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Dynamics of Knowledge in Software Project Development Environments: An Approach Using Affiliation Networks

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Abstract

This work presents an approach to study the diffusion of knowledge in software development project teams based on the formation of complex social network structures in a public organization that offers information and communication technology services. We collected historical data on the allocation and records of hours worked by people in projects to build an affiliation network. We applied the method of reflections to analyze the data obtained. The constructed model enabled the description of the participation of project team members from the perspective of the creation and diffusion of knowledge in affiliation networks that describe the participation of people in projects, mediated by the knowledge and the capabilities developed for the execution of these projects. A contribution of this work is the construction of indicators related to the process of creation and diffusion of knowledge in the context of the execution of software development and maintenance projects, based on the concepts of diversification and ubiquity applied to the process of knowledge diffusion; an additional contribution is the presentation of an application of the method of reflections in an organizational context applied to the creation and diffusion of knowledge. We found that the application of management models associated with the collaborative method applied to the project development process contributed to the joint growth of diversified and more specialized knowledge alongside the knowledge considered more generic and ubiquitous. Our results show that contrary to previous expectations based on assumptions established at the beginning of the study, we concluded that in six of the seven subnetworks obtained in the period between

2007 and 2013, knowledge based on complex and diversified capabilities showed a growth proportional to the growth of knowledge related to the capabilities necessary to more general and ubiquitous activities.

Keywords

Social Network Analysis, Affiliation Networks, Method of Reflections, Organizational Knowledge

1. Introduction

Understanding the process that creates and diffuses knowledge, and develops people and teams in organizations, is essential to promote the sustainable development of companies and raise them to a higher quality level to provide services and products. It is important that this process manages innovations in systematic, disciplined and work-intensive way, as [1] argues. Structures and behavioral patterns that emerge from formal and informal arrangements, which are built to conduct work activities in companies, may indicate ways to reproduce desirable results or signalize ways to inhibit undesirable ones. Allocating people to projects and building high-performance teams depends on the required competencies, which are specific to each type of project. The selection of team members depends on the demands and needs of the projects, as well as the competencies and knowledge demonstrated by the candidates to participate in the teams. Such task requires effort from leaders and managers. While employees develop competencies during project development, new projects emerge and demand new competencies, making it necessary to consider the compatibility of individual competencies and those required by the projects.

In this work, we describe an application of the social network analysis methodology to the study of the creation and diffusion of knowledge in software development and maintenance project teams. The study was conducted at a Brazilian public organization providing information and communication technology services, SERPRO—Federal Data Processing Service. We considered the complexity of activities related to software construction, as well as that related to knowledge networks formed by project team members. Our approach was inspired by the work presented by [2], who addressed the relationship between countries, competencies developed, and products exported in a structurally similar manner. In the analogy between the network structures of this article and the structure presented in [2], people correspond to countries, and software development projects correspond to the products, with competencies being a concept common to both studies. The study was based on historical data on the participation of people in projects. We developed a model that describes this participation, forming an affiliation network in which one of the network modes is the set of team members and the other mode is the set of projects. Projects are the events that motivate the creation of links between members that make up the first mode of the affiliation network. The affiliation of people to projects occurs when they demonstrate capabilities or competencies that enable adequate performance in the execution of their tasks to develop their work. The relationship that occurs between team members is motivated by the need of members to complete the project successfully.

Starting from the question about how the allocation of people occurs based on the competencies required for the formation of software development and maintenance project teams, the aim of this research work was to study the diffusion of knowledge in these teams based on the formation of social and complex networks in a public organization that provides information and communication technology services. For this, it was necessary to obtain historical data on the allocation of and records of hours worked by people in projects, build an affiliation network from the collected data, apply the method of reflections and analyze the data obtained. We took into account the performance, the types of knowledge and the competencies developed by team members, as well as the level of complexity of projects to evaluate the degree of growth of individual and organizational knowledge, mediated by structured knowledge networks during the development of the projects. The study of affiliation networks, together with the adopted methodology, allowed elucidating the dynamics of the process of creation and dissemination of knowledge in the organization, as well as evaluating and measuring the development and accumulation of individual competencies that form the basis for the construction of organizational competencies and knowledge.

The article is structured in five sections, and the first is this introduction. The second section addresses the theory of software project development process, the competencies and knowledge analyzed in this context and the approaches to analyzing complex social networks. The third section describes the methodology adopted in the study. The fourth section shows the results, and the fifth and last section presents the conclusion and the final considerations.

2. Projects, Teams, Competencies and Knowledge Networks

We define projects as suggested in [3], as a temporary effort to create a product, a service or both. In our study, projects address the construction and maintenance of software built using a formal development process. The latter represents a collection of activities, actions and tasks performed when a work product should be created, being responsible for the development method, in accordance to [4]. As demonstrated in [4] and [5], software development and maintenance projects are complex because they combine environmental factors and their tools that are constantly evolving. It is necessary to understand business rules, which are the focus of what will be solved by the software product, and to manage the entire process that depends on the interaction and integration of people in the execution of their tasks. In this sense, [4] defines a generic software development process containing five activities: communication, planning, modeling, construction and deployment of the product. Each activity is related to the demands for specific capabilities, be they interpersonal, technical or managerial. Capabilities are developed by teams in the execution of projects and are linked to the types of knowledge at the individual, group and organizational levels, as proposed by [6], who defends that there are three coexistent levels working in an integrated manner. At the organizational level, we have identified institutional actions that promote and facilitate the creation of knowledge using intellectual capital, material, data and information resources. To these resources is added what [7] called Ba, (*i.e.*, construction of an environment conducive to the process of knowledge creation and diffusion), in which the knowledge spiral idealized by [8] promotes the exchange of knowledge by the members of the organization when interacting and relating during the development of the work.

It is important to maintain an organizational environment with favorable conditions for project development. The structuring of this environment is the responsibility of the organization, but its maintenance to ensure the achievement of the project goals depends on the team members and other stakeholders. Developing capabilities contributes to improving the quality of the construction process and the product. This provides a positive influence on project management and is one of the activities advocated by [3] in the area of people management. Among the processes described in that area of knowledge, those related to management, training, competency development and team building skills stand out.

For organizations to build core competencies and sustain themselves in the market, they must develop individual competencies in their employees. To achieve this purpose, it is necessary to invest in the formation of high-performance teams. Such actions produce an increase in organizational knowledge and induce organizational learning, as [8] demonstrates in the knowledge spiral model. According to [9], to measure and improve organizational competencies and capabilities, it is necessary to divide and categorize the workforce by type of competency. Each competency presents an integrated unit of knowledge, skills, techniques and processes acquired through specialized education and on-the-job experience. The work described by [10], reinforces this idea by indicating that individual competencies can be analyzed in three dimensions: personal competencies, educational background and professional experience. When discussing the evolution of the Fordist-Taylorist model of people management, [11] highlight the need to align organizational strategies with people management policies to increase productivity and obtain competitive advantages. This view highlights the need to align people development strategies with the global strategies of organizations and requires special attention to the network structures built to perform organizational activities.

According to [12], organizational competencies are a small number of strategic skills that allow organizations to obtain competitive advantages. The same authors differentiate core competencies from essential competencies, stating that the former are necessary capabilities but not sufficient to maintain organizations in the market. In turn, essential competencies are a set of skills and technologies that lead organizations to compete for their capabilities and not only for products and/or services. The construction of competencies is related to the individual behavior of employees. The discussion about the need for specialization at a high level or a more generalist approach is related to the issue of competencies and was discussed by [13], whose work also considers the context of competency development.

