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1. Introduction

Understanding how employees interact with one another could help partners, as well as managers, to get a grasp on how the networks in their firm is organized. This information could give them crucial clues on how to proceed to enhance the interactions in the firm. Knowledge management has become an important topic of interest in the last decades. With the apparition of internet, the codified knowledge, which is the knowledge that can be easily transcribed in a list of steps and stored on a computer, has become more easily accessible to an important number of people (Nonaka, 1991). However, tacit knowledge, the knowledge that is hard to formalize and difficult to communicate, has not become more easily accessible in a direct term, but it is the most important knowledge, it makes the difference between the expertise of different employees (Nonaka, 1991). Different systems have been established to allow employees in a firm to gain access on whom to ask for a specific problem they might encounter. Therefore, understating how the information is broadcast is of great importance to ensure that the diffusion of knowledge is more efficient, that there is no repetition of work, and that the work is of greater quality.

2. Problem Statement

This paper will analyse the interactions of 46 employees in a consulting firm, in terms of how frequently information or advice is asked between employees and also how the expertise of each employee is perceived to be helpful to others. The purpose of this paper is to discover which attributes of an employee makes him/her an important actor in the network of the firm.

Four different hypotheses will be considered:
Understanding which types of networks, the observed networks belong to will help comprehend better how they are constructed.
H1: Both networked observed follow a Small-World model.

The second one investigates what makes an employee interact with another employee.
H2: Employees engage in homophily.

Later, the impact of employees' characteristics on their centrality will be examined. The characteristics are organizational level, gender, region, and location.
H3: Certain characteristics of an employee have an impact on its centrality in the network.

The impact of employees' characteristics on the strength of their edges in the network will also be studied. The same characteristics as in hypothesis 3 will be examined.
H4: Certain characteristics of an employee have an impact on the strengths of its connections in the network.

3. Literature Review

Network analyses have been found significantly useful for companies who aim to innovate and stay competitive in today's market (Hollenbeck et al., 2015; Cross & Parker, 2004). Gaining a deeper understating on how a certain network is constructed can enhance knowledge diffusion and performance in the firm (Nonaka, 1991). By enabling managers to find easily which employee appears to have the most central position in the company, they save time to find the person who could be given more responsibilities, or how to enhance the centrality of other employees who seems more disconnected; as having a central position in a firm was found to be positively correlated with the employee's performances (Hollenbeck et al., 2015; Burton, 2007).

Many network analyses, which study relationships, tend to follow a Small-World model. The Small-World model presents that any person in the world can reach any other person through a small number of intermediates (Milgram, 1967). A theory that follows from this is the famous "Six Degrees of Separation". In his paper, Milgram (1967) conducted an experiment where many people had to forward a message to a specific person in the world, by only knowing his name and his address. Participants could only send the message to one person with whom they are close and in whom they believed had more chance of knowing the target person (Milgram, 1967) . The results demonstrate that it took approximately 5 intermediates to reach the target person, some nodes seem more important than others to find the target person, and participants tend to engage in homophily in terms of their gender (Milgram, 1967).

Every network composed of human beings may be subject to homophily. Homophily refers to the act of connecting mainly with people with whom common characteristics are shared (Dictionary.com, 2022). Homophilious behavior has been observed in several network analysis in the past. For instance, a network analysis realized in several health institutions in the aim of investigating how employees help one another, found that there seems to have an important homophily between men (Aydin, 2017). On the contrary, women tend to have more of an heterophilous behavior, which is the opposite of homophily, thus, they ask for help more to men than to women (Aydin, 2017). Additionally, people who have a longer tenure in the firm tend to ask for help people that also have a long tenure in the firm (Aydin, 2017). However, this did not apply for people with a high position in the organizational hierarchy, such as managers and partners (Aydin, 2017). Another study, realized in the U.S.A. revealed that location impact greatly the efficiency of a business network (Gloore et al., 2008). This result was also confirmed by Cross & Parker (2004), in their book "The Hidden Power of Social Networks", where they analyzed data from different authors, as well as data they constructed on sixty different companies. They discover that employees tend to connect mainly with people from the same location, and only a few nodes in the company make the connections between the different locations (Cross & Parker, 2004). Likewise, they found out that senior consultant and junior consultant in consulting firms also engage in homophily, they believe that this is due to the structure of consulting firms, where juniors are sent to clients and do not spend much time in the company. (Cross & Parker, 2004).

Considering the impact of employees' characteristics on their interaction in the firm, few information was found. Many authors recognised other factors to have an impact on employee's centrality. Bizzi (2002), for instance, in his recent network analysis made on 290 employees from 2 different companies, discover that the characteristics of a job have a significance influence on the network centrality of employees. He analysed five different aspects of a job: autonomy, variety, significance, identity, and feedback (Bizzi, 2002). He identified autonomy, variety, and significance

to have a positive impact on employee centrality, while job identity and feedback had a negative impact (Bizzi, 2002). Moreover, he found that the structure of the company may have an important influence on the density of the network (Bizzi, 2002).

It is also important to understand that an important amount of information exchange does not always mean an increase in productivity. As discovered by Lowel et al. (2007), in their network analysis on a large company, which aimed at investigating whether the frequency of information exchanged and the quality of these are positively correlated or negatively. The findings were quite surprising, as nearly half of the interactions between employees did not contain information that could enhance decision-making, and thus productivity (Lowel et al., 2007).

