Cartography M.Sc.

Master thesis

Visualizing Connectivity within Innovation Ecosystems in Europe

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Statement of Authorship

Herewith I declare that I am the sole author of the submitted master's thesis entitled:

"Visualizing Connectivity within Innovation Ecosystems in Europe"

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Munich, September 2019 Zarina Acero

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Abstract

The term “innovation ecosystems” refers to the economic dynamics of the complex relationships that are formed between the material resources and human capital, whose functional goal is to enable technology development and innovation. Because of their importance in economic growth, the promotion of European innovation ecosystems was among the priorities of the Ninth Framework Program for Research and Innovation for 2020.

Studying the driving forces behind innovation as a part of an entire network and not as individual entities is essential to guarantee the creation, survival, and evolution of such ecosystems. As data visualization can significantly improve information exploration, visualizing innovation ecosystems can lead to the discovery of meaningful insights into the complex relationships within them, that otherwise would go unnoticed. However, high complexity socio-economic datasets that describe innovation ecosystems present a significant challenge for data analysis and synthesis. This thesis comes to address this challenge by developing a data model and web prototype that integrates heterogeneous datasets, i.e., multi-source, multi-format, and presenting diverse levels of quality and resolution.

The EuroTech Universities Alliance is a vivid example of European cooperation in science and technology. The Alliance integrates leading technical universities and Europe and beyond, so it was set as the study case to propose a methodology and a prototypical implementation. This thesis proposes a prototype enabled to analyze and retrieve information about relations among European universities, companies, start-ups, and research institutions. The prototype provides an interactive interface that makes use of a thematic web map and statistical charts that allow the navigation of layered data representations. By integrating a solid data model and suitable visualization techniques within an interactive web framework, this thesis offers a state-of-the-art approach to visualizing the spatial connectivity of science and technology across European boundaries.

Keywords: innovation ecosystems, data visualization, network visualization, interactive web cartography, interactive web mapping

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Abbreviations

CSS	Cascading Style Sheets
CSV	Comma Separated Values
D3	Data-Driven Documents
DTU	Technical University of Denmark
EPFL	École Polytechnique Fédérale de Lausanne
EU	European Union
EUA	EuroTech Universities Alliance
HTML	Hypertext Markup Language
JS	JavaScript
JSON	JavaScript Object Notation
L’X	École Polytechnique
MIT	Massachusetts Institute of Technology
OD	Open Data
PC	Pie Charts
R&D	Research and Development
RQ	Research Question
SQL	Structured Query Language
SVG	Scalable Vector Graphics
TU/e	Eindhoven University of Technology
TUM	Technological University of Munich
UCD	User-centered Design
UI	User Interface
UML	Unified Modeling Language
UNESCO	United Nations Educational, Scientific and Cultural Organization
USA	United States of America

1 Introduction

This chapter presents the scope of research by giving a general overview of the main aspects covered by this thesis. Additionally, it introduces the research problems, objectives and questions; as well as the hypothesis guiding this work. Finally, it provides an overview of the thesis structure.

1.1 Scope of Research

Innovation is a key aspect when it comes to the economic prosperity of nations, and so is the development of local and regional innovation ecosystems. Based on these networks, local innovation policies can support technological cooperation, the creation of business networks, business incubation and start-up, and staff training among others. Furthermore, thanks to the exploitation of agglomeration economies, policymakers can promote the identification of collective needs, common opportunities, and collective action. (Online-S3, 2019)

When it comes to Europe, the importance of clusters and the need for nourishing innovation ecosystem for regional development and competitiveness has been long acknowledged (Online-S3, 2019). Promoting European innovation ecosystems was set as one of the priorities of the Ninth Framework Program for Research and Innovation (Horizon Europe). As a result, the EU has implemented several measures supporting the development of the European innovation ecosystem through the integration of education, research, and entrepreneurship (EU Commission - Directorate-General for Research, 2018). Yet, there is a current lack of geovisualization approaches where the user could gain insight into how European clusters are related.

During the last decades, the amount of geospatial data has increased significantly and therefore, many mapping platforms and tools to interact with such data have been developed. However, Smith (2016) has mentioned that for several years platforms containing topographic data such as Google Maps and OpenStreetMap were within the main scope of research, while socio-economic mapping was not attracting much attention. He has also suggested that among the several barriers that were restricting the advance on online socio-economic cartography, the data itself was especially challenging due to its availability, accessibility, and integration complexity. Additionally, only a small number of tools that could create high-quality thematic web maps were available. Recently, the open data movement, the release of technologies that enable standard web browsers to support sophisticated thematic web maps, and the development of open-source software, have allowed the socio-economic mapping field to expand (Smith, 2016). Web mapping tools are now offering a visualization approach and spatial analysis techniques that can substantially improve the exploration of socio-economic datasets. Therefore, several studies on the potential of interactive mapping applied to this domain have been carried out lately.

As the importance of innovation ecosystems has been highlighted within Europe, the need for creating new approaches to visualize them in a geographic context has arisen. This master's thesis proposes a methodology and a prototypical implementation of an interactive thematic web application. This application implements a data visualization method that aims to improve data exploration concerning relations among European universities, companies, start-ups and research institutions. The contributions of this thesis may pave a path towards closer collaboration among European universities, companies and start-ups.

1.2 Problem Statement and Research Identification

Since cluster development has proven to have a strong positive effect on innovation, the geographic aspect plays a key role in the evolution of innovation ecosystems. However, little research concerning how clusters evolve within an innovation ecosystem has been done in the cartographic field when compared to the economic one. Moreover, most of the studies that do address the topic, are not approaching visualization methods to depict the complex relationships that compose such ecosystems. Considering that the data describing innovation ecosystems is heterogeneous and composed of spatial and non-spatial data, finding an appropriate visualization method that can successfully integrate it is challenging. Among the possible methods that could be implemented, network visualization is an adequate approach to represent innovation ecosystems (Still, Huhtamäki, Russell, & Rubens, 2014). Addressing innovation ecosystems as networks allows studying their complex relationships and therefore, can reveal connections and interactions within the ecosystem.

This research aims to visualize innovation ecosystems using a geographic network approach. The implementation of it could visually represent the correlation of node properties and network structure by using visual patterns and implementing effective filtering to allow the user to access deeper levels of the system information. To fulfill this purpose, a concise interactive dashboard integrates cartographic interfaces along with data-driven graphics.

The hypothesis guiding this thesis is that users can gain significant insight when exploring relations among innovation ecosystem clusters using an interactive and geospatial network visualization approach.

1.3 Research Objectives and Questions

1.3.1 Research Objectives

Based on the problem statement, the main objective of this thesis **is to visualize clusters and networks among European innovation ecosystems and to map European competences as well as facilities that support technological advances**. This main objective consists of three sub-objectives:

- To identify the elements that can best describe the complexity of spatial and non-spatial relations among clusters based on a selected case study;
- To compare network visualization techniques and determine a suitable method that can emphasize the connectivity of science and technology across European boundaries;
- To build a prototype of an interactive thematic web map-enabled to visually represent scientific and technological networks and clusters based on a selected case study.

The EuroTech Universities Alliance is a vivid example of European cooperation in science and technology. The Alliance integrates leading technical universities and Europe and beyond, thus it serves here as a perfect study case to represent the intended methodology and develop a prototype of an interactive web application. The architecture of the prototype developed adopts open-source settings, thus extensible to further case studies when necessary.

The prototype developed aims at **target users** such as (1) researchers and decision-makers in charge of anticipating the development of innovation, and interpreting its driving forces and impacts, (2) young entrepreneurs that would like to start new businesses, and (3) parties seeking new partnership agreements.

The results of this thesis aim to enable target users to explore socio-economic data and discover spatial connectivity of science and technology across European borders. Data visualization is a powerful tool to represent data in a comprehensible way. Therefore, this prototype aims to combine thematic web cartography, statistical charts, and intuitive and interactive tools, which results in a user-friendly interface that can be used to gain valuable insights. By using the prototype (https://zarinaacero.github.io/EuroTechProject/), users can learn about scientific competences and clusters which would ultimately lead to better cooperation within innovation ecosystems.

1.3.2 Research Questions

To confirm or reject the hypothesis mentioned in Section 1.2, and to meet the objective and sub-objectives, the main question that this research work aims to answer is: **What can we learn**

about spatial connectivity of science and technology across European boundaries by visualizing it on a map?

To provide an answer to that question and in accordance with the three sub-objectives presented above, the three following research question need to be addressed:

RQ 1: Which kind of relations among clusters need to be depicted to facilitate data exploration and decision making?

RQ 2: How can innovation ecosystems be represented using a geospatial network visualization approach?

RQ 3: Which map elements and user interactions can be used to convey relations among clusters?

1.4 Thesis Structure

This thesis is composed of six chapters:

- Chapter 1 introduces the context of research, states the problem and motivation guiding the research, presents the research questions and defines the objectives to be met.
- Chapter 2 aims to identify scientific background on relevant topics to this thesis and create the solid knowledge base needed to carry out the research work. This section is structured into five parts: (1) Innovation ecosystems; (2) Network visualization; (3) Web mapping applied to economic datasets; (4) Web Interface Design; and (5) Related projects.
- Chapter 3 outlines the methodology adopted for the prototype development, explains the choice of each applied method, and discusses the purpose and functionalities of the prototype features. Additionally, it proposes a user study that could validate the approach.
- Chapter 4 presents the adopted case study and explains how the methodology introduced in the previous chapter was applied. This chapter explains how the users' needs identified by different scenarios and the design principles presented in the theoretical background shaped the data collection and the prototype interface design.
- Chapter 5 outlines the major findings of this research, analyzes whether the research objectives were fulfilled or not, and answers the formulated research questions. The scientific contributions of this thesis are introduced, and a critical discussion of the thesis outcome is provided. Finally, open challenges are announced to present future research.
- Chapter 6 concludes the most relevant findings of the research.

2 Theoretical Background

This chapter provides background knowledge and state-of-the-art analysis of five relevant aspects to the development of the thesis. The first section introduces innovation ecosystems, defines the term, and explains their growing importance during the last decade. The second section addresses network visualizations, discusses different approaches, and analyzes how data could benefit from these types of visualizations. The third section concerns the application of web mapping to visualize economic data. Additionally, it examines its state-of-the-art and the possibility of enhancing the visualization of innovation ecosystems by making use of it. The fourth section discusses general web interface design rules. Finally, some existing examples of interactive web maps are evaluated to set some design principles for the prototype development.

2.1 Innovation Ecosystems

Innovation ecosystems are currently a rising research field in economics. The first related term to such ecosystems appeared in a paper by Moore (1993) more than two decades ago and was called "business ecosystems". The term was then introduced to explain how companies could be thought of as a part of a network containing other entities. Here, they all collaborate by sharing knowledge, capabilities, technologies, skills, and resources, while they compete and cooperate at the same time. Throughout the years, the employment of the term "business ecosystems" decreased and the use of the term "innovation ecosystems" was widespread among literature. It is important to state that both terms are not used with the same meaning, but there are still some discussions on how they differ from each other. Furthermore, a robust definition of "innovation ecosystems" has not been established yet (Gomes, Facin, Salerno, & Ikenami, 2018).