Individual competencies refer to the characteristics of a team member in terms of knowledge, skills and capabilities, which influence the way in which he/she performs his/her activities. They affect their performance, as highlighted by [14]. However, it is not enough to analyze individual competencies related to the project development process. It is also important to understand the dynamics of the relationships that occur in teams and that influence the development of collective and organizational competencies. Additionally, [15] believes that there is a distinction between groups and teams, and considers teams to be groups engaged in achieving goals that should be clearly established. For the author, when transforming a group into a team, it is necessary to incorporate competencies and skills related to conflict and problems diagnosis and resolution into their interaction process and their relationship dynamics. During this process, a virtuous cycle is formed, which is reinforced by the interaction among team members while seeking to improve the knowledge necessary for the development of their work activities and interpersonal relationships, identifying and solving technical, management and behavioral problems. The work of [16] suggests that real teams have a limited number of people with complementary competencies and skills and are committed to common purposes in addition to clear performance goals. This view complements that of [15] who suggest that team cohesion is an essential factor for project success. In the referred work, [15] describes human and behavioral factors in the workplace as complex and multidimensional, and the studies conducted to date have not allowed for the complete understanding and elucidation of aspects associated with the relationships that characterize networks in organizations. The referred author states that the behavior of teams results from the interrelationship of internal and external variables, and it is not possible to determine the precise influence of each of these variables on the observable results in work performance. The composition of influence factors and team behavior can be studied with social network analysis (SNA) techniques, which emphasize the behavior of the network rather than the individual behavior of its components, as suggested by [17], who argue that the main unit of analysis used in SNA is not the individual but the set of individuals and their interactions.

In regard to two-mode networks, [17] argue that they should be selected according to the characteristics of the study and the network itself. These authors justify the applicability of the techniques to address the study of these networks based on the intended objectives. The first objective refers to the interest in the relationships between the elements of the first network mode or the need to study the relationships between the elements corresponding to the events. The second refers to the interest in research in which the formation of pairs between the elements that make up the members of affiliation networks is important. Finally, the third group is about modeling between actors and events seen as a single system. After constructing the network, any of the modes can be studied, and the emphasis given to each approach depends on the research focus, as noted by [18].

The work of [19] emphasizes the importance of the relationships created by actors of the affiliation networks and the established relationship between events based on the multiple participation of the actors in events, with the actors acting as intermediaries. In our study, the events correspond to the projects, and the actors correspond to the team members. While projects provide the opportunity to create relationships between actors, on the other hand, the participation of actors in multiple events helps to form links between projects. For [19], the participation of actors in multiple events facilitates the sharing of information and diffusion of knowledge among the participants. This position reinforces the assumption advocated in the present study that the formation of network structures facilitates the process of generation and diffusion of knowledge. It is important to note that the research approach based on social network analysis can be combined with other techniques that allow for more in-depth analyses. In addition, the application of this methodology opens possibilities for applying theoretical approaches and the indicators developed and described by [20], who studied the process of creation and diffusion of organizational knowledge.

3. Materials and Methods

The present work is an extension of the work presented in [21], and consists of adopting a different methodological approach to that presented in the referred article. The data that supported the study were collected from SERPRO (Federal Data Processing Service), a public company providing information and communication technology services linked to the federal government of Brazil. The sample was limited to the area of software development of the regional office in Salvador, involving the project teams. After mapping and selecting the sectors of the company considered in the study, the next step was the collection, interpretation and analysis of historical data on the participation of people involved in projects, forming the affiliation network. In this network, one mode or category is formed by people, and the other mode corresponds to projects. Data used in the construction of the affiliation network were collected from January 2007 to December 2013, using the hour allocation system for employees allocated to projects. The initial selection encompassed the sectors responsible for the development and maintenance of the company's software, covering 5077 projects and 264 people. The network was built from the data extracted from the information system used to record the time the software development and maintenance project teams spent performing their tasks between 01/01/2007 and 12/31/2013. The allocation record that informs the type of work performed by a project team member contains the project in which the employee worked in the period, the time in hours related to the work performed and the type of activity performed that is related to one of the five areas of knowledge considered in the present study (software development, project management, development process management, business area and training). The adjacency matrix that represents the complete network consists of two modes, one of them related to the projects and the other to the people allocated to them. The indices were calculated using Gephi software, presented by [22] and MS-Excel. The random networks that originated the null models for each of the seven years considered in the study were generated in the software Pajek, shown in [23] and then exported to the Gephi software to ensure the consistency of the calculations performed by using the same methods and algorithms used for the networks that formed the basis of the study.

The organization studied adopted formal management and governance models for managing the software development process. The first is based on the capability maturity model integrated (CMMI), as described by [24]. The project management approach described by [3] in the PMBOK—Guide to the Project Management Body of Knowledge was also adopted. The use of these models enabled the storage and retrieval of historical data on the allocation of people to the projects, given that the documentation of each stage of the procedures performed was a recommended practice in the standards adopted from these models at the time the projects were carried out. To enable the study, the extracted data were imported into a database in which a model was constructed to represent the interactions between the network modes, adding categorical data to classify the relationships and enabling more in-depth analyses of the cause-and-effect relationships that can be obtained from the studied network.

The selected sample is representative both from the quantitative point of view, because it encompassed all the projects in the seven-year period, and from the qualitative point of view, since the projects belong to the area of software development and maintenance, being aligned with the proposal established in the research plan. After data extraction, data quality control was performed to eliminate spurious records containing incomplete or inconsistent data that could negatively affect the study results. The criteria used for data extraction were availability, performance of employees in the areas of knowledge selected for the study, reliability of the data source and representativeness of the sample. These criteria were met because the company maintains an updated record of the hours worked by employees in each project, and each record is associated with the type of activity performed and one of the areas of knowledge addressed in the study. The flow of the research methodological process is shown in **Figure 1**.

In [25] we found the study of the economic complexity of countries, where

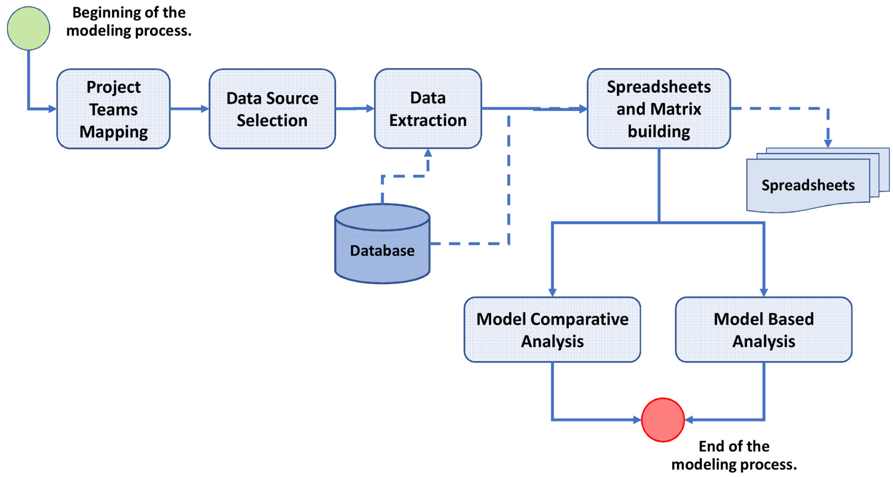


Figure 1. Flow of the research and modeling process. Source: (The authors, 2021).

products and countries are defined as vertices of the network, and an edge exists when a country proves to be a significant exporter of a given product. The authors [2] argue that the method allows capturing valuable information that would otherwise be lost. Based on this method, we constructed the adjacency matrix that represents the bipartite network of projects and people so that the intersection between columns and rows can take the value 1 (one), when a team member is shown to have participated in a given project, or the value 0 (zero) if participation does not occur. The initial values calculated for each of the vertices are considered as a baseline for the subsequent calculations. In the referred work, [2] collected data from three different sources that deal with export relations between countries to form tripartite networks between products, competencies and countries, and these networks were subsequently reduced to affiliation networks between products and countries. The method produced symmetric sets of variables based on the calculation of mean values of the relationships between the network vertices.