4. Methodology

4.1 Descriptive statistics

The dataset used in this paper was created by Cross & Parker for their analysis on social networks. The dataset gives information on how often each employee asks for information or advice to another employee, on how each employee agrees with the statement that a certain employee has expertise that could be helpful to its work, and on the employees themselves (Cross & Parker, 2004). The frequency and perceived usefulness of the expertise is represented as a number ranging from 1 to 5. 1 being "Never" for the frequency question and "Totally Disagree" for the expertise question, 2 "Seldom" and "Disagree" , 3 "Sometimes" and "Neutral", 4 "Often" and "Agree", and 5 "Very Often" and "Totally Agree"(Cross & Parker, 2004). The information was retrieved from a survey answered by 46 employees working in a consulting firm. Each employee is identified by a number, and its organizational level (Research Assistant, Junior Consultant, Senior Consultant, Managing Consultant, and Partner), gender (Male and Female), region (Europe and USA), and location (Boston, London, Paris, Rome, Madrid, Oslo, and Copenhagen) are given (Cross & Parker, 2004).

For the network analysis, the 46 employees, who participated in the survey, will represent the nodes of the networks. The frequency of information asked and the perceived usefulness of an employee's expertise to another employee will constitute the edges. Both networks are directed and weighted. As a matter of simplicity, the first network will be called "the Frequency Network", and the second one "the Expertise Network" in the rest of this paper.

The dataset was modified to fit better the research question. For the Frequency Network, the weight of 1, corresponding to "Never", was deleted as it cannot be considered a connection. Therefore, the weight was reduced to a number ranging from 1 to 4. A similar issue was observed in the Expertise Network, the weights 1 and 2 mean that a certain employee does not assume the expertise of another employee to be helpful to its work. Consequently, 1 and 2 were deleted from the datasets and the weight was reduced to a number ranging from 1 to 3.

Table 1 displays some information about the nodes, which can be useful to understand how the networks are constructed.

35 men and 11 women in total	20 employees from Europe and 26 from the U.S.A.	6 research assistants, 9 junior consultants, 10 senior consultants, 17 managing consultants, 4 partners.
26 employees working from Boston, 1 from London, 9 from Paris, 2 from Rome, 2 from Madrid, 3 from Oslo, and 3 from Copenhagen	Most managing consultant are men (16 vs. 1)	Research assistant has an equal number of men and women
The U.S.A. has more senior consultant than Europe (27% vs. 15%)	The ratio men-women are similar between the U.S.A. and Europe (0.8% and 0.73% respectively)	3 partners out of 4 are men
Partners are only present in Paris and Boston		

Table 1: Information about the nodes

4.1.1 Frequency Network

This network originally consisted of 46 nodes. However, considering that two employees, 24 and 30, do not have any interaction with anyone, they will not figure in this analysis. Both employees are research assistants from Boston. Those shared characteristics may explain why they do not interact with others.

The number of edge and the density implied that employees only connect with a small number of employees. However, the low average path length implies that each employee is only approximately 2 connections away from another employee, meaning that each employee is easily reachable. These specificities could signify that this network follows a Small-World model, which will be tested later in this paper. The overall transitivity implies that employees tend to form clusters, the reasons for such clusters will be analyzed later as well.

Number of nodes	Number of edges	Density	Average path length	Transitivity
44	523	0.276427	1.937985 SD: 0.9549749	0.6159674

Table2: Frequency Network - Network Statistics

Considering the centrality measures, it can be seen that one employee, employee 18, is the most central for the three different centrality measures. Employee 18 is a man working in Boston, USA, as a senior consultant. He has the highest strength centrality[1], eigenvector centrality[2], and betweenness centrality[3], with numbers more than double the means for each measure. His connections appear to be strong with the other employees, and he has an important influence in the network. His central position can be observed in figure1, where he possesses many edges coming and going. He also represents the link between different clusters in the network. This position is probably due to his characteristics, which will be studied at a later stage in the paper.

Strength Centrality	Eigenvector Centrality	Betweenness Centrality
Employee 18 54 Mean: 23.77273 Median: 23 SD: 11.52523	Employee 18 1 Mean: 0.44293 Median: 0.4218152 SD: 0.27615	Employee 18 250.9931740 Mean: 38.5 Median: 13.77502 SD:52.85748

Table3: Frequency Network - Centrality Measures

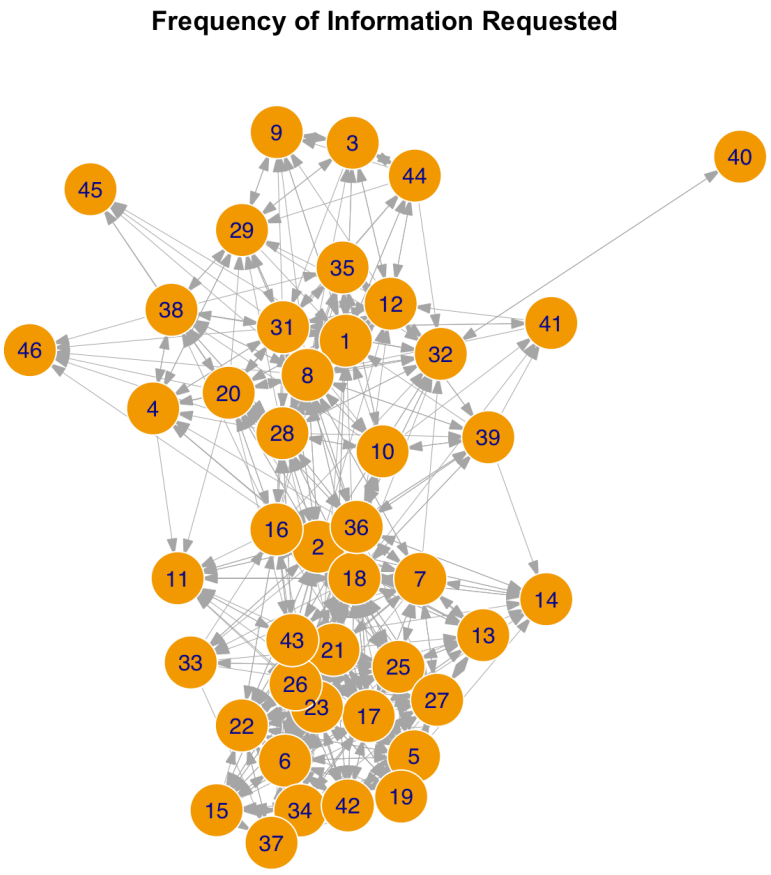

Figure1: Frequency Network - plot of the network
NB: The numbers correspond to the identifier of each employee.

