to reduce the number of nodes on the user group network by removing one-off responses. The reduced network is then visualized by drawing vertices with strong connections close together. Important vertices are identified. These include the most highly connected workplace environment features and thought or feeling responses, and the most central workplace environment features and thought and feeling responses. The vertices that, if removed, break the network are found, as they are important links in the overall perception of the workplace as well as possibly indicating the location of clusters in the network. The identification of metatopics follows on from the above steps and through domain knowledge. These clusters can be ranked and compared through number, sizes, values and density of their nodes and the location of the cluster in the network. Highlighting metatopics reveals additional pivotal vertices in the network, such as vertices that connect clusters together, but whose importance as a link may not been so clearly seen without domain metatopic clustering. This section presents these steps using the data gathered from interviewing a user group of case study *workplace x*.

The automatic layout to generate all depictions of networks uses the Kamada-Kawai algorithm. For small networks that have less than 500 vertices it produces regularly spaced and stable results (Nooy, Batagelj & Nooy, 2005, p.17).

Reducing and drawing the network

The vertices are sized proportionally by the number of respondents mentioning it and the edges thickness by the number of respondent mentioning the link. Drawing all the connected constructs or vertices, totalling around 100-120, makes for a very difficult to read graph (Fig. 2). Removing one-off responses makes the graph more valid and helps to focus on items that are important across individual conversations.