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_{p} M_{cp} k_{p,n-1} \quad (1)$$

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_{c} M_{cp} k_{p,n-1} \quad (2)$$

For $N \geq 1$, the initial conditions of the calculations are given by the number of links between countries and products.

$$k_{c,0} = \sum_{p} M_{cp} \quad (3)$$

$$k_{p,0} = \sum_{c} M_{cp} \quad (4)$$

In the formula, $k_{c,0}$ and $k_{p,0}$ represent, respectively, the diversification levels of a country, corresponding to the number of products exported by the country, and the ubiquity of the product, corresponding to the number of countries that export that product. The concepts of specialization and ubiquity as used by [2] require a more detailed explanation. The specialization of an individual may imply that he/she has a well-defined focus in his/her activities, as opposed to the concept of generalization, which mean an individual capable of acting professionally in a flexible, varied or multifaceted manner. However, the concept of specialization as understood by those authors implies the need for the accumulation of various capabilities, either by an individual or by a team and its members. The diversity associated with specialization, in the study by [2], is measured by the number of products that a given country is capable of producing or manufacturing, given its knowledge. This measure corresponds in our study to the number of different projects that a person is able to participate in during the construction of software products, given the knowledge and capabilities exhibited by them for inclusion in the project teams. The concept of ubiquity used by [2] refers to the penetration of products in the global market through exports. Products with high market penetration products require a small number of capabilities to produce it and, therefore, a low degree of specialization. These products are not associated with high diversification. Ubiquity is measured by the number of countries capable of producing a given product. Low-complexity products can be produced by many countries. In our analogy, people are equivalent to countries, and projects are equivalent to products, the measure of ubiquity represents the possibility of a software product being built by many people, indicating that these people have technical skills and knowledge for building it. However, because the product requires a small number of capabilities, several people with a low degree of specialization may contribute to building it.

The analyses performed were based on the six-component group presented in **Table 1**. With respect to projects, the indicator used was the number of projects

Table 1. Analytical model.

Concepts	Attribute	Indicator	Authors
Projects	Endeavors delimited in time for the construction of software products.	Number of projects.	[3] [21].
Teams	Groups of people involved in the construction of software projects.	Number of team members.	[15] [21].
Knowledge	Skills and information applied to perform a project or service.	Knowledge categories. Work performed in hours per knowledge category.	[7] [8].
Competencies	Set of knowledge, skills and techniques applied to a given task.	Number of capabilities developed.	[14].
Diversification	Individual possibility of performing different types of projects.	Number of projects in which a team member participated.	[2] [13] [26].
Ubiquity	Indicates low-complexity software products that can be built by most team members.	Number of people participating in the project.	[2] [13] [26].

Source: The authors (2021).

performed per period. In regard to the teams, the indicator selected was the number of members of the project teams. With regard to knowledge, it was sought to identify the main knowledge categories involved in the software development process and the volume of work performed considering that this work represents the conversion of knowledge into software products. Two types of knowledge stand out in the software production process. The first involves the technology used to build the software and the knowledge about the construction process and project management techniques and models. The second type of knowledge refers to that required to coding the business process that the software intends to automate in the form of commands in a given programming language. It is knowledge related to the process that was previously executed manually or in an automated manner in another software and that is now being transposed to the new software under construction. Competencies represent aggregation of knowledge, skills and techniques that are jointly applied in the construction of the software during the execution of the projects. The corresponding indicator is the number of capabilities developed by each project team member. Diversification reflects the ability to perform different types of projects and measures the degree of sophistication that each project member has in regard to the applicability of their knowledge, skills and techniques in different types of projects. This indicator reflects the ability of a team member to execute projects with a higher level of complexity. Finally, ubiquity refers to how much a given project can be performed by different teams, given its low level of complexity.

The concepts of diversification and ubiquity were measured based on the method of reflections. Table 2 describes the analytical structure developed and adapted to analyze the results from the unfolding of these concepts, using the metrics obtained by applying this method. The first level of interaction obtained from the method of reflections described in Table 2 involves two concepts that interact with each other. The first, $k_{a,0}$ represents the number of projects in which a particular team member participated in the period considered. From the point of view of the creation and dissemination of knowledge, this metric indicates the degree of diversification of knowledge that a team member has. In this case, the greater the number of projects, the greater the accumulation of knowledge by the individual. However, for the diversification of knowledge to occur, there must be a great diversity of knowledge categories that differentiate the projects. Otherwise, there will be a trend towards individual specialization in a limited number of capabilities, which will also restrict knowledge to a small number of areas.

The second level of interaction given by $k_{a,1}$ is the metric corresponding to the number of people participating in a given project. From the viewpoint of knowledge diffusion, it represents how much a given set of capabilities associated with one or more types of knowledge can be diffused within the organization to the extent that a larger or smaller number of people participate in a project that applies these capabilities and this knowledge. In this case, ubiquity refers to the

Table 2. Interpretation of the results of the interactions generated by the method of reflections.

Interaction	Abbreviation	Concept or Measure	Description/guiding question
1	$k_{a,0}$	Diversification	Number of projects in which member M_a belonging to a team participated. How many projects did member M_a belonging to a team participated in?
	$k_{\alpha,0}$	Ubiquity[1]	Number of team members in project α. How many people participated in project α?
2	$k_{a,1}$	$K_{p,1}$	Average ubiquity of the projects in which person M_a worked. How "common" are the projects person M_a worked on?
	$k_{\alpha,1}$	$K_{pr,1}$	Average diversification of the project team members How diverse are the team members who worked in the project?
3	$k_{a,2}$	$K_{p,2}$	Average diversification of people with a portfolio similar to team member M_a. How diverse are the team members who worked on projects that require the same set of capabilities as those in which person M_a worked on?
	$k_{\alpha,2}$	$K_{pr,1}$	Average ubiquity of projects worked by people who also worked on the project How ubiquitous are the projects worked by people who worked in the project?

Source: (The authors (2021), adapted from [2]).

knowledge applied in the project in question. Simpler projects require a reduced set of capabilities and a narrower set of areas of knowledge. Larger projects, on the other hand, require more diverse skills and knowledge areas. From the third level onward, the interpretation of the iteration results becomes more complex, and the values tend to converge, as highlighted by [2].

4. Results

The complete affiliation network containing projects and team members is shown in **Figure 2**. The total number of projects each team member participated in and the total number of participants in each project were obtained and added in the column represented by the sum (Σ) symbol presented in **Table 3**. The successive iterations generated by the method consist of calculating the matrix

[1]Here the term ubiquity cannot be used in the same way as [2] used it. The value obtained in this interaction corresponds to the number of people who participated in the project within a defined period of time, generating knowledge, learning and exchanging this knowledge with the other participants. The concept and metric obtained at the corresponding level of interaction in the model of [2] refer to the number of countries that exported a given product in a specific period and represent the degree of penetration of the product in the market whose participants are the different countries considered in the work by these authors.

product between the matrix that represents the allocation of employees in projects (when the row corresponds to a team member) or the participation of each employee in each project (when the row represents a project), and the column that contains the sum of each row. This matrix product is then multiplied by the inverse of the sum of the row being multiplied. These calculations were made successively, generating columns N1, N2, N3, etc. shown in Table 3, which represents a fragment of the complete matrix. The results of the method of reflections were stored in a database and tabulated in a spreadsheet to facilitate the understanding and visualization of the data.