Currently, several definitions are being used by experts in literature. Among the most used is the one proposed by Russell et al. (2011), using the term to refer to "the inter-organizational, political, economic, environmental and technological systems of innovation through which a milieu conducive to business growth is catalyzed, sustained and supported". Moreover, Russell et al. (2011) also emphasized the importance of the relationships among the network, stating that they are a source of sustained value co-creation and that they are substantial in the creation and survival of innovation ecosystems.

Jackson (2011) proposed another definition that provides information on the innovation ecosystem components that consist of actors or entities including "the material resources (funds, equipment, facilities, etc.) and the human capital (students, faculty, staff, industry researchers, industry representatives, etc.)", whose functional goal is to enable technological development and innovation. Figure 2.1 illustrates a scheme indicating the major pillars of innovation ecosystems: university, industry, capital, entrepreneurs, government and technology transfer.

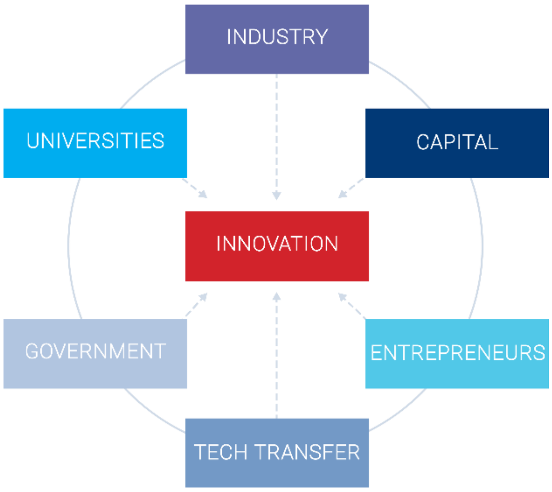


Figure 2.1. Partners in the innovation ecosystems. Figure redrawn from Econom (2019)

Innovation ecosystems are better described by their relationships rather than by their entities. They are considered highly dynamic since entities are constantly entering and leaving the network. Meanwhile, relationships between them are being created, changed, and deleted; and their attributes vary constantly. Entities involve material resources and human capital as previously mentioned, while relationships may be about partnerships, alliances, and litigations, among others. Due to this emergent dynamism, their scale, and their complexity, the process of identifying and then connecting the different entities and relationships in meaningful ways is considered to be particularly challenging (Basole, Srinivasan, Patel, & Park, 2018).

In the last decades, innovation ecosystems have attracted much attention from research teams due to their importance in economic development. Indeed, this terminology was repetitively appearing in the literature related to entrepreneurship, strategy, and innovation. Nevertheless, many studies on these kinds of ecosystems have been undertaken revealing that there are still some interesting and relevant research streams to be addressed. As an example, Dedehayir et al. (2016) have mentioned that there are still several unanswered questions regarding the actions that lead to their formation, the influence of each actor on the whole ecosystem, and how they can be used to predict later ecosystem performance. Gomes et al. (2018) have reviewed more than a hundred papers on the subject and have also concluded that there are still several interesting and relevant matters to be explored, such as the need for more theoretical development on innovation ecosystems. The implementation of suitable visualization methods on the subject is certainly another stream to be addressed.

Previous research has shown that compared to numerical and textual formats, data visualizations significantly reduce the user´s cognition load when it comes to discovering phenomena and revealing certain patterns when understanding and exploring a dataset. Furthermore, several publications have indicated that interactive information visualizations are especially useful for the user to form mental models of the correlations and relationships in the data (Roth & Harrower 2008, Lodde 2009, Russell et al. 2011). Russell et al. (2011) studied the use of visualizations to depict relations among companies, people and financing organizations. They further showed that they can provide users with meaningful knowledge, and eventually help them identify influential individuals for critical actions within the innovation ecosystem. Ultimately, visualization models could lead to a better decision-making process to plan the development and evolution of it.

Derived from the definition and throughout the literature, innovation ecosystems are often treated as networks. As mentioned in Section 1.2 and discussed by Still et al. (2014), addressing them as networks allows us to study their complex relationships, which therefore can lead to a better understanding of connections and interactions within the ecosystem. The study of the actors and relationships between them have been gaining importance in recent years due to the hypothesis that the components of the network have a greater value if they perform activities together, rather than individually. Still et al. (2016) have also proven that data-driven network visualizations are suitable and effective approaches when illustrating structures, key actors and interactions of the ecosystems, and revealing their context and the potential for novel structures and relationships.

2.2 Network Visualization

Murray (2017) has stated that data is only valuable when methods to derive insights are applied, as the raw data is often insufficient to reveal powerful knowledge and patterns. Thus, data visualization is the fastest way to unwrap the hidden information that humans cannot spot at a first glance when they deal with the raw data (Murray, 2017). Visualizing data is about mapping the information to visuals, expressing data content using visual variables. The challenge in developing and designing an accurate visual model will always be proportional to the complexity of the dataset.

The user studies in the last decades have proven that the implementation of a “good” visualization approach can result in users, independent from their expertise level, needing less previous knowledge to gain valuable insight and make simple analyses of the data (Lodde, 2009).

Networks consist of a group of entities called nodes, and a set of relationships between them called links. The innovation ecosystems could be seen as complex networks where entities composing them are the nodes and relationships between them are the links. Visualization techniques applied to innovation ecosystems have the same objective as when applied to networks: to reveal correlations of node properties and system structure by using visual patterns (Heymann & Le Grand, 2013). Consequently, they could be depicted using methods developed for network visualization.

The literature on network visualization methods shows a variety of classifications. Most of them propose three different categories, where two of them always refer to the position of nodes, making distinctions between whether they are drawn in their geographical position or not. The third one varies from author to author. For instance, Withall et al. (2007) mentioned a Plot-based Network Visualization, Heymann & Le Grand (2013) proposed a Time-Varying Network Visualization, and Hennemann (2013) introduced Circular information-rich layouts for network visualization. Nevertheless, this research only focuses on the analysis of the first two categories, and uses the term "**Geographic Network Visualizations**" for the approaches that place the nodes in their geographical position, and "**Abstract Topological Network Visualization**" for those that do not, as in the publication by Withall et al. (2007). The main reason for this decision is that this project deals with spatial components and abstract data.

There is a current lack of adequate visual methods for innovation ecosystems depiction. Thus, based on the review of the available network visualizations methods down below, suitable approaches to represent innovation ecosystems are adopted within this master's thesis.

2.2.1 Geographic Network Visualization

In geographic network visualization, the data is presented based on the spatial location of the nodes. Maps showing the edges and vertices to display the network structure are the most common tools employed for this type of visual representations. Such maps offer the possibility of overlaying different types of information. Thus, their application can be extended from only conveying the location to providing additional information. Additionally, geographic network approaches are extendable to 2- and 3-Dimensions (Withall et al., 2007)

Noori et al. (2016) have researched the topic of crisis response networks (Figure 2.2), and it serves as an example of geographic network visualization. In their work, they show the worldwide air transportation network using grey links to depict the passengers' air traffic, and red lines to sketch the basic structure of the network.

With a large number of nodes and links, some parts of the map can get crowded, making it hard for the user to read and understand it. Figure 2.2 represents how many links result in confusing overlapping. Visualization experts should take this into account during the data aggregation process and the definition of zoom levels. Another problem derived from these visualizations is related to distance perception since long links usually give the impression of being more important than shorter ones.

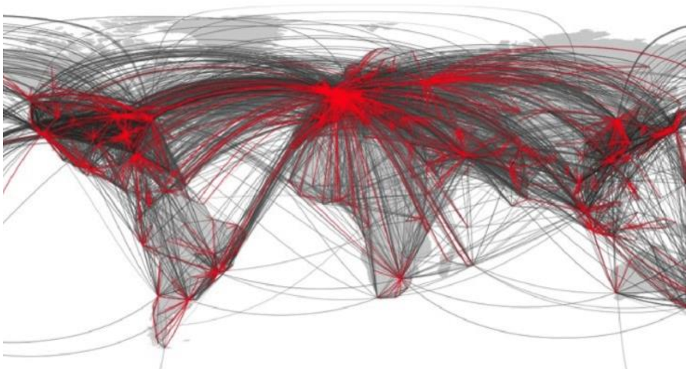


Figure 2.2. Example of a geographical network visualization: The worldwide air transportation network. Picture copyrights of (Northwestern University 2012).

2.2.2 Abstract Topological Network Visualization

In abstract topological visualizations, nodes are placed without considering their physical location. Instead, nodes and links are placed meaningful way to enhance readability. Commonly, these types of visualizations involve node and link diagrams. As the nodes' physical location is not imposing any restriction, designers can adjust visual properties to convey information on nodes and links characteristics effectively. A prominent example (see Fig. 2.3) shows an approach, where the distance between entities is based on the relationship strength: the stronger the relationship, the closer they appear in the diagram. Even more approaches have been developed for these visualization methods, depending on whether nodes or links properties want to be highlighted.

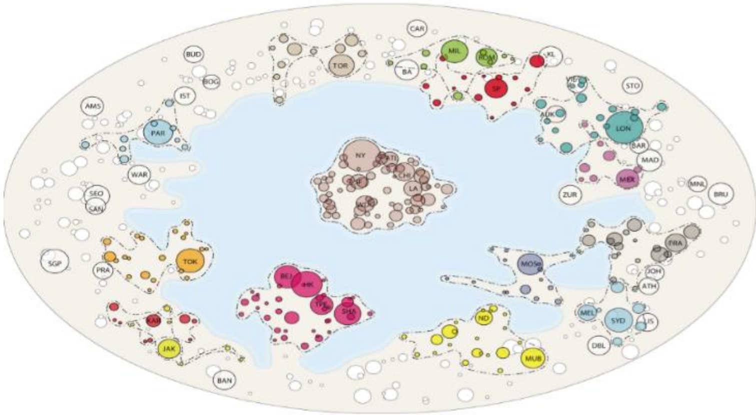


Figure 2.3. Example of an abstract topological network visualization: The Contemporary Mappa Mundy by Vinciguerra et al. (2010)

Using abstractions can be challenging, since choosing an ambiguous one could entail a high risk of users misunderstanding the representation. Figure 2.3 shows the "Contemporary Mappa Mundi" by Vinciguerra et al. (2010), who made use of an abstract topological network to depict "the American exceptionalism in the world city network". Hennemann (2013) described this map as "an analogy to produce a clustered map of relations among global cities according to their intra-regional coherence and the importance of groups of cities for the global city network". He also pointed out how the authors have aimed at maximizing readability by introducing an abstract representation of the relationships, but that they may have sacrificed information concerning the network and geography.

To sum up, every method has its advantages and disadvantages, and the choice should always be based on the available dataset, its properties, and the derived information that needs to be represented.

As Heymann & Le Grand (2013) mentioned, the process that starts in the data collection and eventually finishes in the knowledge discovery is often dynamic. Before analyzing the raw data, one rarely knows which methods are indeed applicable to the case study. Therefore, it is essential to get to know the nature of the data, to be able to choose an appropriate visualization method. Only after acquiring, parsing, filtering, mining and understanding the data, an interactive visualization approach should be adopted, which may even reveal the need for repeating previous steps using different techniques.

In some cases, several methods could be implemented to complement each other. Table 2.1 presents the strengths and weaknesses of each method, which should be considered when implementing them.