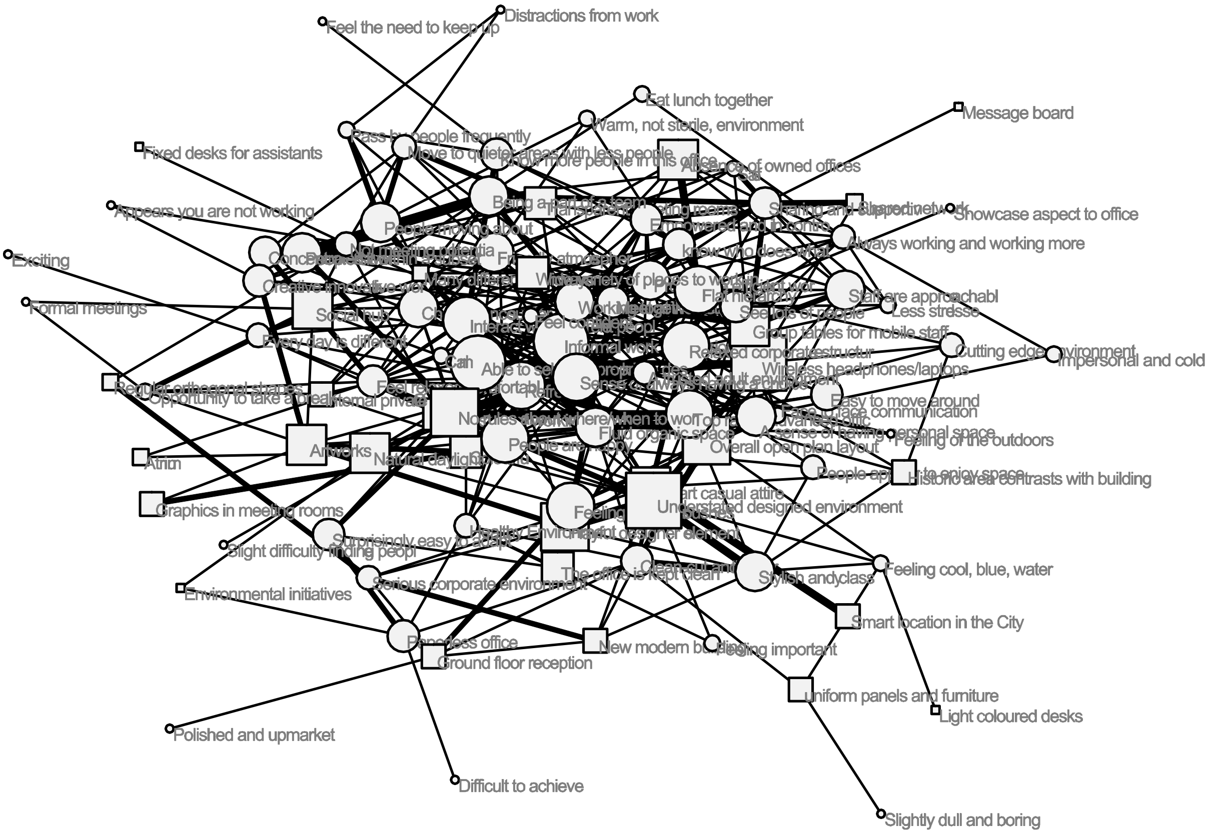

Fig 2. The complete environment-response network for the group of users interviewed in workplace x. The network is difficult to read when all the coded responses are included.

The reduced consensus network is drawn by positioning vertices with strong connections close together using proportional strength of ties (Fig. 3). Visualising proportional strength of ties helps identify categories of themes later, but is shown now so that the same graph layout may be used to demonstrate all the following analysis steps. The calculation considers the importance (or exclusivity) of an edge. It is calculated as the edge weight of a tie to a vertex divided by the sum of all ties incident to that vertex. A tie is not very important for a vertex if it has a low edge weight and is just one of many. For each edge there are two results depending on the vertex the strength is calculated relative to. For instance, in Fig. 3, the ties between *sense of having a choice* and *fluid organic space* have two values. The vertex *sense of having a choice* is one of three ties that *fluid organic space* has and the connection has a value of 0.33. In the opposite direction the tie is much weaker with a value of 0.08 as *sense of having a choice* has many more ties, several of them also having stronger edge values.