The method was applied iteratively in the complete adjacency matrix until the 10th level. The interpretation of the results is shown in Table 3 in a summarized way up to the third level of interaction. Table 3 describes the first three pairs of variables that help characterize the relationships between people and projects. From the third level of interaction onward, the interpretation of the results becomes more complex, as [2] admit and as [26] discuss when presenting an alternative calculation method to the method of reflections.

Table 3. Fragment of the complete matrix with six iterations.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	Σ	N0	N1	N2	N3	N4	N5
PR-1	0	1	0	0	0	0	1	0	0	2	25,000,000	6,691,002	21,032,355	7,686,217	20,151,690	8,057,771
PR-2	1	0	1	1	1	0	0	1	1	21	7,095,238	14,279,947	12,416,212	11,270,105	15,175,042	9,911,736
PR-3	1	0	0	0	0	0	0	0	0	2	35,000,000	5,970,000	25,757,354	7,253,269	22,020,050	7,854,970
PR-4	0	1	1	1	0	1	1	1	0	21	10,523,810	12,299,167	14,953,938	10,099,094	16,697,846	9,411,987
PR-5	1	0	1	0	0	1	1	0	1	9	17,777,778	7,368,062	20,312,433	7,757,686	20,120,506	8,047,351

Source: The authors (2021).

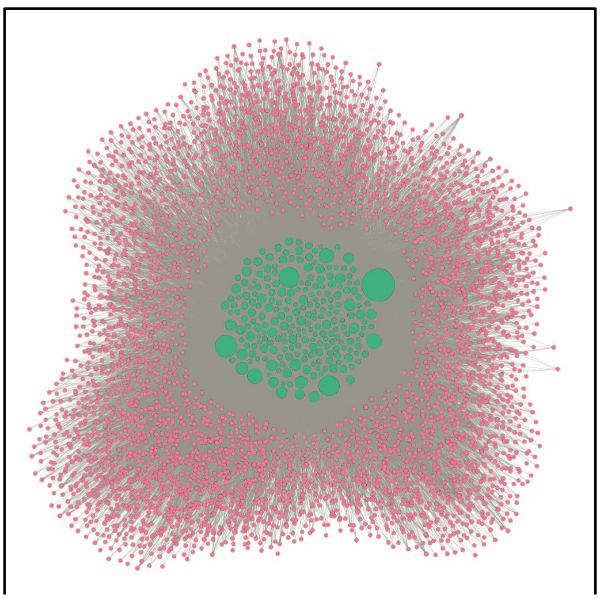


Figure 2. Two-mode network of project team members projects from 2007 to 2013. Source: The authors (2021).

Figure 3 shows the dispersion of $k_{a,0}$ and $k_{a,0}$ values for the adjacency matrix constructed for the period between 2007 and 2013. The original figure was divided into four quadrants, and the interpretation of each quadrant is given in **Figure 4**. The horizontal axis represents the evolution of knowledge specialization or diversification, and specialization is represented by increasing values from left to right. The vertical axis corresponds to the evolution of ubiquity regarding the participation of team members in projects. The ubiquity values are represented in ascending order from bottom to top. In addition, high ubiquity values indicate that projects require a low level of specialization on the part of the development team participants, given that the knowledge necessary to execute them does not require a large set of capabilities.

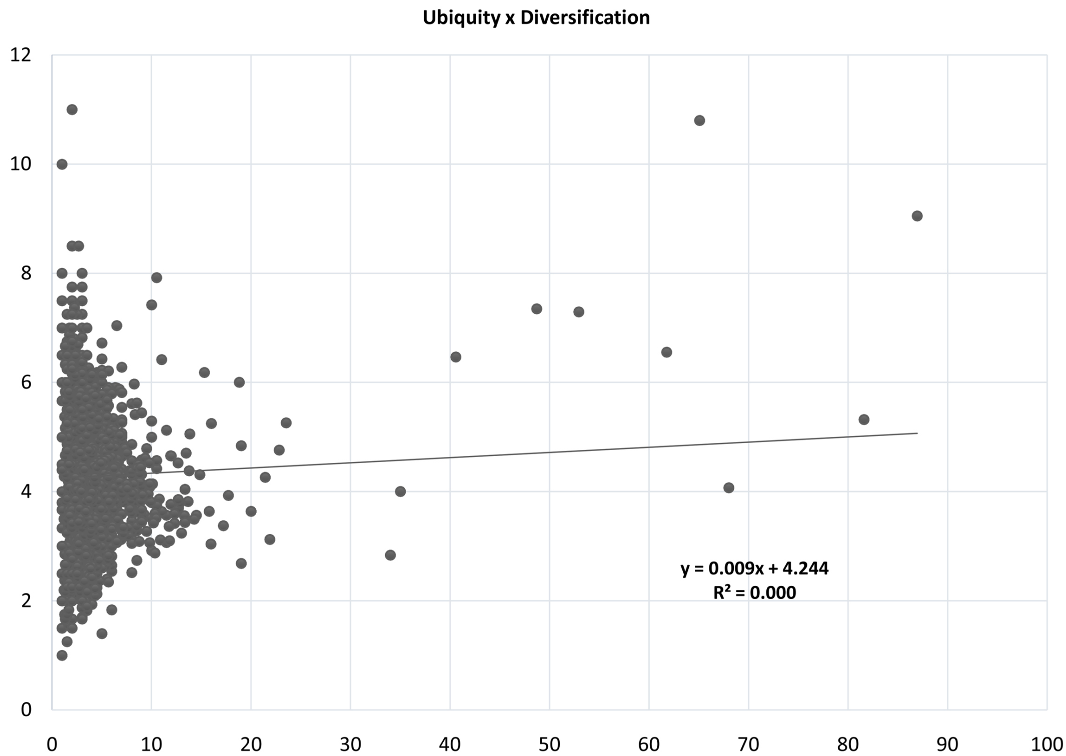


Figure 3. Scatterplot N0 × N1 (Ubiquity × Diversification) between 2007 and 2013. Source: The authors (2021).

Q4 Low-skilled people working on low complexity projects.	Q3 Highly skilled people working on low complexity projects.
Q1 Low-skilled people working on high complexity projects	Q2 Highly skilled people working on high complexity projects.

Figure 4. Interpretation of the quadrants. Source: The authors (2021).