Network Visualization	Strengths	Weaknesses
Geographical	By providing spatial context, it can reveal spatial patterns. Clusters can be easily identified.	The co-existence of spatial and network clustering can result in heavy cluttering and poor readability if filtering or aggregating processes are not performed. Distance between nodes influences the perception of the links between them: the furthest they are, the strongest they seem due to its length.
Abstract topological	Position attribute can be used to convey network characteristics. Better readability and less overlapping.	No spatial context is provided. Clusters might be hard to identify. The applied abstraction principles can be misunderstood if they are ambiguous or not clearly explained.

Table 2.1. Network visualization approaches: strengths and weaknesses.

Even though the research community has not adopted a single method, it has been actively addressing the subject of visual analysis of complex networks in the economic field during the last decades, resulting in the development of software such as Gephi (https://gephi.org/), Pajek Tulip (http://tulip.labri.fr/TulipDrupal/), Cytoscape (https://cytoscape.org), and Sci2 (https://sci2.cns.iu.edu/user/index.php), among others. All of them have one objective in common: to provide a tool that can combine statistical and visualization analysis of networks. (Heymann & Le Grand, 2013). Then, we can infer that a successful network visualization method needs both: statistical and visualization analytical tools.

2.3 Web Mapping Applied to Economic Datasets

Mapping economic data is a long-standing trend. At the end of the 20th century, the importance of the spatial component in the study of interaction between economic agents has already been acknowledged. The roles of location, space, and spatial interaction were considered central to analyze how individual interactions could lead to emergent collective behavior and aggregation of patterns. (Anselin, 1999)

Basole et al. (2018) have pointed out the need to replace the existing business intelligence tools that despite providing relevant and valuable functionalities, lack interactivity when it comes to exploring and analyzing the interconnected structure of the ecosystems. Moreover, they mentioned the lack of intuitive and easy-to-use visual analytics tools that could allow more users to benefit from them, unlike the existing ones that are generally designed for experts with computer skills.

Socio-economic datasets can be quite large and present challenges regarding the analysis and synthesis of the data. In the particular case of innovation ecosystems, Basole et al. (2018) have underlined the importance of multi-source and multi-scale data integration and analysis to derive meaningful insights. In almost every case, multiple datasets need to be combined, which are often heterogeneous, coming from different sources, using different formats, and presenting diverse levels of quality and resolution. These data characteristics could lead to significant difficulties but also to interesting opportunities when it comes to the development of suitable visualization approaches. Successful solutions should consider diverse user groups that could be using the model (with different technical and analytic skills) and provide different analysis options.

As reported by Smith (2016), global and national socio-economic platforms could benefit from web mapping tools since they can simplify research and allow the users to compare a range of indicators within different locations. Interactive cartography could be a promising solution for this issue since interactive web maps are a powerful means of overviewing datasets from a spatial point of view. Furthermore, he suggested that there are further research disciplines where interactive mapping could be applied, including spatial economics and network analysis.

In the literature, the term "interactive cartography" is defined as the dialog between a cartographic representation and its user. Map users are therefore enabled to make changes on the map, through a technological device and based on their context. Interactivity allows the complex navigation of layered data representations. Discovering information through different steps reduces the user's cognitive load. The main objective of interactive visualizations is to avoid users being overwhelmed by large amounts of information that can interfere with their knowledge discovery.

2.4 Web Interface Design

To achieve an effective web map design with an eye-catching interface, basic cartographic design principles need to be applied. Since the first “design rules” proposed in the early 1990s, technologies and trends have changed a lot and so did those rules.

2.4.1 The Visualization Mantra

The visualization mantra proposed by Shneiderman (1996) is one of the most crucial principles applied in visualization models, which is still relevant at the time: "Overview first, zoom and filter, then details-on-demand". To avoid overwhelming the user and to enhance the user experience, this design philosophy suggests that information should be gradually revealed to them. Once the users get a first overview, they should be able to decide if they want to take a closer look at specific parts of the network components by zooming and filtering options. The last part of the mantra, details-on-demand, refers to the fact that users should be given a chance to extract essential data, depending on their needs. Some relevant details could appear even if the user does not ask for them, depending on the zoom level.

2.4.2 User Interface Design Basics

The "Usability.gov", the leading resource for user experience best practices and guidelines serving practitioners and students in the government and private sectors in the USA, has most recently proposed seven user interface design principles listed down below. (U.S. Department of Health & Human Services, 2019)

1. **"Keep the interface simple"** intends to encourage the designers to only include essential elements with meaningful functionalities. Before adding a new feature, they should ask themselves: "Does the user really need it?"

2. **"Create consistency and use common UI elements"** refers to the importance of using well-known UI elements to keep the user's confidence when performing tasks. Creating patterns in language, layout, and design throughout the website enhances the user learnability process, usually resulting in more efficient user experiences.

3. **"Be purposeful in page layout"** emphasizes on the placement of items based on the importance they have, since they might affect scanning and readability of the site.

4. **"Strategically use color and texture"** focuses on the power that color, light, contrast, and other visual variables might have when it comes to directing attention toward or redirecting attention away of items.

5. **"Use typography to create hierarchy and clarity"** highlights how using different font types, sizes and arrangements can result in better scannability, legibility, and readability.

6. **"Make sure the system communicates what is happening"** suggests that the system should always keep users informed about the status of elements.

7. **"Think about the defaults"** aims to make the developer think about the possible user needs that the target group might have to set the default options and improve the user experience.

2.4.3 Interactive Web Mapping Design Principles

In recent years, design principles specific to interactive web mapping have been proposed. As well as the design rules for all user interfaces, they are constantly changing and following web design trends.

In his book, Muehlenhaus (2013) analyzed interactive web map design rules, which can be thought of as the basic design principles presented in Section 2.4.2 applied to web maps. The first principle suggests that only those elements which fulfill a specific purpose for the intended map audience should be added. "Just because you can include a map element does not mean you should". As an exception, he recommends including map elements that the target group is expecting to find to ensure successful communication. This principle is, in essence, as if we were applying the second design principle to web maps.

Muehlenhaus (2013) also included a chapter related to the third rule, where he discussed the arrangement of map elements and highlights the importance of establishing a visual hierarchy for the map elements. The location of each element should be defined considering its purpose since a poor map layout can compromise the communication between the user and the map.

Roth (2013) pointed out that just as every information visualization model, an interactive web map involves both representation and interaction. Design guidelines for both processes cannot be generally defined since different rules may apply depending on the case study. On the one hand, the representation part has been mostly handled by manipulating the so-called visual variables. On the other hand, the interactive aspect of map design has only gained importance during the last decade, and the kind and quality of cartographic interactions are now playing a key role in the cartographic interface utility and usability of web maps (Roth, 2013b).

2.5 Related Projects

During the last decade, several projects have used network visualization approaches combined with interactive web mapping to display information related to innovation and entrepreneurship. Even though to the author´s knowledge none of them are dealing with entire ecosystems, some interesting network visualization methods on elements that are part of them (start-ups and universities) were found and analyzed here below.

When it comes to Europe, relevant examples for the design of the prototype proposed in this thesis can be found, such as "Startup Heatmap Europe" (https://www.startupheatmap.eu /analytics/) (see Fig. 2.4) and "Startup Hubs Europe" (http://www.startuphubs.eu) (see Fig. 2.5). Both models were created to visualize the European start-ups' network, employing geographic network visualization approaches to display start-up clusters and relationships among them.

Figure 2.4. Example of existing European projects: the Startup Heatmap Europe

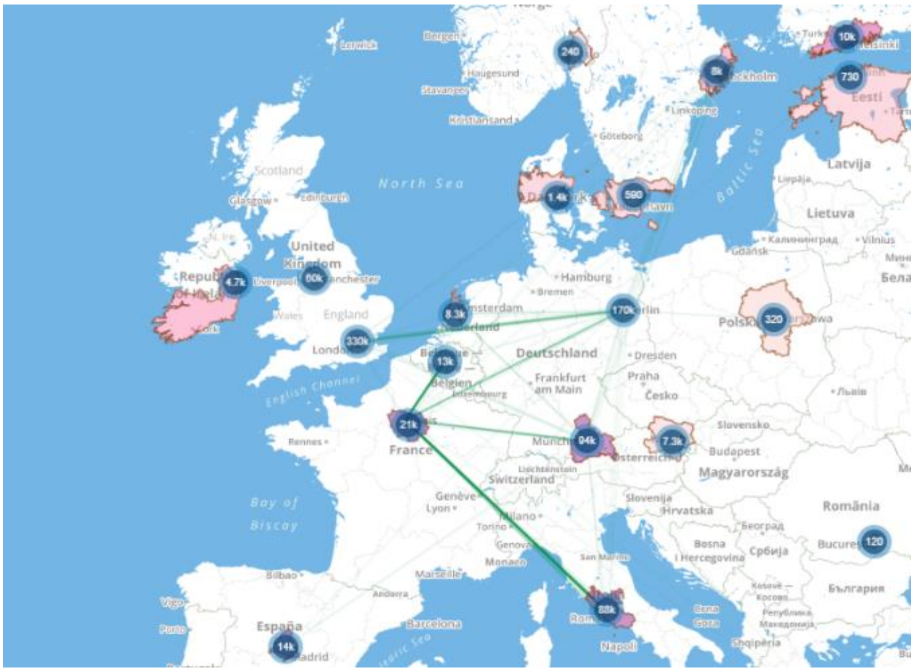


Figure 2.5. Example of existing European projects: the Startup Hubs Europe

Based on these examples, the possibility of adding elements offering effective user interaction to explore the network's links arises. This could enable users not only to get information about the nodes but to gain insight into the nature of the relationships between them as well. Furthermore, analyzing the role that the maps play in both projects, we could consider implementing new functionalities. Besides updating the dashboards and statistical graphs with information about the nodes, it could provide additional information that is not in the charts. The maps and the rest of the analytical tools are not presented together, missing the opportunity of using both elements to display complementary information and improve the knowledge discovery.

Figure 2.6 presents The "Startup Cartography Project" ("Startup Cartography Project", n.d.), which serves as a tool to explore the foundation of start-ups across the American territory from 1988 to 2012. Here, start-ups are not presented as part of a network. Thus, the relationships among them are not within the study scope and the start-ups are treated as individual entities. Despite not being a network visualization, this project was analyzed because the number of tools offered to interact with the map and filter the data makes it particularly engaging.