[1] Strength centrality: how strong the connections of an employee is (Cowan, 2019).
[2] Eigenvector centrality: the importance of one's connections in the network (Cowan, 2019).
[3] Betweenness centrality: how often does an employee appears on a shortest path (Cowan, 2019).

4.1.2 Expertise Network

In this network, each employee has at least one connection. The density and number of edges is larger than in the Frequency Network, which can also be observed in figure2. The small average path length and the diameter indicate that every employee is easily reachable. The transitivity is large and means that employees tend to form clusters, which we can observe in Figure2. The assumptions that this network follows a Small-World model can also be made.

Number of nodes	Number of edges	Density	Average path length	Transitivity	Diameter
46	800	0.38647343	1.6794548 SD:	0.6872918	3

Table4: Expertise Network - Network Statistics

Two employees are the most central in this network, employee 18 for eigenvector centrality, and employee 20 for strength and betweenness centrality. Employee 20 is a male, working as a partner in Boston. From the numbers in table 4 and the plot in figure 2, we can conclude that employee 20 has an important position in the firm, his connections with the others are strong and he appears on many shortest paths. This is no surprise considering is position in the firm, he is a partner who corresponds to the highest level in the hierarchy, therefore, he needs to be aware of everything that is happening in the firm. Employee 18 has 1 for eigenvector centrality, implying that he has many strong connections making him have a central position in this network as well. Both employees share the characteristics of working in Boston and being male, thus it can be hypothesised that those characteristics are important to obtain a central position in the firm.

Strength Centrality	Eigenvector Centrality	Betweenness Centrality
Employee 20 71 Mean: 34.78261 Median: 34 SD: 14.3974	Employee 18 1 Mean: 0.488857 Median: 0.5386342 SD: 0.217383	Employee 20 190.3148245 Mean: 29.26087 Median: 13.31537 SD: 40.34659

Table5: Expertise Network - Centrality Measures

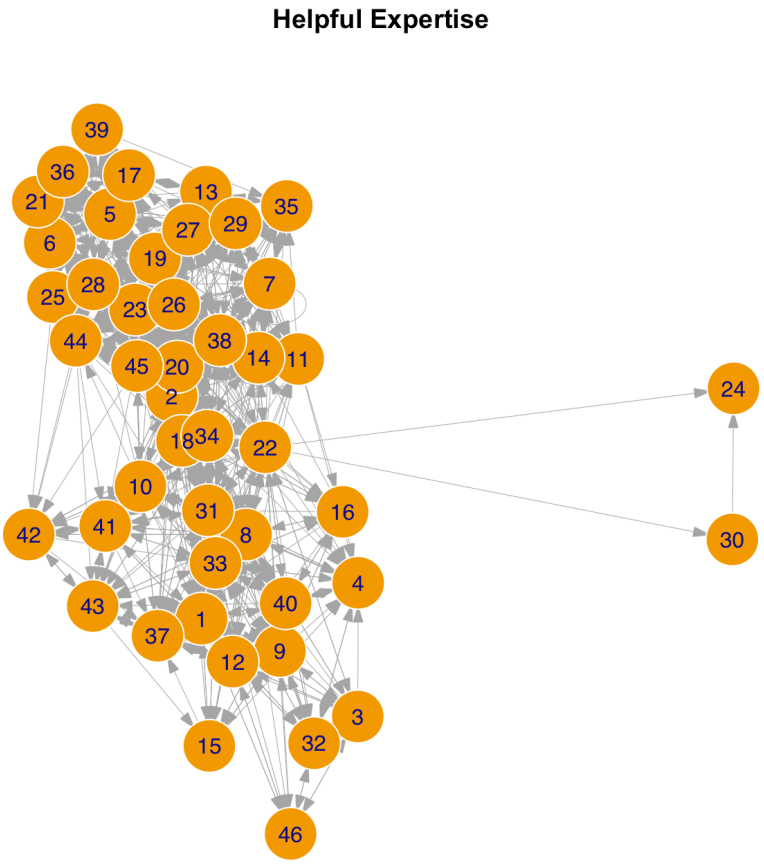

Figure2: Expertise Network - plot of the network.
NB: The numbers correspond to the identifier of each employee.

4.2 Analysis Plan[4]

The dependent variables of these networks correspond to the frequency of information or advice asked and the helpfulness of once expertise to others. The independent variables are different characteristics of employees: organizational level, gender, region, and location.

To visualise the data in a more efficient way, plot of the networks in terms of the different characteristics of the employees will be drawn to assess how the network is organized. Histograms of the degree of each network will be investigated to gain insight into the type of network those networks belongs to. Box plots of the degree per group of employees will be examined to gain an understanding on which characteristics have the biggest impact on the strength of the relations between employees.