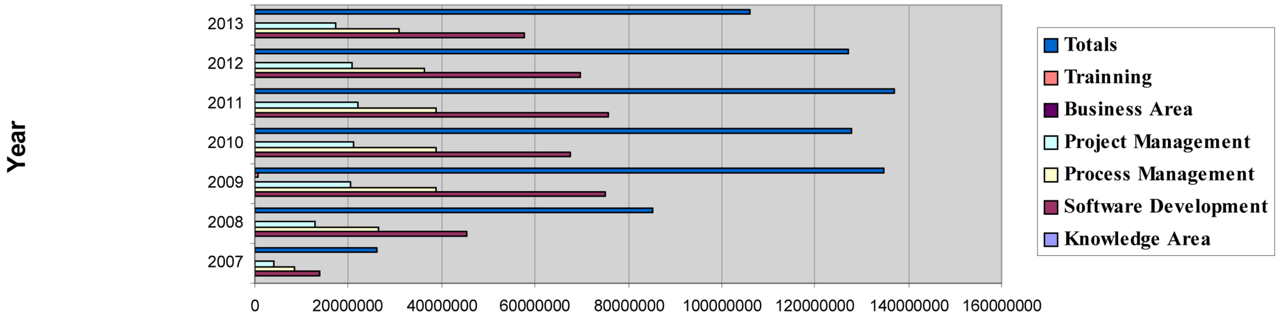
When interpreting the plot shown in **Figure 3** that aggregates the quadrants shown in **Figure 4**, we observed that a low degree of specialization predominates among the sampled individuals and that this group of people is divided evenly between projects of low and high complexity. Regarding people with a high degree of specialization, we can observe that they represent a small sample, compared to the total of people with a low degree of specialization. In addition, low-complexity projects predominate in this group.

When observing the figure and based on the interpretation of the quadrants of **Figure 4**, we notice the concentration of people in projects with low demand for specialization and that require a low number of competencies, which are distributed in quadrants Q1 and Q4. At the same time, it is observed that these same projects are divided equally and evenly between the low complexity quadrant (Quadrant Q4—projects associated with high ubiquity) and quadrant Q1 (projects associated with low ubiquity and high diversity and complexity). On the other hand, projects that require a greater number of competencies correspond to a minority of projects studied and have a low degree of allocation.

In the present study, we identified five areas of knowledge: business, training, software development, project management and software construction process management. We also observed that a small number of people with more diversified knowledge were allocated to more complex projects. However, the degree of allocation of these individuals is high. Taking into account the knowledge categories, this seems to indicate that the area of knowledge development process followed by the area of knowledge project management are the areas whose application involves practically every type of project, regardless of the specificities of the area of knowledge software development. These two first areas contribute a greater volume of allocations in projects, while the area of software development, because it is more specific and specialized, has a lower allocation volume compared to the first two. The allocation time that represents the knowledge converted into work performed in projects per type of knowledge in 2007 corresponds to the areas of knowledge considered in this study.

The volumes of knowledge per year presented in **Figure 5** show that there was a proportional relationship between the knowledge categories that remained constant between the years considered in the study period (2007 to 2013). This pattern of evolution of organizational knowledge can be explained by the formal structure imposed by the company's development process, since the software project development process adopted foresees the allocation of people based on their specialties and specific areas of knowledge. These allocations also take into account the areas of knowledge and activities included in the management model. The areas with lowest allocation volume were the business and training areas. Each one had an allocation volume lower than 1% of the total volume.

The area project management had an allocation volume between 15% and 17%. The area corresponding to the management of software development processes had a minimum allocation volume of 31% and a maximum allocation



	2007	2008	2009	2010	2011	2012	2013
Totals	26.205.618	85.357.540	134.853.574	127.934.146	137.119.882	127.283.628	106.189.044
Trainning	85.915	300.530	490.348	456.982	431.522	342.414	236.321
Business Area	14.130	21.960	21.270	15.420	10.020	10.800	8.850
Project Management	3.947.168	12.968.357	20.409.498	21.084.675	21.955.365	20.947.274	17.324.781
Process Management	8.369.853	26.633.734	38.966.339	38.752.261	38.921.466	36.262.073	30.986.865
Software Development	13.786.545	45.430.951	74.964.110	67.622.798	75.799.498	69.719.055	57.630.214
Knowledge Area	2007	2008	2009	2010	2011	2012	2013

Cummulative work/Knowledge Area

Figure 5. Areas of knowledge related to software development and maintenance. Source: The authors (2021).

volume of 32%. The area with the highest allocation volume was the Development area, which showed a minimum of 53% and a maximum of 56% in the studied period. This low variation observed in the period demonstrates that the adoption of a formal standard management model guides the evolution of organizational knowledge, with a predominance of the development area because it is directly related to the organization's core business.

Given that there are specific areas of knowledge within the development process and that these areas have peculiarities that can influence the process of creating and disseminating knowledge in the organization's core, the analyses performed must consider such particularities. In general, the type of capability required for performing work in the areas of knowledge related to process management and project management can be considered as a group of capabilities applicable to any type of software product because it involves generalist knowledge. On the other hand, knowledge related to the area of development is more specific, focused and sophisticated and is therefore rarer because it is directly related to code implementation techniques related to specific coding languages. The areas with the lowest allocation volumes in our study, which deal with knowledge related to training and business to be converted into software, are hybrid in terms of diversification and ubiquity, considering that they have general characteristics when analyzed from the perspective of macroprocesses that compose them. However, they also exhibit a high degree of specialization when analyzed from the point of view of the core of the topic addressed by each of them. In the case of the business area, the topic concerns the understanding of the particular business that will be modeled and transformed into a system. In the case of the training area, the topic refers to the content to be taught in that training process.

The implications of these considerations for the analyses performed herein influence expectations regarding the results. When we compare the results found by [25] when they sought to determine a pattern that describes the correlation between diversification and ubiquity, we found that [25] found that producer countries with a high degree of diversification are able to develop highly sophisticated products, but without a high degree of market penetration, which represents a low degree of ubiquity. In contrast, countries with a reduced set of capabilities and less diversified are usually capable of achieving a high degree of ubiquity of their products.

On the other hand, in our study, it is necessary to consider two factors: collaboration and the use of a formal software production process management model. The first factor implies that team members who work in software production work in collaboration and not in competition, at least with respect to the internal scope of the organization. Therefore, people with more generalist skills and knowledge as well as those with more specialized and diversified knowledge work together on a collaborative project to achieve a common goal, which is the production of good-quality software. The second factor concerns the use of a process management model that requires the performance of tasks based on knowledge and capabilities in a directed manner. This may explain the proportionality and regularity of the use of the areas of knowledge presented when we analyze the distribution of the work performed and the resulting knowledge production during the study period. This uniformity influences the allocation of people to projects to accomplish the activities provided in the management model adopted by the organization. By completing the activities included in the model, the team members systematically contribute to the creation of knowledge in the specific area to which they are allocated.

As a result of the type of interaction between people working on projects, the necessary conditions for the creation and diffusion of knowledge are favored. These conditions are evidenced by the formalism imposed by the software development process adopted by the company that includes a routine of continuous training of its employees in addition to the production of material for documenting the development process that is considered explicit knowledge. In this sense, the transformation of tacit knowledge into explicit knowledge can be observed throughout the process of developing software products. Similarly, the documentation produced serves as a source for the transformation of explicit knowledge into tacit knowledge and can be consulted and applied in new projects as a historical source of procedures and lessons learned.