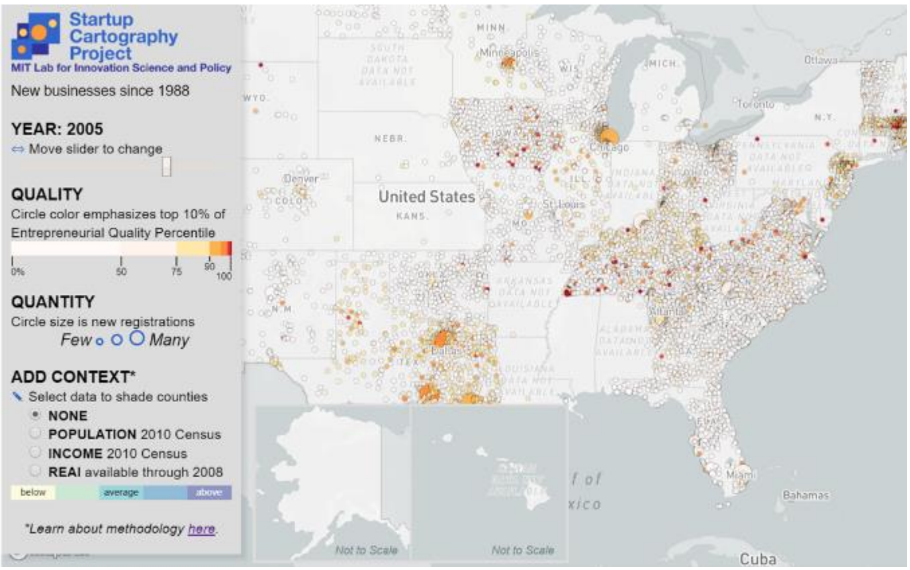


Figure 2.6. Example of existing non-European projects: the Startup Cartography Project

The "MIT World" ("MIT World :: MIT Senseable City Lab", n.d.) (see Fig. 2.7) depicts the mobilities between the MIT and universities worldwide. Unlike the previous example, the MIT project focuses on the relationship between the entities. The integration of statistical graphs and tables with the web map is successfully achieved, as they are showing complementary information. Other remarkable elements are the animation effects applied during transitions.

Both approaches are giving the users the chance to make changes on the map content based on their interest, providing them with relevant information to the topic. In other words, the offered interactive options have indeed an impact on the map, giving it a real propose in the cognitive process and justifying the choice of including a cartographic representation in the visualization of the data.

Figure 2.7. Example of existing non-European projects: the MIT World

Table 2.2 compares the reviewed projects from Europe and the USA regarding offered functionalities for data visualization. The prototype developed within this thesis is inspired by these examples and aims to propose features that could overcome their discussed limitations. The examination of available software to create network visualizations also had an impact on the design of the tools offered in the web map.

	Startup Heatmap Europe	**Startup Hubs Europe**	**Startup Cartography Project**	**MIT World**
Provides information on nodes	✓	✓	✓	✓
Provides information on links	✗	✗	✗	✓
Uses animation effects for transitions	✗	✗	✗	✓
The map provides not only locations, but also additional relevant information	✗	✗	✓	✓
Charts are linked to the map: changes on the map update the statistic charts	✓	✗	No charts	✗
User can look at the map and the charts simultaneously	✗	✗	No charts	✓

Table 2.2. Offered functionalities for data visualization of existing projects

3 Methodology

Building upon the related work, this chapter provides a detailed description of the methodology adopted to develop the prototype within this thesis. The chapter outlines four sections, which present the tools, software, and methods that need to be employed for each of the main aspects of the prototyping process: (1) Data Collection; (2) Database Management System; (3) Web Interface Design; (4) Data Visualization Charts; and (5) User Study.

3.1 Data Collection

The data collection is a challenging aspect for an innovation ecosystem description, since that data is dynamic, heterogeneous, and might also be inconsistent or unavailable. Creating a consistent database is challenging since some entities may have more comprehensive and accurate records than others. Moreover, data availability and currency may vary from source to source.

The amount of economic data that can describe the entities considered for the study can be too large. Therefore, another challenge is to define the database size: focus shall be made on collecting only relevant data to the case study, to avoid an unnecessarily long collection process.

Not all innovation ecosystems have the same components since they are driven by different forces, goals, and interests. The efficiency of the data collection process relies on the identification of such components. For the case of universities, Morrison (2016) has suggested that their innovation ecosystems are composed of five components: The Start-up Firms, the Investor Networks, the Innovative Growth Companies, the Skilled Talent Pool, and the Research Infrastructure. (see Fig. 3.1)

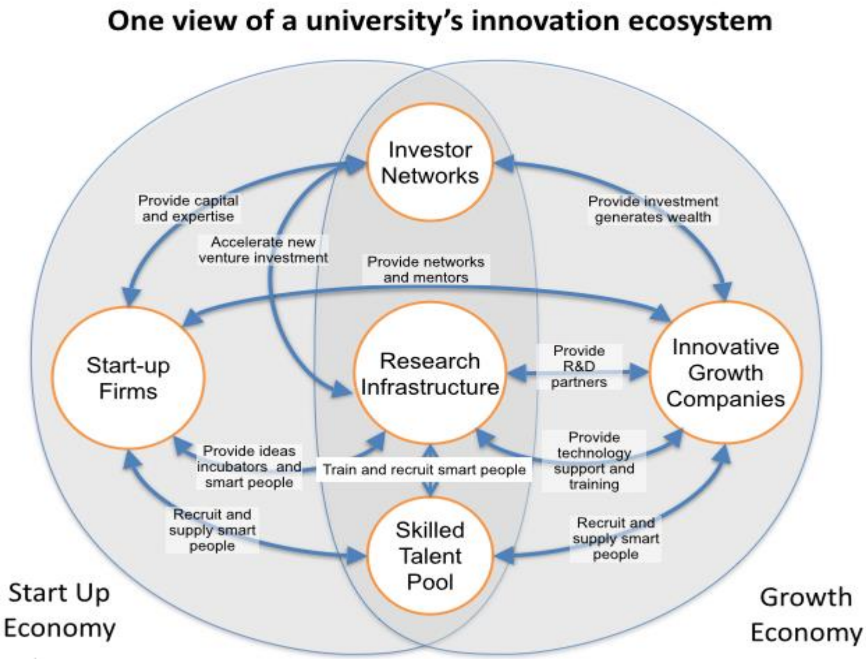


Figure 3.1. Components of universities' innovation ecosystems

Only after the innovation system components have been identified, the data model can be defined. Based on the literature review (see Section 2.1) and Fig. 3.1, the UML diagram in Fig. 3.2 proposes a data model for the prototype. Extended view on the database structure includes various classes and attributes and represents the potential for further development.

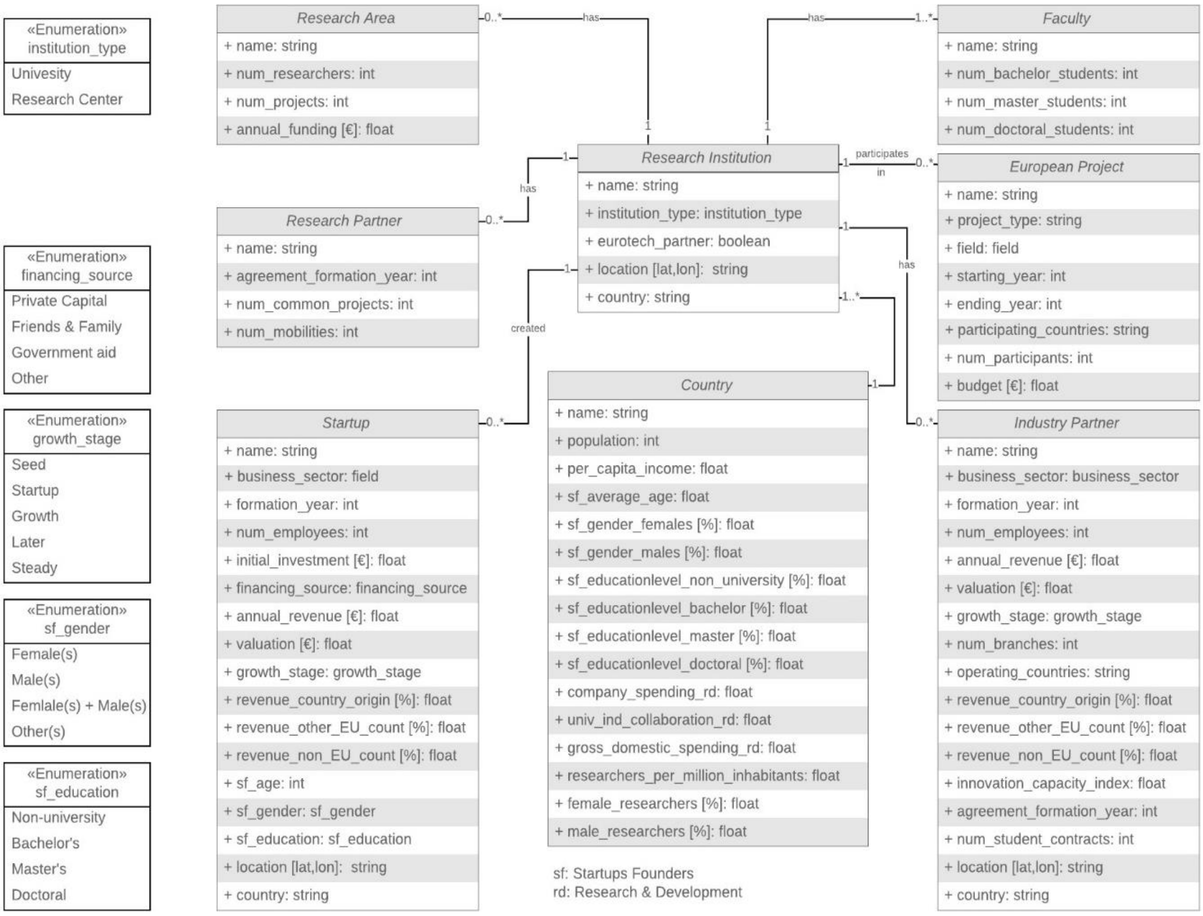


Figure 3.2. Proposed data model for the prototype development

3.2 Database Management System

Relational and non-relational models are two types of database storage components that have been thriving within the technology industry. A relational database is "a collection of data items organized in formally-described tables from which data can be accessed or reassembled in many different ways" (Jatana, Puri, Ahuja, Kathuria, & Gosain, 2012). In other words, data is distributed across multiple tables and connected through relations. Most of them use Structured Query Language (SQL) to access and modify the content of the database. They can be powerful due to their strong schema and the relational nature of their data. On the other hand, non-relational databases are systems capable of managing databases, and they have been presented as a solution to the increasing amount of data storage required on the internet today. In comparison to the previous ones, they do not use tables as its storage structure nor make use of SQL. The main advantages they offer are that they can handle huge amounts of data and that they perform queries in a fast and efficient way. The non-relational databases are recommended when:

- There are few relationships between the "collections" (equivalent to relational databases' tables);
- The application requires mostly reading stored data rather than entering or updating records that modify other elements related to them.

A non-relational database model seems an appropriate choice, considering that universities' innovation ecosystems can claim to fulfill both conditions:

- Relations will only be established using the attribute that contains the name of the university;
- As the only attribute that the collections have in common is the university name field and it is highly unlikely that a university name will change, new records for existing collections would not require updating the records from others.

TaffyDB

In the interest of keeping the prototype development within the same programming environment, the open-source JS library called TaffyDB was employed. Its powerful in-memory database capabilities to both browser and server applications provide appropriate tools for data extraction and manipulation. TaffyDB can quickly perform queries like the ones that are typically offered by sophisticated SQL software. For instance, it can create, modify, and delete records; retrieve and filter data based on specific attributes, and do some complex calculations. By combining the potential of TaffyDB and JS, it was possible to perform all the required data analysis to retrieve the necessary input for all the visualization methods implemented in the prototype.

To run TaffyDB, the developer only needs to download a file called "taffy.js" containing JS code, and put it in the same directory where the rest of the code is. All the data TaffyDB will handle needs to be in files using JSON format.