To analyse the data, correlations will be considered to gain a better understanding of the impact of the attributes on centrality measures. Coleman's homophily index will be analysed to detect any homophily between the different groups of employees. A table of the average path length and transitivity of the observations and three types of networks will be inspected to discover to which type the observed networks belong to. For location, results made for Boston and Paris will be the only taken into consideration, as the other location comprised only between 1 and 3 employees and no sample bias conclusions want to be made in this paper.

[4] The complete analysis plan can be found in appendix.

5. Findings and Discussion

5.1 Type of Network

As observed in figures 3 and 4, both networks have a more or less bell-shaped histogram. It is slightly skewed to the right, but not enough to question whether it can be a scale-free network. Three different types of network display a bell-shaped curve: the Ising model, the Small-World, and the Random model. The comparisons between the observed networks and the three different types mentioned above can be seen in table 6. For both networks, the average path length is slightly closer to a Random model, and the transitivity to the Ising model. If we also consider the information discover in part 4.1, which stipulates that employees only connect to a small number of employees but everyone is still easily reachable, it can be concluded that it resembles the Small-World model the most.

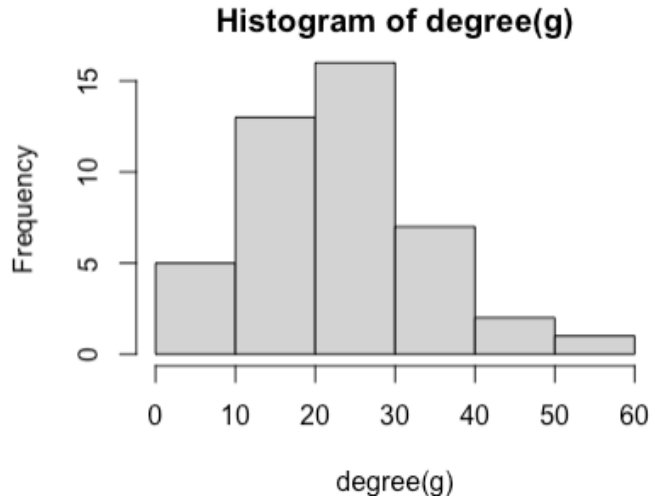

Figure 3: Frequency Network – Histogram of Degree

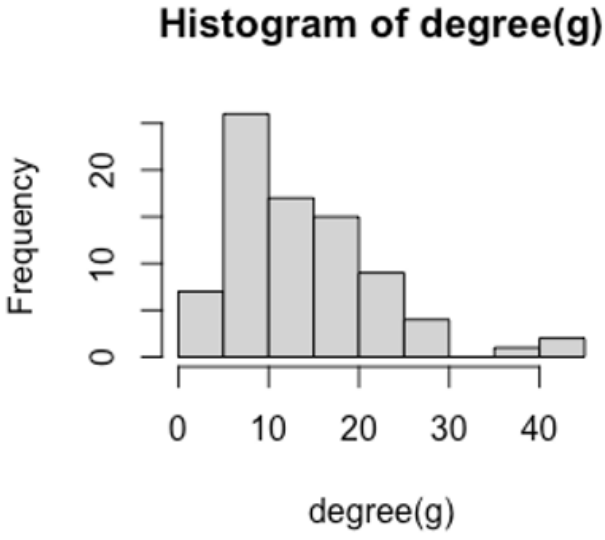

Figure 4: Expertise Network – Histogram of Degree

	Average path length		Transitivity	
	Frequency Network	Expertise Network	Frequency Network	Expertise Network
Observed Network	1.937984	1.813953	0.6159674	0.6159674
Ising Model	3.375000		0.6923077	
Small World	2.063262		0.4080608	
Random	1.894515		0.1754535	

Table6: Type of Network Analysis

5.2 Homophily

The Colemans's homophily index represents a number between 1, implying an homophilic network; and -1, a heterophilic network.

5.2.1 Frequency Network

Research assistants tend to engage the most in a heterophilous behaviour, which makes sense considering they occupied the lowest position in the company's hierarchy. Considering regions, more homophily is observed in the USA than in Europe. Homophily seems to occur more in location such as Boston. In contrast, heterogeneity can be observed in Paris. This difference might be due the fact that Boston seems to be the headquarters of the firm, with the biggest number of Senior Consultant and Managing Consultants, which are often considered the employees with the most useful expertise, with partners. The other groups have all an index approaching 0, implying that their network is quite neutral, and do not tend to engage in homophony or heterophily. Those results can also be observed in figure 5.

Organisational level						
Research assistant	**Junior assistant**	**Senior assistant**	**Managing consultant**	**Partner**		
-0.38512	-0.00541	-0.06625	0.02219	0.01031		
Genre			**Region**			
Male	**Female**		**Europe**	**U.S.A.**		
0.07066	0.00917		-0.08409	0.14150		
Location						
Boston	**London**	**Paris**	**Rome**	**Madrid**	**Oslo**	**Copenhagen**
0.19713	-1	-0.13882	0.05172	0.04827	-0.29107	0.17760