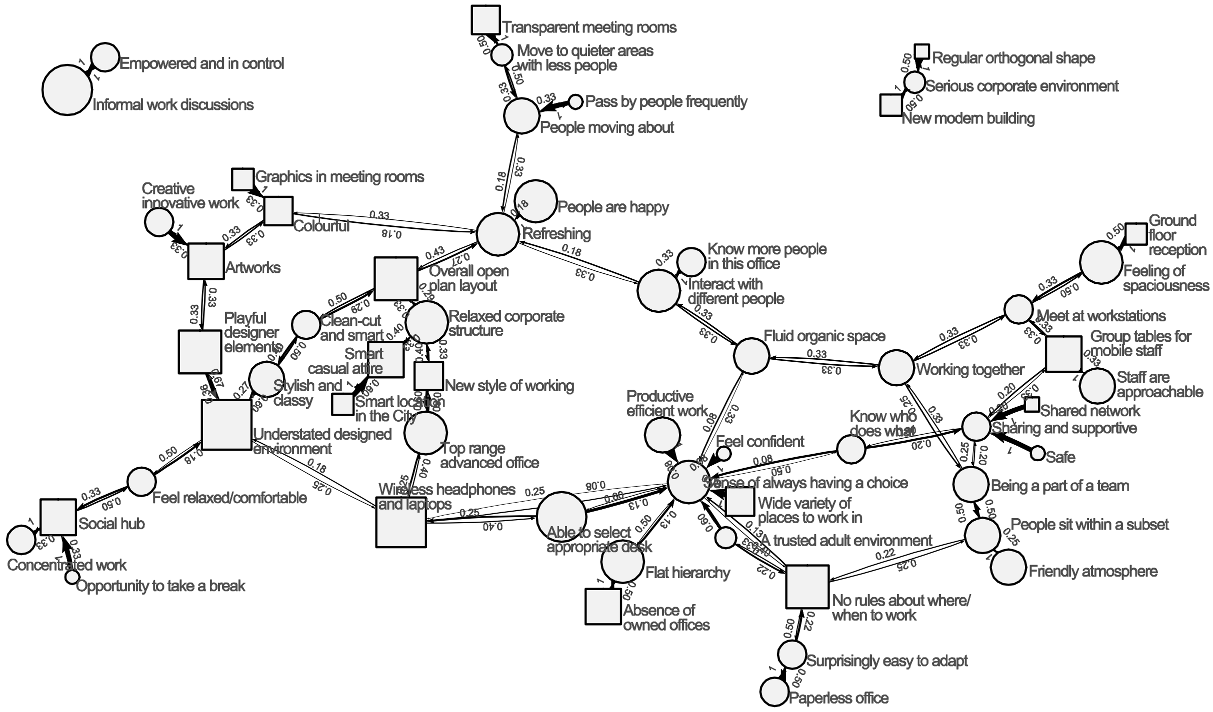

Fig 3. A consensus environment-response network for a user group in *workplace x*. One-off responses are removed and vertices with strong connections are drawn closely together. The squares are workplace environment features and circles thoughts and feelings.

Most highly connected vertices

Highly connected environmental features control a constellation of feelings about the workplace, and highly connected thoughts or feelings are quite permanent and strong. A vertex ‘degree’ is simply the number of lines incident with it. They are likely to be found in dense sections of the network.

The most highly connected workplace environment features (squares) are shown in grey in Fig. 4. These three elements of the workplace (*understated design, wireless headphones/laptops, no rules about where to work*) have the most control and influence over how the user group thinks and feels about the experience of the workplace. Removing or changing these features will have a major impact on the structure of the network, thus perception of the workplace.

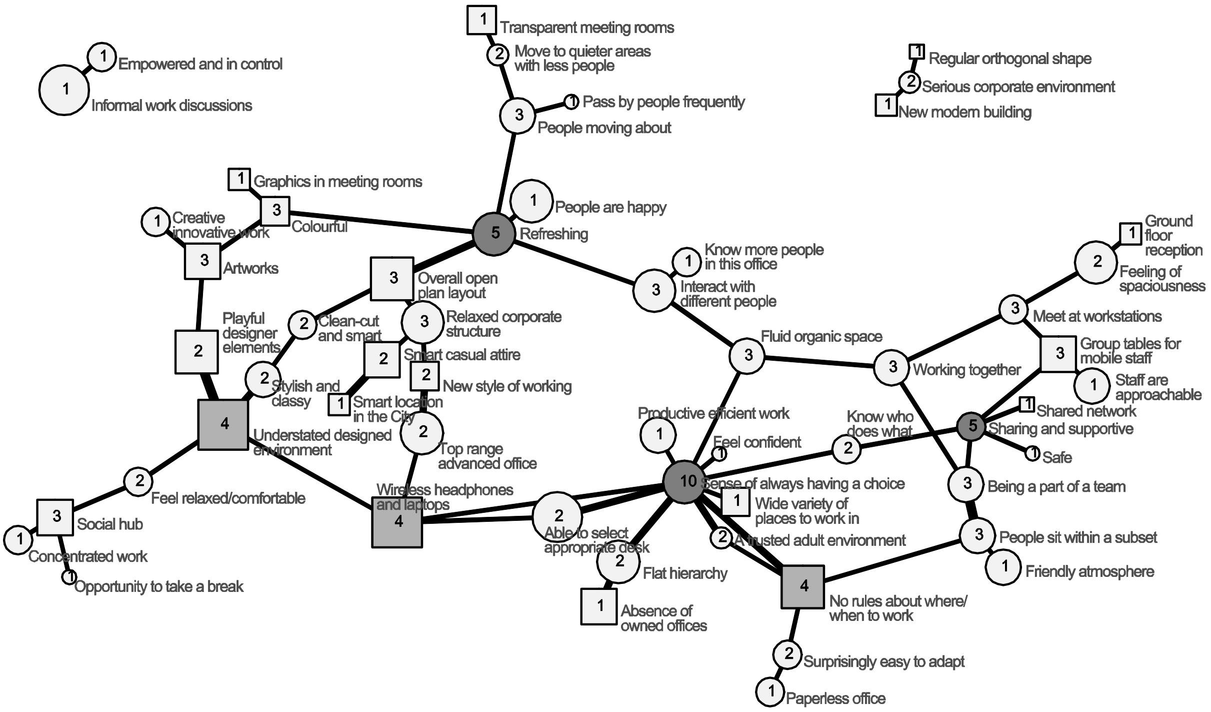

Fig 4. Highly connected vertices (degree centrality). These show the most controlling/influential vertices on the environment response network.