3.3 Web Interface Design

Chapter 2 discusses the possibility of seeing innovation ecosystems as complex networks and presents geographic and abstract topological network visualization methods potential approaches that could be used to depict them. As the main goal of this thesis was to evaluate the spatial connectivity among clusters of innovation ecosystems by visualizing them in a spatial context, a geographic approach was implemented for the development of an online thematic map prototype.

Web technologies such as HTML, JS, and SVG have significantly improved during the last decades, especially regarding graphical and data manipulation capabilities. Simultaneously, new powerful web visualization libraries such as D3 have been developed. These four technologies combined have been able to produce lots of eye-catching web mapping visualizations, making use of maps, charts, and plots, often with high-quality design and sophisticated interactivity (Smith, 2016). Muehlenhaus (2013) also suggested that web mapping can truly benefit from HTML, CSS, and JavaScript and that SVG is a great choice when producing maps that are not meant to be displayed using the Mercator map projection.

Defining accurate map elements and user interactions to convey relations among clusters is within the research goals of this thesis. Therefore, the prototype benefited from HTML, CSS, JS, SVG, and D3 to develop a web visualization model. Smith (2016) has recently analyzed the strengths and weaknesses of several web thematic mapping approaches, including those that combine the four previously mentioned technologies. On one hand, he concluded that together they can offer a high-quality design that includes appealing interactive and animated features. Additionally, they are also considered to have a more flexible and simpler implementation compared to other web mapping techniques. On the other hand, fixing the map extent results in the user not being able to perform standard navigation and zooming, so the developer needs to decide whether and how to include those functionalities.

HTML, CSS, and JS are three coding languages that are commonly used together for the development of websites and web applications:

- HTML is responsible for the structure of the website, putting its layout and skeleton together;
- CSS rules specify the style and layout of the web page;
- JS is the actual programming language providing functionality.

D3 is a JS library for creating and manipulating elements based on data. D3 is extremely fast, supporting large datasets and dynamic behaviors for animations, transitions, and interaction (Bostock, 2019). D3 can be powerful when it comes to handling geographic information since it is able to render SVG maps from data in JSON formats, making it possible to draw it using a variety of different map projections, place different elements using geographic coordinates, zoom in and out, among many other actions that can be implemented. The usage of smooth transitions and animations between map transformations can create wonderful visualization experiences.

3.3.1 Web Map Layout

To avoid overlapping between the map and the statistical charts, the prototype was designed using a compartmentalized map layout. In contrast to the fluid web map layout where the map is extended to the edges of the visual field, the compartmentalized map layout appends a frame with 100% height to the left or the right side of the web map (Muehlenhaus, 2013). The advantages of using such layout are that people are familiar with it, that it is easy to design, and that it can produce accurate and elegant looking maps. On the contrary, disadvantages include inappropriateness for small screen devices, poor aesthetics and requiring the eye to jump across graphic breaks (Tait, 2018).

The prototype layout is therefore composed of two parts that complement each other (see Fig. 3.3). One of them is the Map View hosting the web map, and the other one is the Compartment that contains the title, the Focused Field buttons, the Statistics View. While the Map View is the core part of the prototype, the content in the compartment is used to present non-spatial information that cannot be displayed on the map but that it is directly connected to the spatial elements on it.

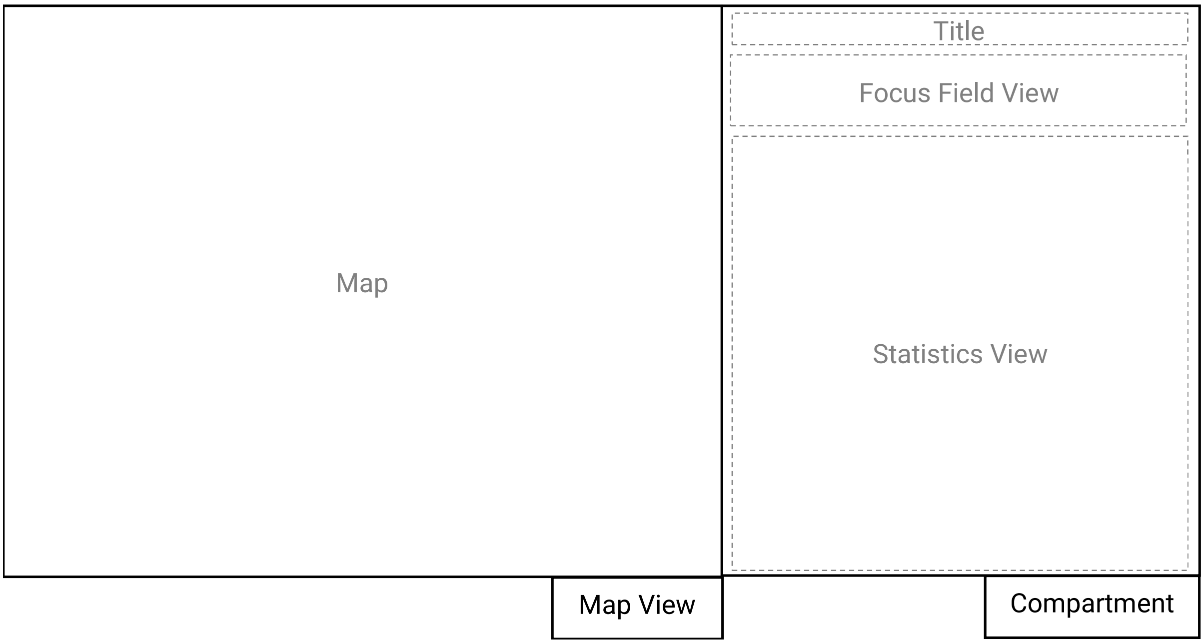


Figure 3.3. Schema of the prototype layout

3.3.2 Prototype Features

Smith (2016) has reviewed six online thematic mapping functionalities in the context of socio-economic data that were considered when designing the features of the prototype:

1. The **data layers selection** was not included since offering other layers (e.g. raster data) would not have added any meaningful information. Besides, it would have imposed a data volume challenge.

2. **Thematic map representation** is provided by giving the user the chance to change the map to a choropleth one using the desired index with the “Add layer” panel and is also provided by making it possible to make the map a proportional symbol one with the Focused Field buttons.

3**. Navigational interactivity** is restricted to zooming in and out of lines and points. Just as Muehlenhaus (2013) and Smith (2016) suggested, zoom levels should be only included if some data cannot be seen at a fixed scale. Providing too many zoom levels could have affected the usability and would have required more development time as well. Therefore, the only one used to highlight the user’s selection was included. If the prototype was to be further developed and new data layers were to be added, implementing more zoom levels might be necessary to provide more appropriate levels of detail.

4. **Display and classification interactivity** gives the users the chance to manipulate the cartographic representation by letting them change map elements such as legends or color schemes. Since the prototype already has complex legends and colors are used with specific meanings, this kind of interactivity could have overcomplicated the interface and was therefore not included.

5. **Analytical interactivity** is provided in the form of data visualization charts that are directly connected to the cartographic representation to enhance the economic data insights.

6. Regarding **narrative interactivity**, no map tours or guides were included hoping that the interface would be intuitive, and users will not need it.

3.4 Data Visualization Charts

Data concerning universities' innovation ecosystems are mostly quantitative. Table 3.1 describes charts that are typically used for the comparison of quantitative variables that were used throughout the prototype to visualize data.

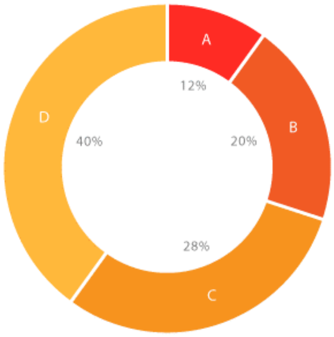
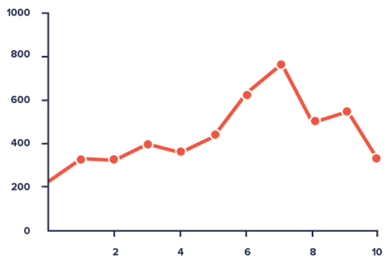
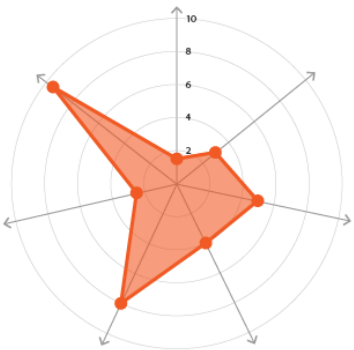
Chart Type	Description	Strengths	Weaknesses
Donut Chart 	They are essentially like Pie Charts (PC) with an area of the center cut out. By encouraging readers to focus more on reading the length of arcs than comparing proportions between slices as PC does, they are considered more efficient	Good at depicting percentages or parts of a whole The blank space inside the chart can be used to display more information	By only showing proportions, the exact variable values are unknown User may have a hard time registering the differences in the ring's filled-in angle area
Line Chart 	Line charts are composed of lines that connect data points that are plotted on a Cartesian coordinate grid. Normally the X-axis is used as a timescale or an interval sequence	Good at depicting values over a continuous interval or period, and consequently at showing patterns and trends	Can become cluttered and confusing when using more than 3 or 4 lines
Radar Chart 	Each variable is represented by an axis starting from the center. All axes are arranged radially and equidistantly, always keeping the same scale between them. Equidistance circles are usually used as guides, and each variable value is plotted along its axes. All those dots are finally connected forming a polygon	Within a dataset, it is easy to identify outliers, variables with similar values, and variables that are scoring high or low	Can become cluttered and confusing when too many polygons are overlapping or too many variables are considered

Table 3.1. Introduction of implemented data visualization charts – Data taken from https://datavizcatalogue.com

3.5 User Study

Interface success depends on several aspects: (1) programming and debugging, (2) an in-depth study of potential users to propose supported use case scenarios during the design phase, and (3) evaluation stages that should be conducted at some point of the development process to test the usability and utility of the tool (Roth, Ross, & MacEachren, 2015). Therefore, an interface evaluation study should be carried out to test the usability and utility of the prototype.

Roth et al. (2015) have introduced three types of user evaluation methods depending on the evaluators: (1) Expert-based methods: evaluators are not from the project team and have previous experience in interface design and evaluation; (2) Theory-based methods: designers and developers evaluate the tool themselves and (3) User-based methods: a representative set of target users is in charge of evaluating the product.

The user-based methods are considered essential to effective UCD (User-Centered Design). Although conducting such evaluation can be more challenging in terms of time, money, and participant access when compared to other methods. Thus, a user-based evaluation study should be undertaken with at least a few participants relevant to the target group.

The user test studies can also be classified depending on the collected type of data into qualitative and quantitative. Qualitative data consists of observational findings aiming to identify whether design features are easy or hard to use, while quantitative data appear in the form of one or more metrics (such as task completion rates or task times) aiming to explain if the tasks were easy to perform (Raluca, 2017). Roth et al. (2017) have indicated that after only adopting quantitative methods for several years, specialists in geography and related fields have recognized the need to implement qualitative and mixed method research as well for user studies in interactive maps and visualizations.