The results from the application of the method of reflections also show that the favorable conditions provided by the development process management model can be considered as one of the main factors that allowed the growth of both knowledge in highly specialized areas, as well as knowledge related to more general and ubiquitous areas of knowledge. This fact is evidenced and represented in **Figure 6**, which represents the correlation between ubiquity and

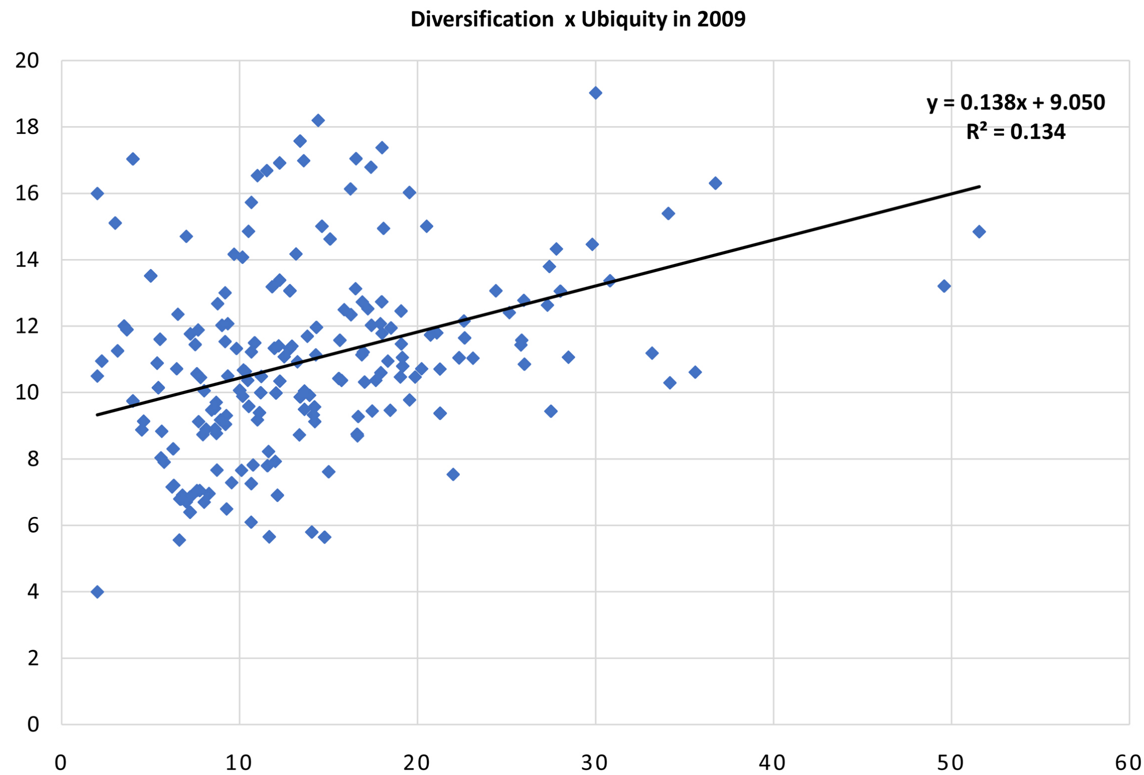


Figure 6. Correlation between diversification and ubiquity in 2009. Source: The authors (2021).

diversification for the year 2009, but it also presents itself as evidence to support our hypothesis that diversified knowledge and more generalist knowledge grow together and proportionally with the support of the structure and conditions established by the development process management model. This evidence is repeated for the years 2007, 2008, 2009, 2010, 2011, 2012, 2013.

Figure 6, which represents the dispersion for the ubiquity and diversification of the variables, indicates that in 2009, there was a predominance of low-complexity projects demonstrated by the high allocation of people to these projects. However, this allocation was distributed evenly among people with a low level of specialization and people with a high level of specialization. This figure is similar for the other years, with a positive correlation between ubiquity and diversification, except for 2008, shown in Figure 8, which shows a negative correlation between these two variables. Correlation matrices that show the dispersion between the knowledge, diversification and ubiquity dimensions are presented in Figure 7 and Figure 9 for the years 2009 and 2008, respectively.

In 2008, unlike the other years, there was an inversely proportional relationship between ubiquity and diversification, as shown in Figure 8 and Figure 9. The deviation observed in 2008 from to positive correlation pattern shown in other years deserves a more thorough investigation that can be performed by disaggregating the data that characterize the network of that year, based on the detailing of the knowledge categories and the characteristics of the projects developed. Applying the analysis of the quadrants of Figure 4, it can be inferred

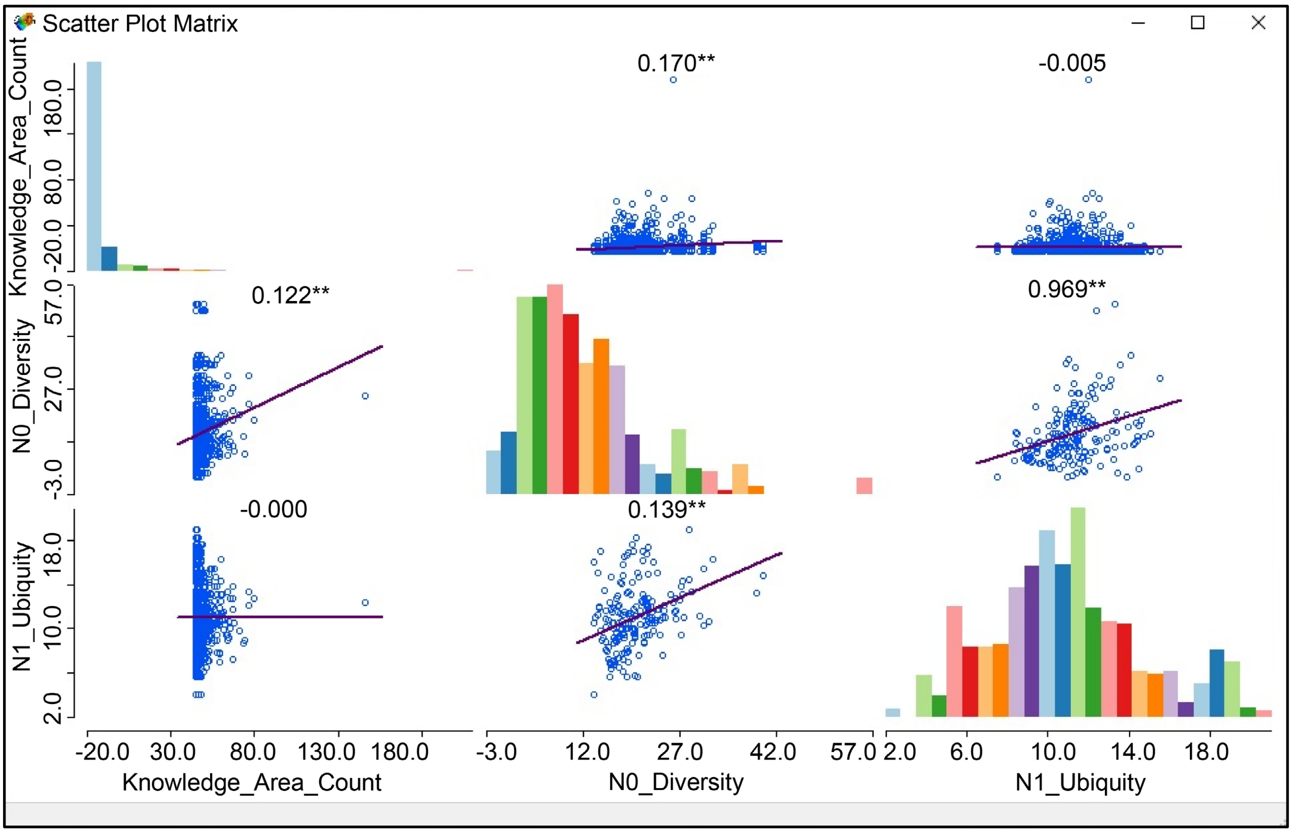


Figure 7. Correlation matrix of knowledge, diversification and ubiquity areas in 2009. Source: The authors (2021).