The most highly connected thought or feeling responses to the workplace (circles) are shown in a darker grey in Fig. 4. These thoughts are quite permanent and strong. Many workplace changes are needed to change these thought responses. For example, the feeling that the workplace is *refreshing* is connected to five other constructs. Interestingly, only one, s*ense of always having a choice*, is directly connected to one of these influential workplace features. The degree average for all vertices in the network is 2.18.

Most central vertices

These are the most central or embedded vertices within the network. Their centrality is brought on by often distant nodes in the network, making it difficult to determine the impact changing a workplace feature (square) will have, or what features effect a central thought or feeling (circle). They are found using a closeness centrality algorithm. This is based on the total distance between one vertex and all the other vertices, where larger distances yield lower closeness centrality scores. The closer a vertex is to all other vertices the higher its centrality. The degree centralities for all vertices are given in Fig. 5, with the most central ones in grey. The closeness centrality calculation results in continuous rather than discrete scores, which enables Pajek to draw the vertices according to its closeness centrality value. The arithmetic mean for closeness centrality across all constructs is 0.186 (from a range of 0.035 to 0.296).

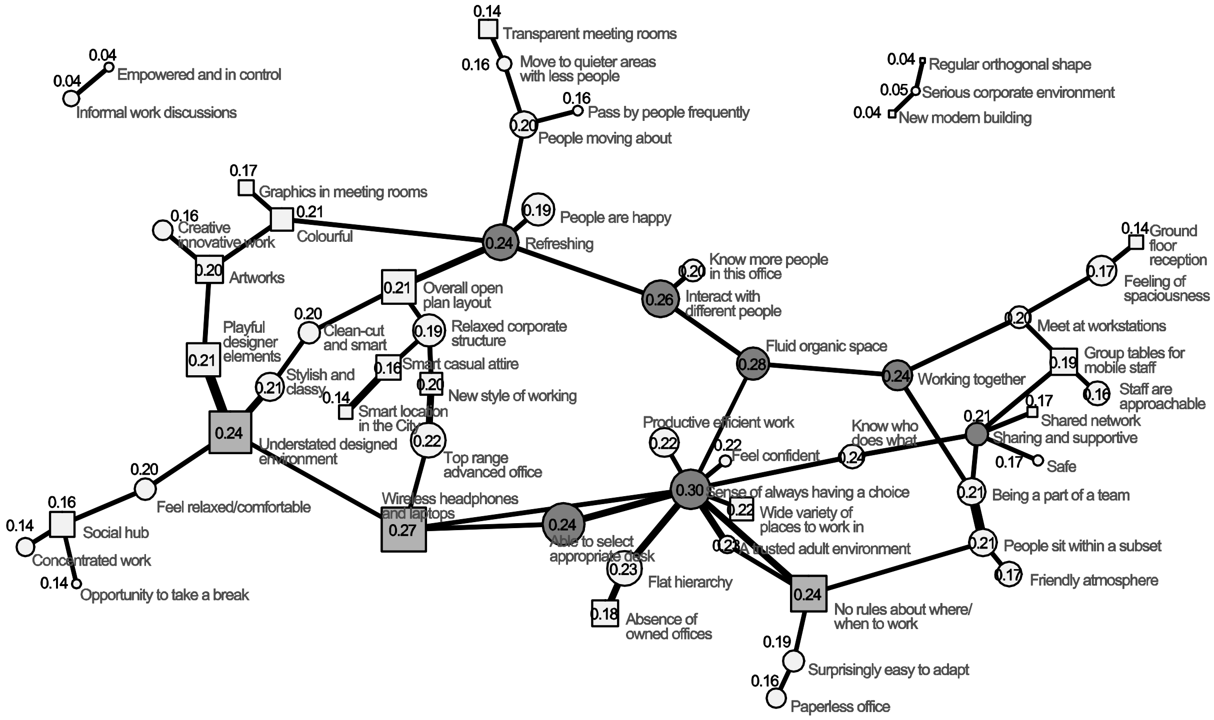

Fig 5. Central vertices (closeness centrality). Vertices are sized according to their closeness centrality values.

Vertices that break the network

Identifying cut-vertices and bi-components can be helpful in locating clusters in the network. Cut-vertices are all vertices whose removal, and all edges incident with it, breaks the network into more than one component. The numbers on the vertices in Fig. 6 refer to the resulting number of components should the vertex and its incident lines be removed from the network. It identifies vertex constructs that are necessary to link constructs (in particular chains or subnetworks of constructs) to the bigger picture. These linking vertices control the flow from one component of the network to another.

Bi-component operations are a subset of cut-vertices. It identifies those vertices that break a network into components whereby each vertex in the subnetwork connects to at least two vertices. They can indicate a more strongly clustering of vertices within the network. No positive result occurs in this example network.

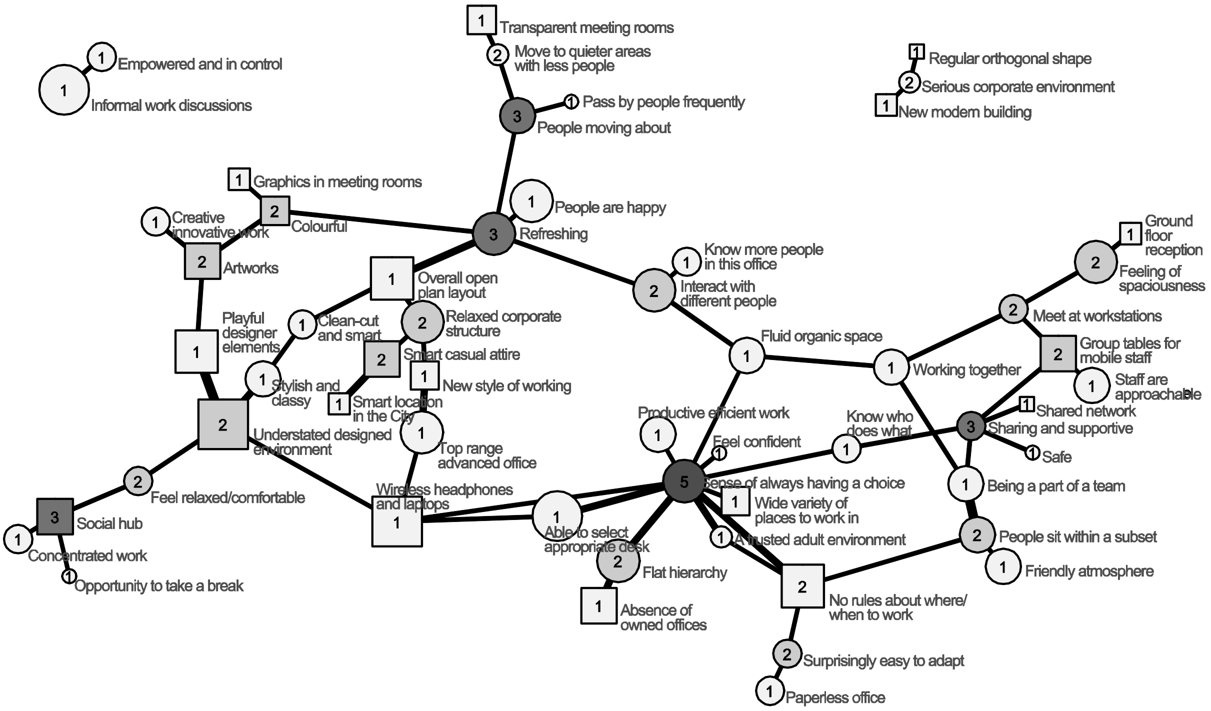

Fig 6. Vertices that break the network (Cut vertex). The vertex values show the number of components that would result should the vertex and its incident lines be deleted.