To guarantee successful communication between the user and the map, user evaluation studies should be carried out at different stages of the development process. Due to a lack of resources, it might be hard to do so, but it is important to conduct at least one user evaluation. A user-based method extracting qualitative and quantitative data is suggested since it can provide relevant feedback from a representative set of target users.

4 Case Study

This chapter explains how the methodology that has been described in the previous section was implemented for the selected case study: the EuroTech Universities Alliance (EUA). The first section of this chapter aims to introduce the EUA, including its members and purposes. As the prototype was built upon the universities that are part of the Alliance, the second section describes how the data collection process had to be adapted for this particular network. The third section refers to the interface design and introduces each of the layout elements and its functionalities. The following section discusses the implementation of data visualization charts to present the economic data. Finally, the last section introduces a user study method that could validate the approach.

4.1 The EuroTech Universities Alliance

Leading European universities in science and technology have strategically partnered to form the EUA, an association committed to excellence in research and developing solutions to society's challenges. To jointly achieve multi-scale initiatives of high-impact to society and industry, the Alliance promotes in-depth collaboration across research and education teams of the partner universities and encourages innovation and entrepreneurship among them. (EuroTech Universities, 2014)

According to the EUA official website (EuroTech Universities, 2014), their long-term vision includes becoming the leading European ecosystem for education in science and technology. To achieve this, it is essential that they establish a dynamic and interdisciplinary network with the active participation of all members of its ecosystem. To reach that goal, they need to gain a thorough understanding of that network. Based on what was discussed in Chapter 2 concerning the advantages of visualizing data and considering that the EUA does not have a current visualization tool for their network, they were chosen as the case study for this thesis.

Activities within the EUA are fully engaged in providing complementary strengths in education and research to contribute to the evolution of five disciplines considered of high relevance to Europe's industrial leadership: (1) Entrepreneurship & Innovation; (2) Health & Bio Engineering; (3) Smart & Urban Mobility; (4) Data Science & Engineering; and (5) High-Performance Computing. As the EUA officially uses these categories to classify its activities and projects, these five disciplines were set as the **fields of interest** throughout the prototype (see Section 4.3).

Even though it might expand soon, the Alliance is currently composed of the six universities presented in Table 4.1 and in Figure 4.1.

Logo	Abbreviation	Name	Location
	DTU	Technical University of Denmark	Copenhagen, Denmark
	EPFL	École Polytechnique Fédérale de Lausanne	Lausanne, Switzerland
	L'X	École Polytechnique	Paris, France
	TU/e	Eindhoven University of Technology	Eindhoven, Netherlands
	TUM	Technical University of Munich	Munich, Germany
	-	The Technion	Haifa, Israel

Table 4.1. Member universities of the EUA.

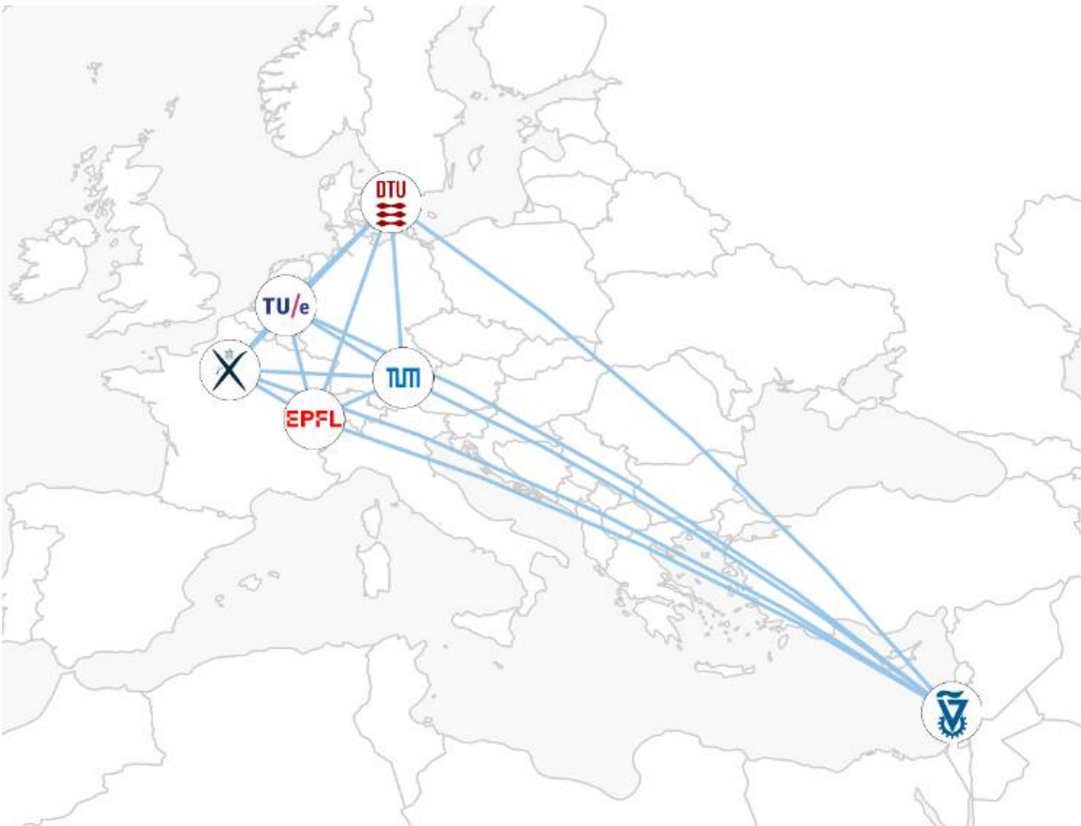


Figure 4.1. Connectivity between Eurotech's universities

Following the thesis objectives, the focus is placed on the European Universities (highlighted in Table 4.1), thus the case study was further scaled down to the European Union.

This work aims at certain target groups that include: (1) researchers and decision-makers in charge of selecting participants in innovative projects, (2) young entrepreneurs that would like to start new businesses, and (3) institutions seeking new partnership agreements. The possible needs and requirements that members of this target group guided every stage of the prototype development. Based on them, three different sample scenarios to illustrate their needs were proposed, and set as tasks that the prototype should be able to fulfill:

- *Scenario 1 – EuroTech employee:* "Since we are planning to carry out a new project concerning healthcare devices, I need to propose universities that are well prepared to participate in it."
- *Scenario 2 - Electronic engineer:* "I would like to initiate my start-up, but I need to know which is the most profitable business sector within my field of study. Additionally, I need to discover which universities are doing better in this field since I might need help and advice, and maybe to establish a partnership."
- *Scenario 3 - Private research company:* "We should establish new agreements with universities that have competences in the field of microchips."

4.2 Data Collection

As anticipated, the data collection was among the most challenging aspects of the thesis, since the desired data (see Fig. 3.2) presents the following characteristics:

- As most economic data, it is highly dynamic. For instance, when mapping economic indexes, one is never working with current values, but with values that were collected at a certain point of time and that probably became quickly outdated. This was the case for all the collected country indexes.
- As there is no common database where data regarding universities' partnerships can be found, different sources had to be used. In most cases, data was taken from their websites, and the provided information varied considerably from one site to another. The desired data coming from different sources and being often outdated, unavailable (most official data regarding private entities is not in the public domain) or incomplete resulted in an inconsistent and heterogeneous database.

As previously mentioned, the data that could have been considered for this project was massive. Following the thesis objectives and within the time given, priority was given to developing a suitable prototype rather than having a complete database. Therefore, the data collection was carried out focusing on the attributes highlighted in Fig. 4.2.

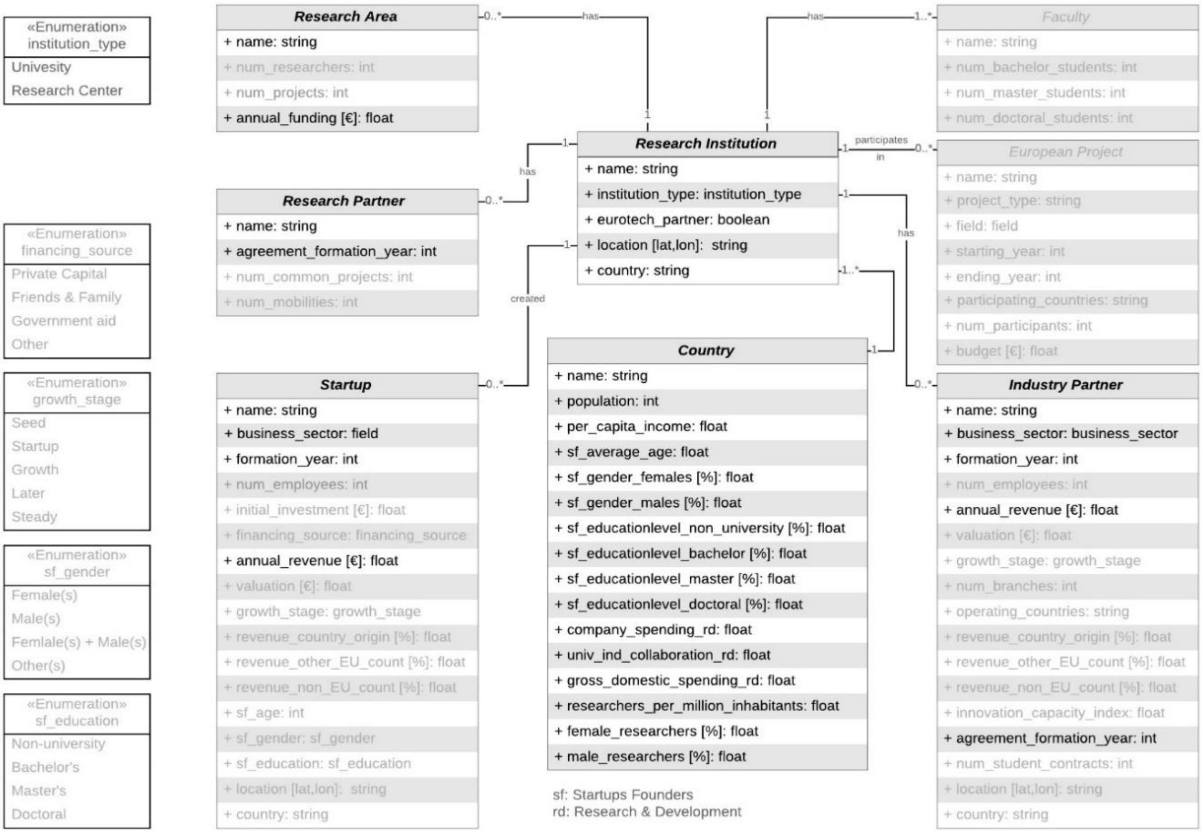


Figure 4.2. Attributes considered for the data collection

Firstly, information regarding each university's partnerships was searched for in each of their official websites: www.dtu.dk, www.epfl.ch, www.polytechnique.edu, www.tue.nl, and www.tum.de. None of them provided data on which are its industry partners, but some offered data regarding its research partners and start-ups created by former students. Information for each identified partner was taken from LinkedIn (https://www.linkedin.com/). Based on the available real data that was collected, the missing data were **randomly** generated to have a consistent database with entries for all universities. Furthermore, economic indexes were taken from different entities: the European Statistical Office (https://ec. europa.eu/eurostat/), the EU Startup Monitor (http://startupmonitor.eu), the World Economic Forum (http://reports.we fo-rum.org/), and the UNESCO (http://data.uis.unesco.org/).