Table 7: Frequency Network – Test for homophily

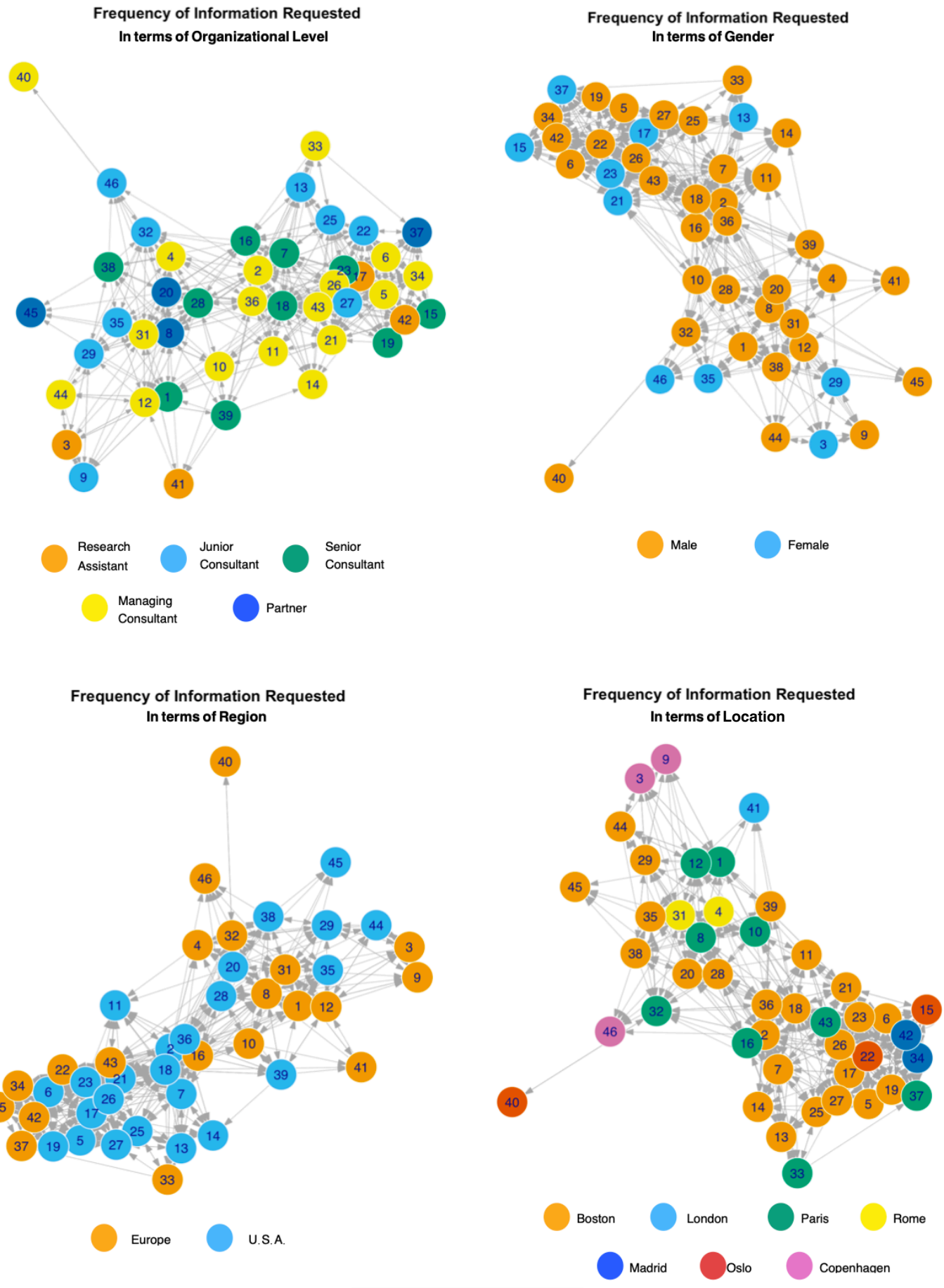

Figure 5: Frequency Network - plot of the networks in terms of the different attributes

5.2.2 *Expertise Network*

Research assistants and Junior assistants tend to engage in heterophily more than the other organisational level, this is not surprising as higher organizational level should have more expertise, and be considered as a great source of information in the firm. Males engage in homophily quite strongly in this network, this is probably because most employees with a higher organizational level are men. Both Europeans and Americans engage in homophily but at different degrees, with Americans engaging the most strongly in it, this can be explained also by their organisational level. Considering location, Boston seems to be the most homophilic networks. The other groups with numbers approaching 0 are neutral. Overall, homophily is more important in this network. Those results can also be observed in figure 6.

Organisational level						
Research assistant	**Junior assistant**	**Senior assistant**	**Managing consultant**	**Partner**		
-0.22523	-0.12327	-0.06581	0.00654	0.01276		
Genre			**Region**			
Male	**Female**		**Europe**	**U.S.A.**		
0.26870	-0.09623		0.14571	0.33105		
Location						
Boston	**London**	**Paris**	**Rome**	**Madrid**	**Oslo**	**Copenhagen**
0.37604	-1	0.07347	0.10471	-1	-0.1394	0.03302