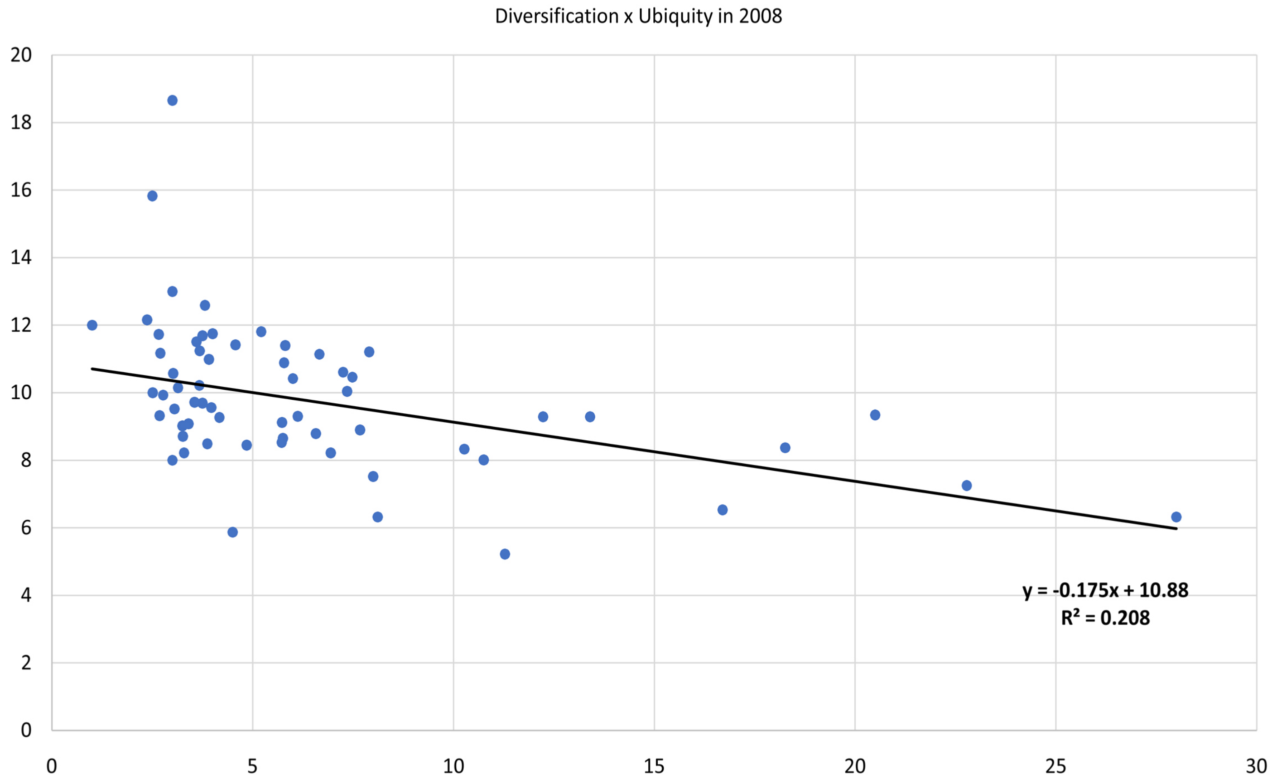


Figure 8. Correlation between diversification and ubiquity in 2008. Source: The authors (2021).

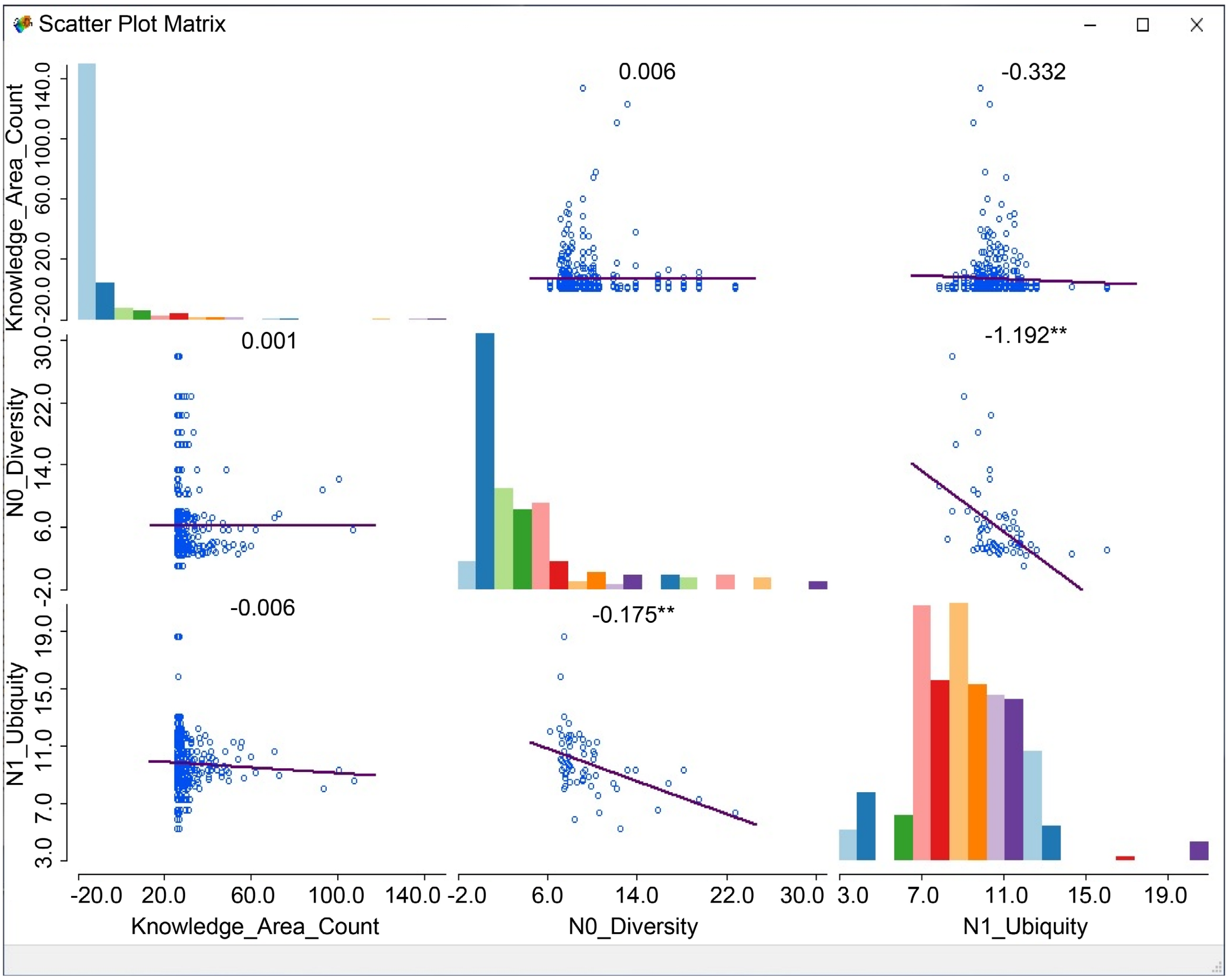


Figure 9. Correlation matrix of areas of knowledge, diversification and ubiquity in 2008. Source: The authors (2021).

that in contrast to what occurred in other years in which people with a high level of knowledge diversification were working on low-complexity projects and therefore requiring a smaller number of capabilities, in 2008, these people were moved to projects with greater complexity. This movement influences the slope of the trend line shown in the figure and shows that in 2008, this group of people began to work on projects of higher complexity.