The database consists of five tables containing the following data for each of the EuroTech members, shown in Table 4.2.

Name	Content	Attributes (see Fig. 4.2)	Usage
universities	Basic information	"Research Institution"	Place universities on the map
startups	Start-ups formed by former students	"Startup"	Provide statistical data for thematic map layers and charts
research	Research partners	"Research Area" & "Research Partner"	Provide statistical data for thematic map layers and charts
companies	Associated companies	"Industry Partner"	Provide statistical data for thematic map layers and charts
country_indexes	Economic indexes of countries	"Country"	Draw the choropleth map

Table 4.2. Description of tables in the database

All tables were initially created as CSV files and then converted to JSON using the site www.csvjson.com since this is the format that the previously mentioned TaffyDB library deals with. Every entry of the tables whose aim is to provide statistical data has an attribute concerning their field of work: "business sector" for start-ups and companies, and "research area" for research partners. Each entry was manually classified into one of the five fields of interest defined in Section 4.1 and stored under the attribute "field". This was essential since the data is first filtered by the field of interest and then by the university.

4.3 Prototype Interface Design

As explained in Section 3.3.1, the prototype was built using a compartmentalized layout containing a Map View, and a Compartment which includes the title "EuroTech innovation ecosystems", the Focused Field buttons, and the Statistics View. The design of each element on the layout is introduced down below, and the previously mentioned functionalities (see Section 3.3.2) that they offer are described as well.

4.3.1 The Map View

This is the core section of the prototype since it is the one the user needs to manipulate to gain insight into the universities' innovation ecosystem. It consists of a basemap, the thematic symbols and its legends, and a panel that makes it possible to turn the basemap into a choropleth one.

Basemap

As D3.js can draw maps from data stored in a JSON-compatible data format, a GeoJSON file containing the borders of all countries in the world on a large scale (1:10m) was downloaded from www.naturalearthdata.com (Natural Earth, 2019). As only European countries had to be displayed on the web map, all the non-European countries were removed from the file using QGIS, a software designed to view, edit, and analyze geospatial data.

As the European Institute for Environmental Sustainability recommends using the Lambert azimuthal equal-area projection for statistical analysis and display, this was the chosen geographical projection for the prototype (EU Commission - Joint Research Centre, 2001). Like every other map projection, it is not perfect: while it can accurately represent areas in all regions of the sphere, it does not accurately represent angles.

Thematic visualization and their corresponding legends

Before the user has chosen a field of interest using the Focused Field buttons (see Fig 4.3), the home page hosts the map showing the member universities of EUA (see Fig. 4.4). Each university is represented with its logo placed on its geographical location. A donut chart around the logo provides an overview of the strength of each discipline within the innovation ecosystem. A legend introduces the color scheme for focused fields and aims to help the user get familiar with them. The focused field colors are repetitive throughout the prototype.

Figure 4.3. Focused Field buttons – Icons downloaded from www.flaticon.com

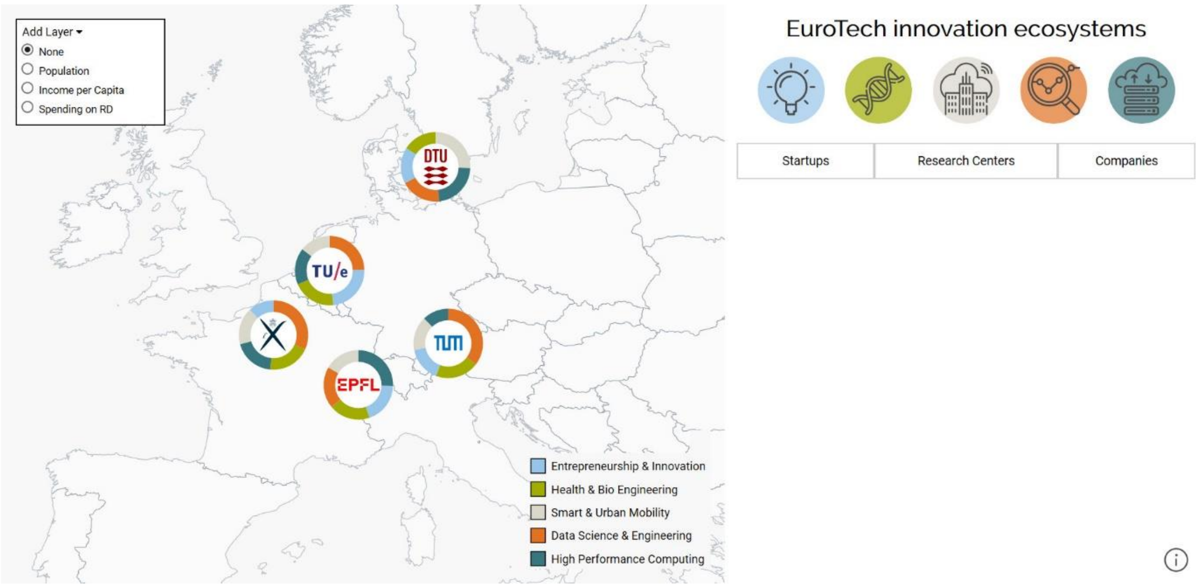


Figure 4.4. Prototype interface: Home page

Only after one of the Field Focus buttons is pressed, the map content is updated showing data regarding the chosen field of interest in the form of proportional circles and the user is given the chance to update the statistical charts by clicking on points and lines. Figure 4.5 shows how the map looks when the field of interest “Smart & Urban Mobility” is chosen. Proportional circles are drawn on the map to provide information on the number of entities (start-ups, companies and research centers), that belong to each of the universities’ innovation ecosystems, that work on that field. The legend on the bottom left used to introduce the fields of interest is now dedicated to the proportional circles. The proportional circles are providing an overview of what the user can discover on the tabs in the Statistics View, where statistical information regarding each ecosystem is presented. However, charts cannot be inspected until a university (point) or a connection between universities (line) is selected.

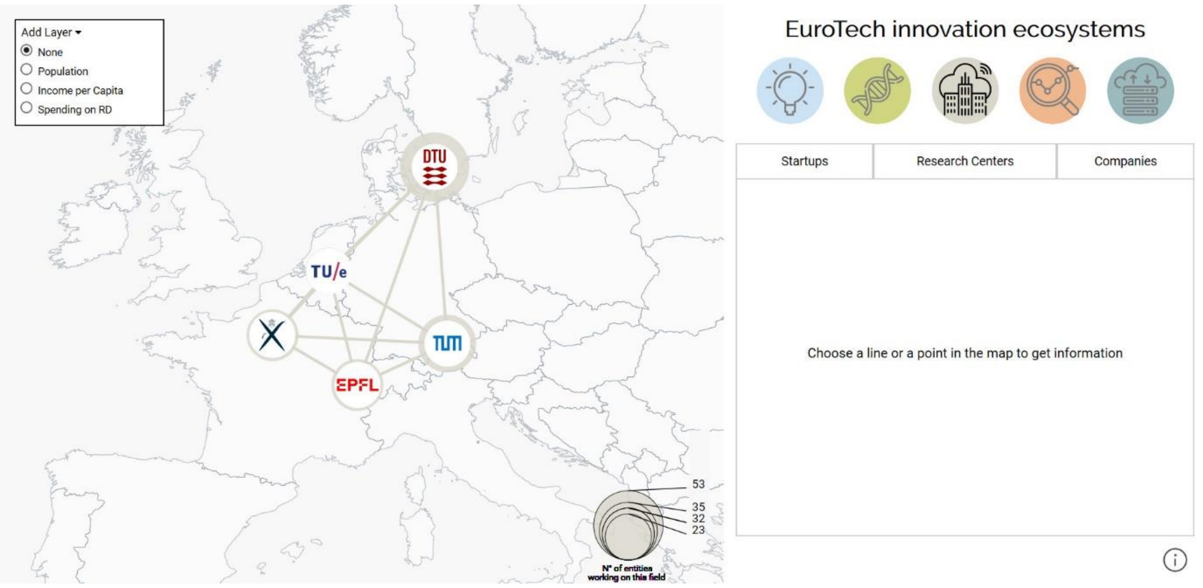


Figure 4.5. Prototype interface: a field of interest has been selected

Once a field of interest is selected, users can interact with the map: (1) by using the “Add layer” panel that turns the basemap into a choropleth map, (2) by clicking on points, or (3) by clicking on lines. The last two will trigger zooming in of the clicked element, and the update of the statistical charts in the Statistics View.

“Add layer” panel

This panel turns the basemap into a choropleth map of data related to the checked parameter, and it is always available but when the user zooms in on a line or a point. It was included to provide information on the economic indexes that are considered essential for innovation development, but only for the countries where EuroTech members are located.

The panel is arranged into four categories through a dropdown menu: Default, Startups, Companies, and Research Centers. They can be switched at any moment, and the menu is set to default every time the user changes the field of interest. By default, the panel offers general indexes such as population, income per capita and spending on research and development.

On the “Startups” category, parameters change to provide information on start-up founders: average age, percentage of female founders, and percentage of male founders. When the category “Companies” is selected, users can choose between University-Industry collaboration index, company spending on research and development index, and a third parameter yet to be defined. The last category “Research Centers” provides data about the scientific community: number of researchers, number of female researchers and number of male researchers.

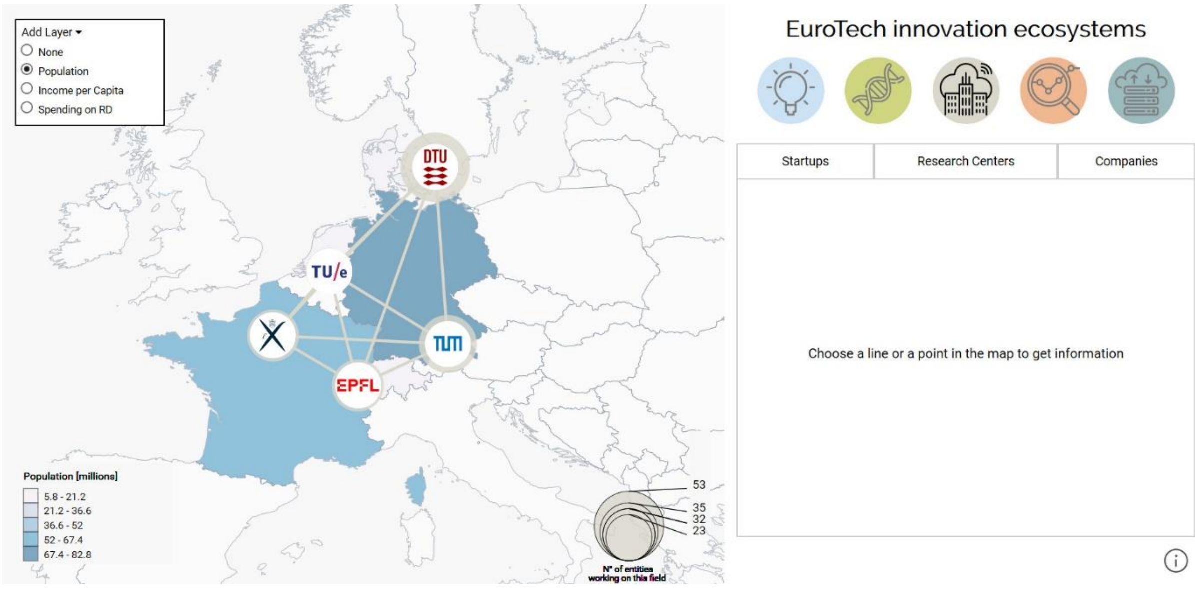


Figure 4.6. Prototype interface: a parameter of the “Add layer” panel has been chosen

Whenever an option different from “None” is checked, the choropleth map is drawn or updated, and so is the legend on the bottom right. Figure 4.6 shows how the interface looks when the option “Population” is checked.