Table 8: Expertise Network – Test for homophily

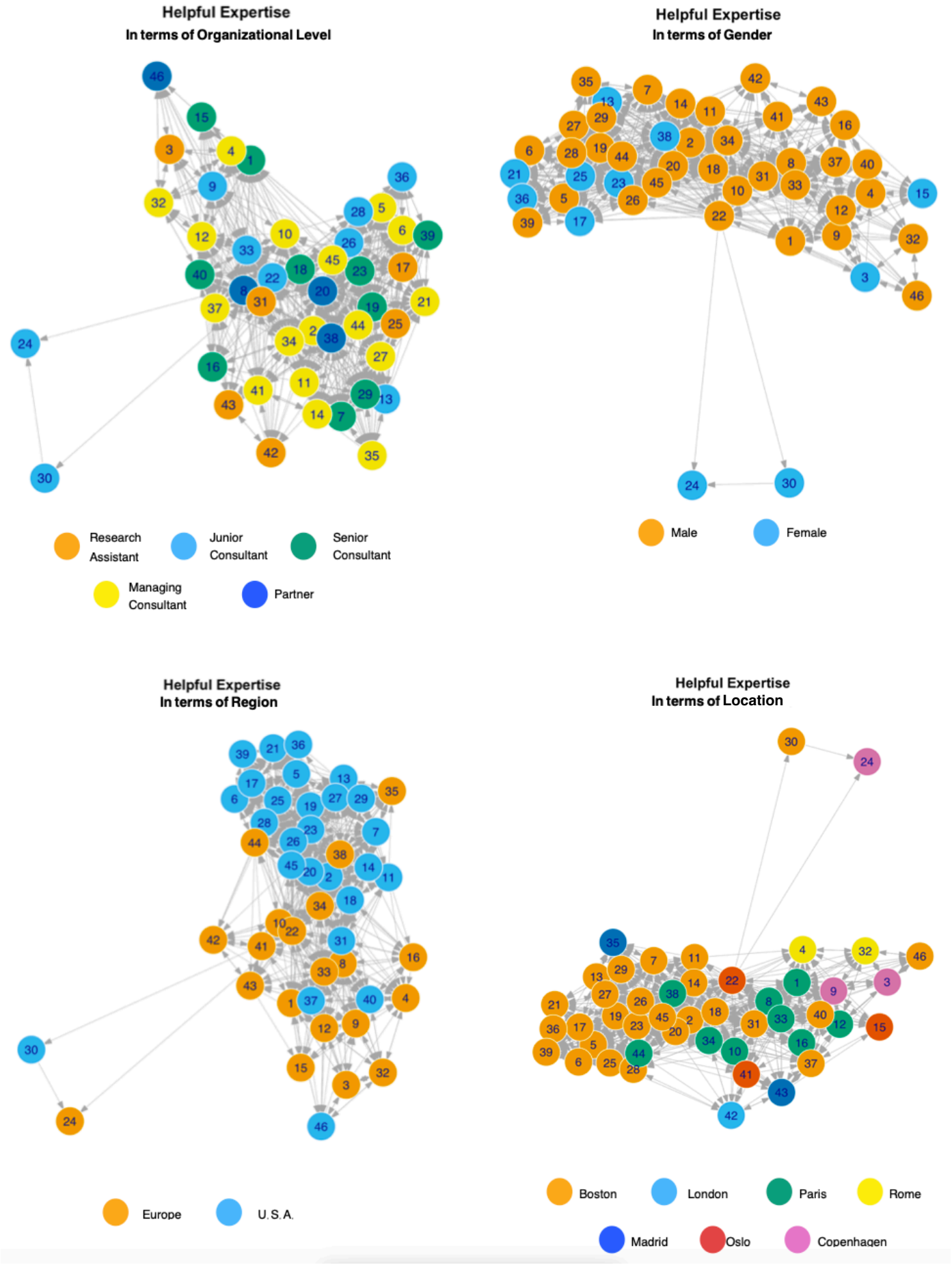

Figure 6: Expertise Network - Plot of the network in terms of the different attributes

5.3 Attributes and Central Position in the Network

The null hypothesis of a correlation test is that the correlation is equal to 0 (RDocumentation, 2022).

5.3.1 Frequency Network

Two null hypotheses can be rejected, implying that a negative correlation can be observed between location and strength, and location and eigenvector. Considering that there is 6 different locations and that the one corresponding with number 1 is Boston, which is the location with the most employees, and the most employees that are part of high organisational levels, it makes sense that the strength and eigenvector decrease in importance when location increase. As a result, employee from Boston seems to have the strongest connections and the most important connections in the network.

	Organisational level	Gender	Region	Location
Strength	0.1237641 (0.4235)	-0.0871684 (0.5737)	0.2511136 (0.1001)	-0.3356595 **(0.02592)**
Eigenvector	0.05894323 (0.7039)	-0.02204085 (0.8871)	0.2957269 (0.0513)	-0.3161385 **(0.03656)**
Betweenness	0.1875654 (0.2228)	-0.1806196 (0.2407)	0.03993461 (0.7969)	-0.1972317 (0.1994)

Table 9: Frequency Network - Correlation Matrix

5.3.1 Expertise Network

Three null hypotheses can be rejected, region and eigenvector, location and strength, and location and eigenvector. Region is divided into two groups, Europe and U.S.A. Taking into consideration the positive correlation observed between region and eigenvector, it can be concluded that employees working in the U.S.A. tend to have more connections with employees that have an influential position in the network than employees working in Europe. The same conclusions for location and strength, and location and eigenvector as for the Frequency Network can be made for this network.

	Organisational level	Gender	Region	Location
Strength	0.2464614 (0.09871)	-0.27777594 (0.06163)	0.2268154 (0.1296)	-0.3344291 **(0.02311)**
Eigenvector	0.236175 (0.1141)	-0.2052132 (0.1713)	0.3643319 **(0.0128)**	-0.4516145 **(0.00163)**
Betweenness	0.1645075 (0.2746)	-0.2496201 (0.09432)	-0.1045964 (0.4891)	0.05343191 (0.7243)

Table 10: Expertise Network - Correlation Matrix

5.4 Attributes and strength

5.4.1 Frequency Network

As observed in figure 7, a higher position in the hierarchy does increase (slightly) how often information is requested to an employee, this can be because higher position in the hierarchy needs to know what is happening in the company continuously. In average, males tend to ask more information than women, but as most employees with a high position in the hierarchy are men, this is not surprising. Americans also seem to ask more question, this difference in region might be due to cultural differences. The location with the highest strength is Boston, but this is also the one with the highest standard deviation, so no conclusion will be made.