When comparing the results obtained for the years 2008 and 2009, adding the data that describe the evolution of knowledge presented in **Figure 5**, it can be inferred that the generation of knowledge occurs in a constant and, therefore, sustainable way. The variation in annual allocation volumes by area of knowledge can be explained by the variation in the demand for services. However, regardless of the demand, it is observed that the proportionality of the areas of knowledge remains constant for the entire period studied. What differentiates the correlation between diversification and ubiquity is the type of project and the knowledge profile of the team members allocated to these projects, causing people to move between higher-complexity and lower-complexity projects.

5. Conclusions

Keeping companies in a process of constant learning in the search for innovations to ensure their sustainability with the support of work teams involved in projects is one of the challenges that managers face. Understanding the process of creating knowledge diffusion in networks formed by members of software project development teams is an important example of the application of social network analysis. In addition, project team leaders should seek to maintain the appropriate conditions for the exchange of information and generation of useful knowledge for carrying out projects. Simultaneously, a high level of productivity must be maintained without losing sight of the motivation goals of these team members. Our proposal to help address and understand these challenging conditions consisted of constructing a model to describe the dynamics of organizational knowledge exchange while carrying out projects based on the construction of individual, group and organizational capabilities. We sought to describe how this intricate correlation of components and forces interacts to result in the achievement of the planned objectives for the project teams in a way that is aligned with the organizational objectives. We proceeded from the assumption that the process that involves the relationships of knowledge exchange and generation is a complex one and that studying requires using techniques that are able to adequately address this complexity. We also considered that organizational knowledge is built from the practical application of information that becomes knowledge when products and services are created and made available.

This article describes the example of an application of social network analysis and of the method of reflections presented by [2] to build affiliation networks that enable the study of the process of creation and diffusion of organizational knowledge based on the relationships between people and projects of software development in a public organization in the area of information and communication technology. The work contributed to the construction of indicators related to the process of knowledge creation and diffusion within the scope of software development and maintenance projects, in addition to presenting an application of the method of reflections in a context different from that proposed by [2] but that exhibits structural components that allowed the construction of an affiliation network capable of describing relationships between software products and development teams, mediated by the construction of knowledge based on individual capabilities. Thus, the model and methodology applied by [2] were adapted for forming affiliation networks that relate people to software development projects.

Unlike other approaches, the method used here differentiates the ability to perform analyses that consider the correlation of data in its completeness to study the phenomenon of creation and diffusion of organizational knowledge. This completeness was obtained from the use of the method of reflections, considering that the relationship between people, projects and knowledge-based capabilities have been described and studied based on the correlation between different types of knowledge, which will have impacts and can be observed by analyzing the complexity of the software products generated by the use of this knowledge. From this perspective of the complexity of the software products built in the projects, we could observe that there is a combination of diverse knowledge that depends on a high level of specialization, with more generalist knowledge. Thus, diversification and ubiquity measures were employed to describe and measure the level of complexity and ubiquity of the software products developed and delivered. We found that more specialized knowledge and general knowledge both contribute to building organizational knowledge in a collaborative manner. It was also observed that the exchange of knowledge is intensified through the interaction between members participating in project teams with different types of knowledge. The relationship between the ubiquity and diversification dimensions was studied for each of the years between 2007 and 2013, and we found a positive correlation between these two variables for most years, with the exception of 2008, which showed a negative correlation. This difference can be explained by the combination of factors related to the level of specialization of the people allocated to the projects, combined with the type of project. When people with a high level of knowledge diversification are allocated to projects with high ubiquity and low demand for diversified capabilities, it generates a positive correlation between these variables. In contrast, when highly qualified people with diverse knowledge are allocated to projects that require a high level of knowledge diversification, it generates a negative correlation between ubiquity and diversification.

We structured a network to demonstrate the relationship between the measures of project complexity and the required capabilities of the team members as a function of this complexity. This network was then partitioned based on the year of project execution, forming seven subnetworks. The structure of these networks enabled obtaining more in-depth knowledge on the dynamics of the process of creation and diffusion of organizational knowledge, as well as on the influence of the structures of the networks on this process. One of the purposes of the study was to contribute to better understanding the process of developing people and teams and consequently to understand the process of constructing organizational knowledge through the formation of network structures. However, when using teams as units of analysis, we will be faced with the problem of mobility of its members. In this sense, the temporal analyses performed undergo transformations, since these teams also transform themselves with the entry and exit of components. This can be considered a limiting factor of the approach adopted here, although it can also be seen as an opportunity to study the diffusion of knowledge, as people move through different teams and projects disseminating knowledge.

Based on the results obtained, it was possible to characterize the process of creation and diffusion of the knowledge of the organization studied in terms of the degree of specialization of its employees when doing work involved in software construction and maintenance projects, and we were able to evaluate how a particular type of knowledge applied to work on certain projects can be reused in other projects. Such evaluation was possible based on the analysis of values associated with the concepts of specialization and ubiquity obtained by the application of the method of reflections. These two concepts that could be measured demonstrated how knowledge and individual capabilities interact in the organization during project execution. These metrics have helped to raise important questions involved in the process of creating and exchanging organizational knowledge in a differentiated manner that takes into account the whole and not only the parts of the system that represent the software production process, while simultaneously generating organizational knowledge.

The data corresponding to the allocation and recording of working hours of people linked to projects enabled the construction of the affiliation network and the application of the method of reflections. Basic statistics were obtained that allowed the interpretation and analysis of the network, and values were generated for the indicators developed and presented in the analysis model. Thus, the method applied enabled the construction of the network, preparing it to perform the analysis of the relationships using historical data on the allocation of team members to projects. The study expanded the application of the method of reflections to other types of affiliation networks, which, despite their similar structure, may present information with characteristics different from those originally demonstrated by [2].

Contrary to the expectations and initial hypothesis established at the beginning of this study, we concluded that in six of the seven subnetworks obtained in the period between 2007 and 2013, knowledge based on more complex and diversified capabilities showed a growth proportional to the growth of knowledge related to the capabilities related to more general and, therefore, more ubiquitous activities. A possible explanation for this behavior is the fact that the study organization comprises three main categories of knowledge that act in a coordinated and collaborative manner for the construction of software products: the area of development and the area of process management, which involves the software production process and finally the area of project management. The first has more complex characteristics in the composition of the knowledge and capabilities required to perform the work and can be considered more diversified. The last two are characterized by being more generalist and therefore more ubiquitous. However, in addition to these factors, we believe that the collaboration and direction given by the management model of the software production process contribute to diversification and ubiquity growing together during the execution of the projects.

One of the limitations of the application of the methodology, from the operational point of view, is the fact that the volume of data can make the construction of the network and the calculation process a computationally costly process.

The very application of the method of reflections in large matrices, without the aid of a suitable software tool, represents a considerable computational effort. Therefore, one of the possible extensions of this work may be the construction of software for structuring the network and calculating the main statistics with a focus on the method of reflections.

We also observed that there are specific questions in the relationships between the modes of an affiliation network, which are due to the characteristics of the type of affiliation that this network represents. These specificities must be interpreted and treated in a particular way for each application case of the networks, which restricts the ability to generalize the method. An example of this is the fact that in the affiliation networks of people to projects, as discussed in this work, the mobility of people between teams or even outside the environment or context of the organization in which the method applies leads to changes in the results and influences how they are interpreted. However, it is possible to establish a generic structure, in the form of a data model, that absorbs data from different affiliation networks and allows the aggregation of additional characteristics, attributes or parameters, for categorizing the network vertices, and enabling the expansion of the model and the enrichment of the analyses. This could be a way of minimizing the effects of the particularities of two-mode network relationships. The construction of this model, coupled with the construction of the software to support the calculations, is thus possible recommendations for future studies.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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