Metatopics

All previous network analysis steps help to understand where clusters of themes or topics may emerge from the network. But separating vertices into thematic clusters also requires domain knowledge of which vertices can be grouped together in a meaningful way, and to be able to define and name metatopics represented by the clusters.

In the users' environment-response network (Fig. 7) there are six metatopics, labelled *creative*, *stylish and professional*, *social*, *freedom and choice*, *team* and, separate from network, *serious*. The most important metatopics are identified by observing the number of nodes, sizes of the nodes, how closely they are drawn together, their interconnectedness (or density), the centrality values of its nodes, the location of the cluster within the network (does it take a central position by having connections with other clusters?) and the connectedness of the cluster to other clusters.

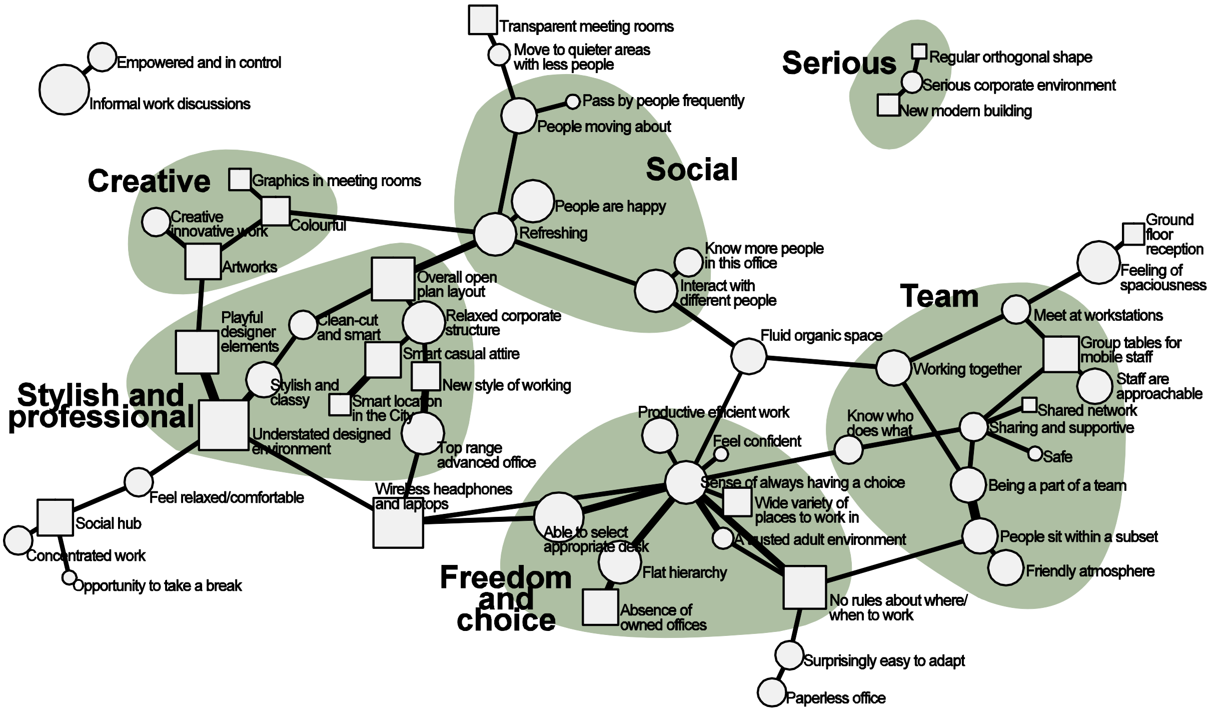

Fig 7. Metatopics for the user group of *workplace x*.