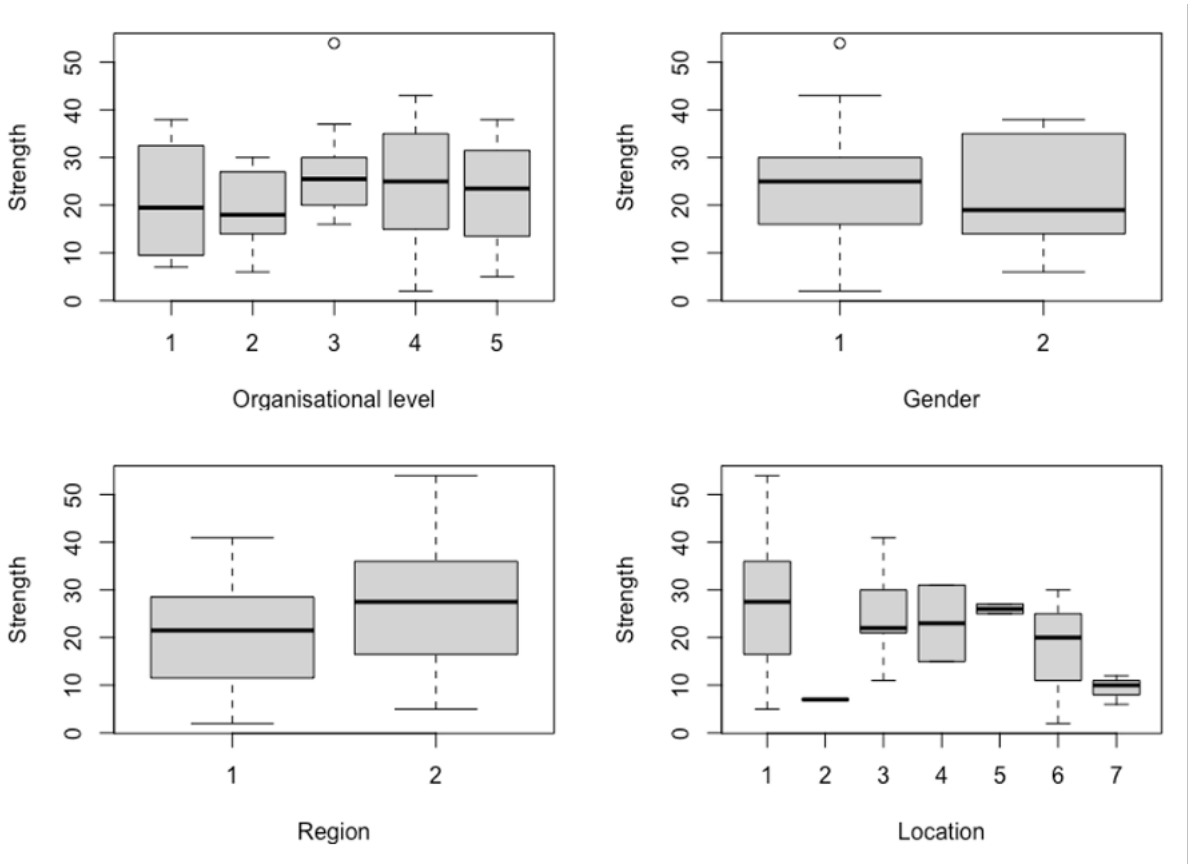

Figure 7: Frequency Network - Box plots of the strength per groups

5.4.2 Expertise Network

Organisational level has a bigger influence in this network, partner seems to know better who has the most useful expertise, which is in accordance with the results found above, with employee 20. Male employee seems to have slightly more knowledge on useful expertise, this is not surprising as 3 out of 4 partners are men. Employees from the U.S.A. tend to have higher strengths. Location with the most knowledge on useful expertise is Paris. This result was more unexpected, but this could indicate that as Americans tend to have many interactions with one another it may be not as productive as Parisians' interactions, since they have a better understating of which employees have the most useful expertise for their work.