In this network the cluster *freedom and choice* is the most prominent cluster by these measures. Although it is not the cluster with the most vertices it contains the highest scoring vertex on both centrality measures (*sense of always having a choice*), a central workplace environment feature (*no rules about where/when to work*) and a high value closeness centrality vertex (*able to select appropriate desk*). It directly connects to two other metatopics and another indirectly, and its vertices connect to each other with multiple weighted edges. At the opposite end, the metatopic *serious* takes a minor role in the user response. While it is a recurring subject in user responses, it takes no influential role on the other thoughts and feelings that the users have.

One of the most pivotal vertices in the network is *fluid organic space*. It connects to the metatopics *social*, *freedom and choice* and *team*, and at the same time is not a part of any of these categories. While its degree centrality is average, its three edges are key in connecting metatopics. Its significance is better indicated by its closeness score, which reflects its average distance to all other vertices. The closeness centrality score is 0.28, the second highest in the network. Although the feeling that the workplace is a *fluid organic space* is a key finding in the network analysis, this certainly is not something that can be easily seen when visiting the workplace. It would also be a difficult property to be asked to 'design' into an environment. Another notable element is the workplace environment feature *wireless headphones/laptops*. It only connects two categories, but it does rate highly on both centrality measures. This indicates it is influential as to how the workplace is thought about.

Comparing the users' network with the designer's

All the steps mentioned above, involved in the network analysis of the user group, also took place to define the clusters of thoughts or metatopics that the designer has towards *workplace x* (apart for step one because it is an individual rather than consensus network). The same colour coding from the user's network (Fig. 7) is used in the architect's (Fig. 8) to allow identification of similar metatopics, with a dotted grey outline used to indicate themes the architect does not share with the user group. Both networks exhibit themes of *serious*, *team* and *social*. Interestingly in the designer's environment-response network *serious* has become one of the more significant metatopics. In this network it contains a greater number of vertices, with increased density (interconnectedness), and it is, albeit at some distance from the rest of the network, now connected to the network. The categories of *team* and *social* match the user group network reasonably well. The architect does not include the themes of *creative*, *stylish and professional*, or *freedom and choice*. Instead, categories of *uplifting*, *informal*, *cutting edge* and *easy* are added. The fact there is no metatopic corresponding the one the users mostly use to categorise their environment, *freedom and choice,* is quite surprising. In this case the users see the workplace generally more positively than the designer does. Further studies may help to clarify what factors contribute to a discrepancy in this direction.

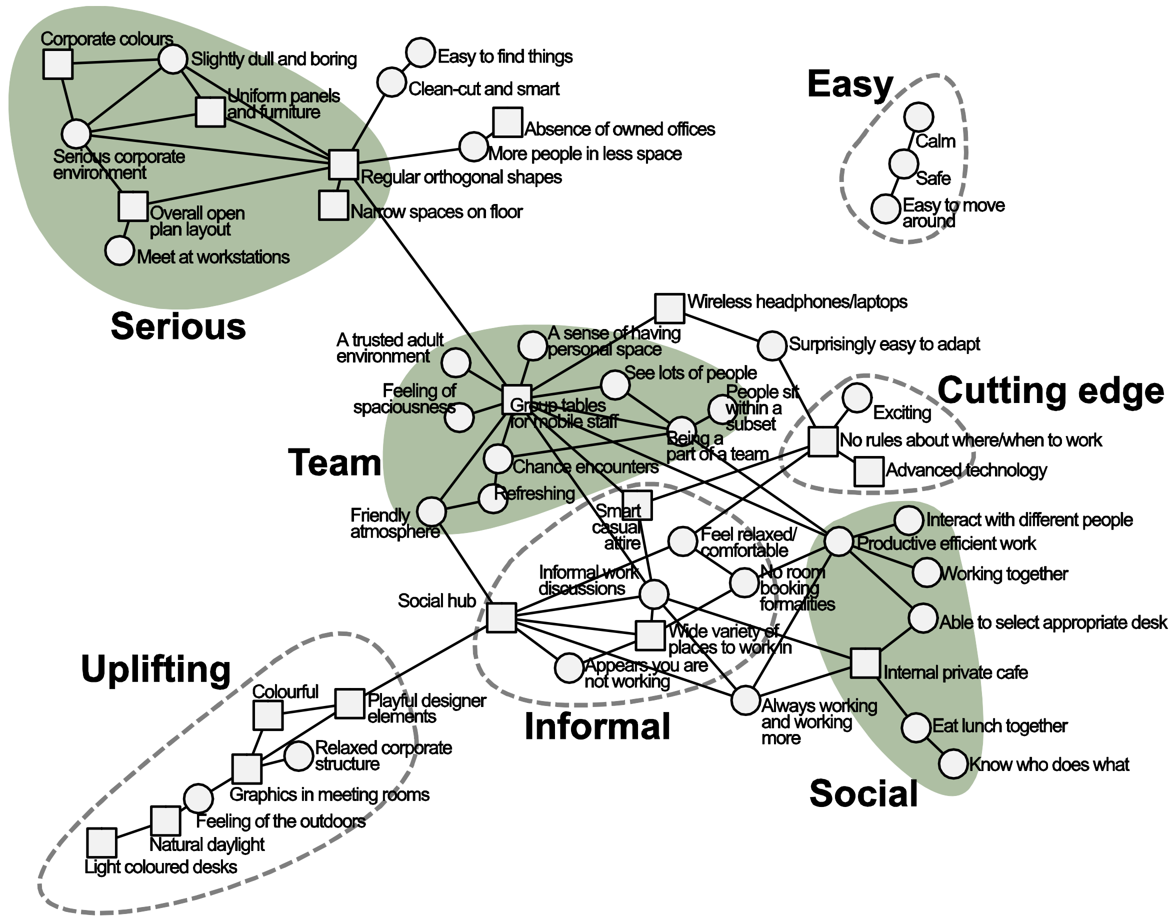

Fig 7. Metatopics for the designer of *workplace x*. The grey clusters indicate metatopics shared with the users' and the dotted clusters are metatopics unique to the designer.

There is no pivotal thought or feeling characterising the environment for the designer. In fact, the construct *fluid organic space* that was so prominent in the user network does not register at all in the designer's response. On the other hand, the workplace environment feature *wireless headphones/laptops* connects, yet stands apart from, two categories in both networks. It also exhibits high centrality within the network of the architect's responses.

Also interesting is that many of the vertices (workplace features or thought constructs) correspond to similar ones in the user group network, but forming different combinations, and thus metatopics. For example, in the user network the workplace feature *overall open plan layout* is allocated to the category of *stylish and professional*, but in the designer network it is connected to very different vertices and is allocated to the metatopic *serious*. In the user network the *social hub* is perceived as somewhat marginal, but for the designer it is an important feature (and has higher centrality values in this network).

It might be expected that workplace environment features would take central positions in the designer's network due to their focus on being on the physical elements of the workplace, with thought constructs taking secondary roles. But this is not the case. In both networks the central elements are roughly equally divided between workplace environment elements and thoughts and feelings.

Conclusion

The application of network analysis to interviewee response constructs demonstrates a way in which networks can be used to visualise 'group think'. The significance of being able to analyse centrality of constructs and identify clusters using network analysis is highlighted in this case by the fact that the user environment-response network is quite different from that of the architect who is professionally expected to predict the implications of design decisions on the users' perception of space.

By using network analysis to help identify central vertices (constructs that control a constellation of themes) and metatopics (collective orientations or themes), observations are gathered on the structure of collective mental representation of built environments. This is considered an initial step towards further research into interaction between designer and users.

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