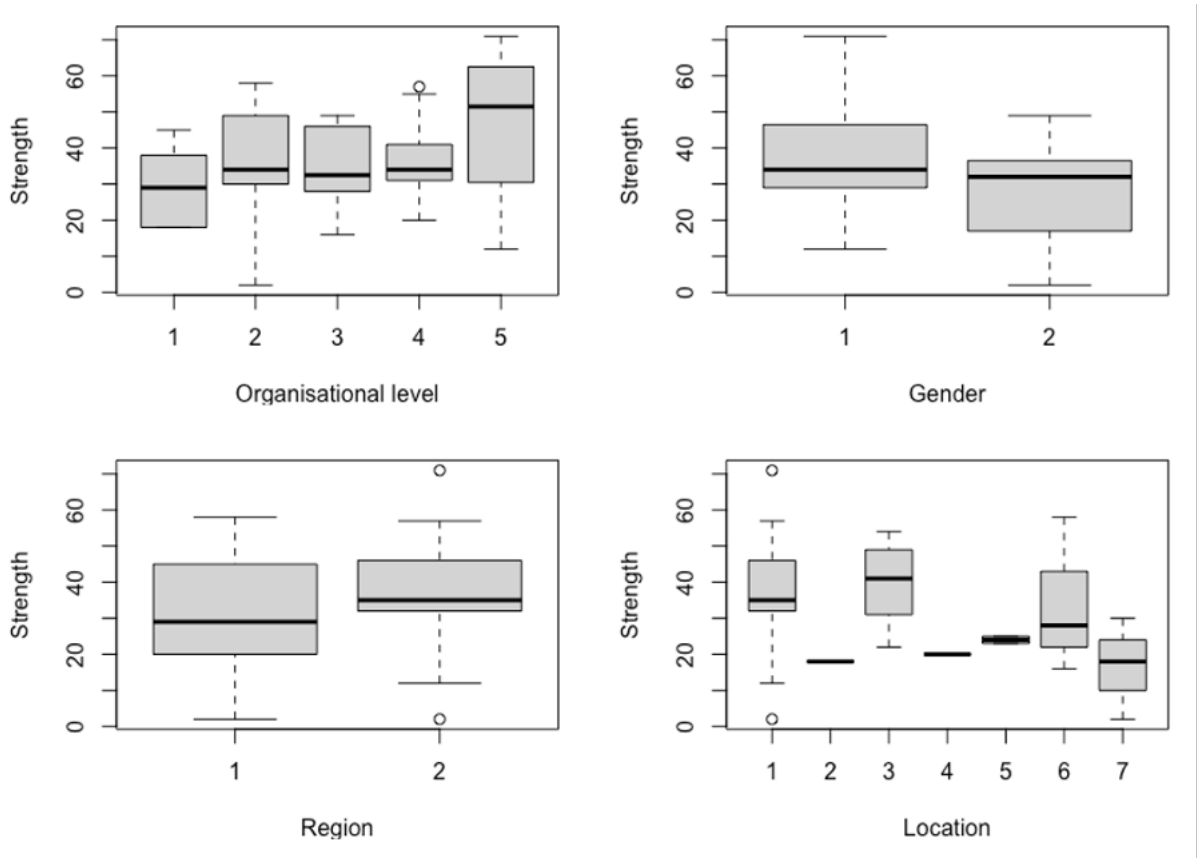

Figure 8: Expertise Network - Box plots of the strength per groups

6. Conclusion

6.1 Discussion

To conclude, both networks observed follow a Small-World model. The second hypothesis was also proven right, in the terms that employees engage in homophily. In the Frequency Network, the U.S.A. and Boston were found to engage the most in homophily. Research assistants engage the most in heterophily. The other groups are neutral. Considering the Expertise Network, male seems to engage strongly in homophily. Both regions also do, but the U.S.A. (and thus Boston) at a more important rate. Both research assistants and junior assistants engage in heterophily in this network.

Overall, it can be concluded that it is more important to have a central position in the Expertise Network, as knowing who has the most useful knowledge is more important than just interacting with someone. In general, men working in Boston, U.S.A. with a high position in the organizational level seems to be the most central employees in the firm. This is not surprising as high organizational level needs to be aware of everything that is happening in the firm, and possess the most knowledge on whom to reach for certain issues they might encounter. Most employees high in the organizational level are men. Many employees in this firm are working in Boston and it seems to be a central location in the firm.

For this firm, it was discovered that the two most central employees are number 18 for the Frequency and Expertise Networks, and number 20 for Expertise Network, both share the characteristics that were found to have the biggest impact on centrality. As employee 20 is a partner, no changes should be made. However, employee 18 could be proposed a better position in the firm or better advantages as he presents an important employee in the firm. If he were to leave, the company will lose from it greatly.

6.2 Limitations

The analysis was made on a small number of employees, 46, with most employees gathered in only two of the seven locations observed. Therefore, the results for most of the location could not be taken into consideration. Furthermore, the results only apply to consulting firms, as this paper does not investigate on other sectors.

6.3 Future Research

It will be interesting to do some research with bigger companies, as well as companies in different sectors. Moreover, going deeper into the analysis by using more attributes, such as age, number of children, relationship statues, nationality, higher level of education, type of contract with the firm, performance, quality of the information exchanged, etc., could give great information on why some people interact more than others, and how do the company and the employees benefit from those interactions.

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8. Appendix

8.1 Analysis Plan

Analysis Plan	
Date: 24/05/2022	**Name of the project:** The impact of employees' characteristics on their interaction in a firm.
Team Members: Cassandre Lecluse	
Introduction to the topic and Research Question	
Brief introduction: This paper assesses how the characteristics of an employee influence its interactions in a firm. Two networks will be analysed. The first one represents the frequency of information or advice asked to an employee, and the second one, how helpful the expertise of an employee is perceived by another employee. Both networks are directed and weighted.	
Research Question: How does the characteristics of an employee influence its interactions within a company?	
Hypothesis: 1. Both networks follow a small-world model. 2. Employees engage in homophily. 3. Certain characteristics of an employee have an impact on the centrality of that employee. 4. Certain characteristics of an employee have an impact on the strength of the edges of the networks.	
Data details	
Data set(s) used: Cross & Parker (2004)	**Analysis Software:** R Studio
Dependent variable(s): the frequency of information asked and the helpfulness of once expertise to others.	
Independent Variables: the different characteristics of an employee, especially the following ones: their organizational level, gender, region, and location.	
Proposed Analytical Strategy	
Data Manipulation: A part of the original data was deleted. For the Frequency Network, every edge corresponding with a weight of 1 was deleted, because this edge meant that the employee did not ask any information to another employee. For the Expertise Network, the edges with a weight of 1 and 2 were deleted because they correspond to "Strongly Disagree" and "Disagree" with the statement that an employee's expertise is helpful to another employee. Therefore, it would make no sense to count it as a link between two employees.	

Data Visualization: Plot of the networks in terms of the different characteristics of employees will be drawn to assess how the network is organized. Box plots of the degree per group of employees will be assessed to gain understanding on which characteristics have the biggest impact on the strength of the relations between employees. Histograms of the degree of each network will be examined to gain insight into the type of network those networks belong to.

Data Analysis: Correlation Matrix will be considered to gain a better understanding of the impact of the attributes on centrality measures. Coleman's homophile index will be analysed to detect any homophile between different groups of employees. A table of the average path length and transitivity of the network and three types of networked will be inspected to discover to which type of network the observed networks belong to.