4.3.2 The Compartment

Focused Field buttons

Each of the buttons represents a field of interest with an icon and a color (see Fig. 4.3) and it can be used at any time. When hovering over them, the name of the corresponding field pops up. When clicking on one of them, the button is highlighted, the information displayed on the statistical charts, the map zooming level is reset and proportional circles on the map are drawn.

Additionally, the color used to display the data changes, so it matches the one that corresponds to the chosen field.

Statistics View

Once a field of interest has been chosen and the user clicks on a point or a line, this section is used to present data visualization charts that intend to describe the innovation ecosystems of the selected universities related to that field. The Statistics View is structured into three tabs: Startups, Research Centers, and Companies. Even though each tab contains charts of the same type, the content varies since the data for each tab is taken from its corresponding table (e.g., The “Startups” tab uses data from “universities” table). Fig 4.7 illustrates how the interface looks like when a line connecting two universities (DTU and TUM in this case) is clicked, and charts (radar chart in this case) in the Startups tab are revealed.

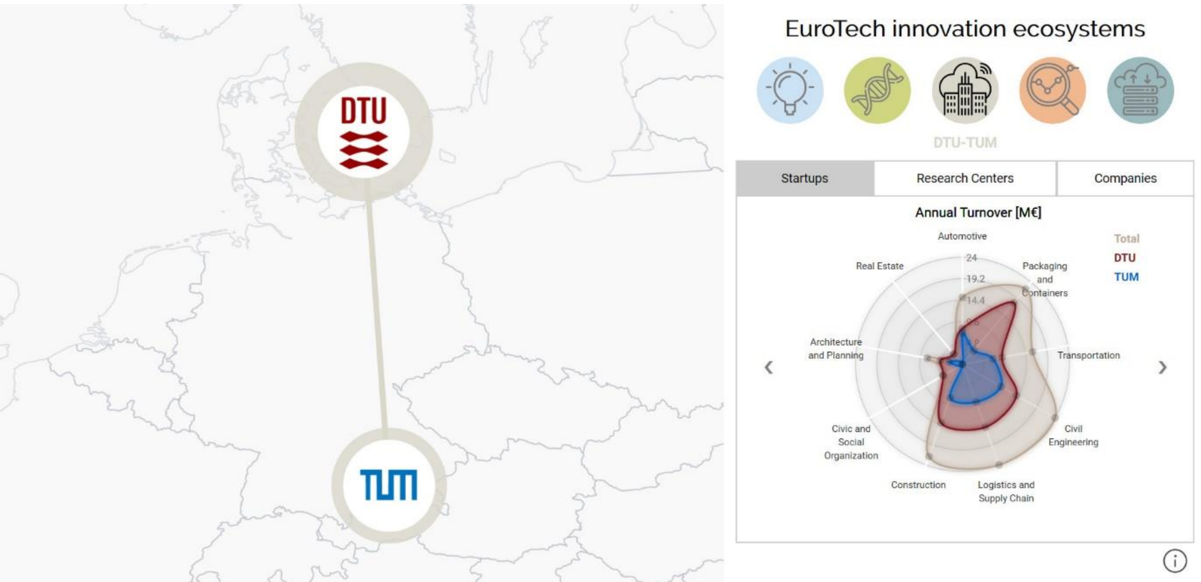


Figure 4.7. Prototype interface: a line connecting two universities is clicked

While a university or a line between two of them is selected, the user can discover all charts belonging to each tab using the arrow on the left or the one in the right. Within the time given, only two charts could be implemented, but there should be several more to make the prototype a meaningful tool. Additionally, the charts for the “Companies” tab were not developed. To have consistent graphs where the user can easily identify each EUA member, a specific color was assigned to each university and was used to represent it in every graph. The selected colors were dark red for **DTU**, pure red for **EPFL**, lime green for **L’X**, dark grayish-green for **TU/e** and dark blue for **TUM**. Figure 4.8 shows another chart type (line chart) in another tab, using the same colors for both universities.

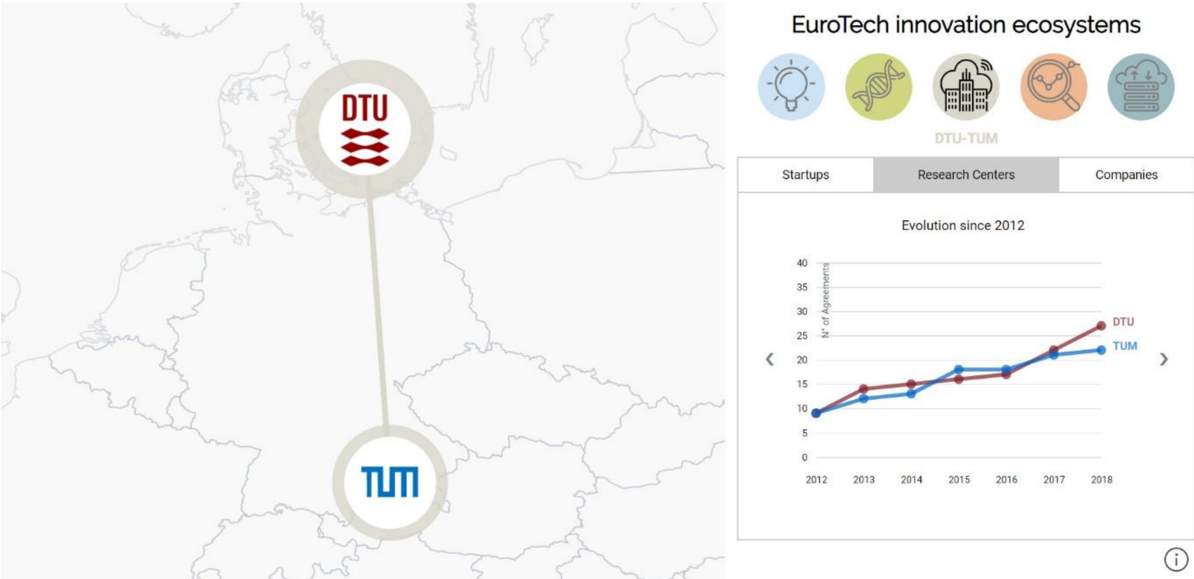


Figure 4.8. Prototype interface: a line connecting two universities is clicked

If a point is clicked instead, it is zoomed in, the proportional circles disappear, and the same chart types are displayed but only showing one variable.

4.4 Data Visualization Charts

As previously mentioned, only the three charts presented in Section 3.4 were implemented in the prototype, always accompanied by their correspondent legends: a donut chart, a radar chart, and a line chart. TaffyDB was able to find the required data for each graph by applying filters to the data stored in the tables of the database.

The donut chart appears in the Map View when the website is opened, and the radar chart and the line chart are used in the Statistics View. While the variables used to build the donut charts do not change, the variables for the others do. For instance, the radar chart in the "Startups" tab shows the annual turnover of start-ups created by former students of EUA members, by the business sector within the selected field of interest. However, if the user checks the "Research Centers" tab,

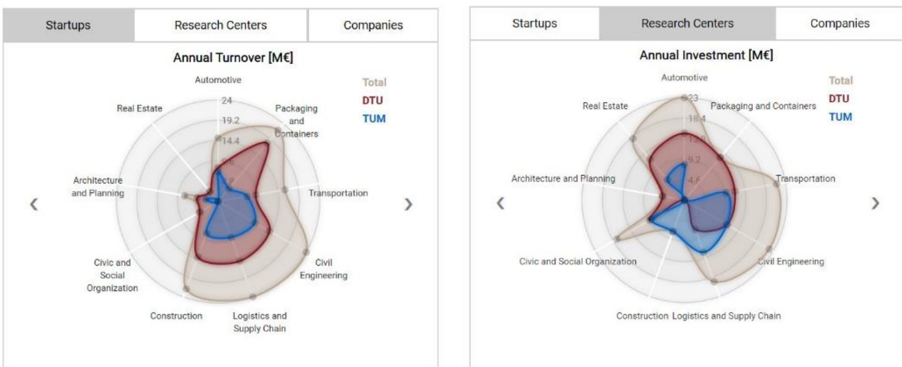


Figure 4.9. Radar charts for different tabs

the radar chart shows the annual investment in the research areas related to the field of interest, that the research partners of the EUA universities are getting (see Fig. 4.9).

The same happens with the line chart, which shows the evolution in time of different variables depending on the opened tab: number of start-ups founded per year in the case of the first tab, and number of research institutions that became partners in the case of the second tab (see Fig. 4.10).

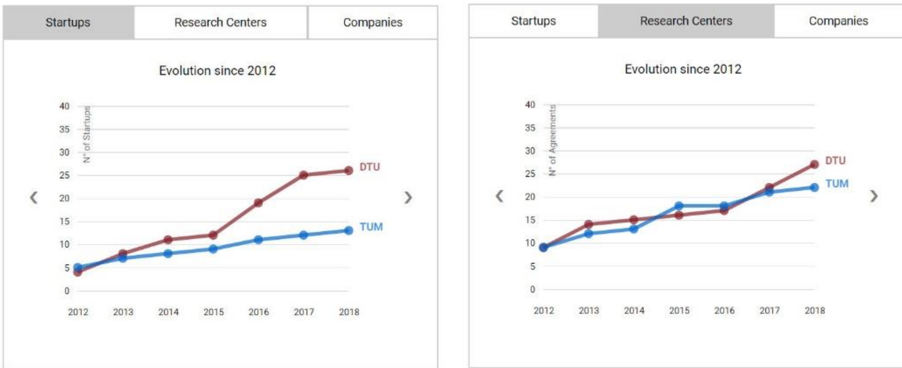


Figure 4.10. Line charts for different tabs

4.5 User Study

Although conducting the user evaluation study was not set as one of the objectives of this thesis, a simple user-based mixed method of quantitative and qualitative is proposed for the user evaluation and can be found in Appendix 1 and anticipated for future work.

The potential user study is divided into two parts: (1) an interaction study providing a set of tasks that the user is asked to solve using the prototype only, and (2) a questionnaire form to gather feedback once the previous part is finished. Before starting the experiment, the users are asked to take some time to get familiar with the prototype interface.

Firstly, evaluators need to provide some general information about their job and their preferences regarding data visualization formats. They are then presented with the scenarios considered for the interface design (see Section 4.3) and asked to solve them explaining which elements their answer is based on. After performing the tasks, they are requested to fill in a questionnaire concerning the user experience. The questionnaire consists of three parts aiming to gather opinions on: (1) prototype usability, (2) interface elements design, and (3) map features. The prototype usability section collects evaluators' impressions regarding the learnability, efficiency, memorability, and subjective satisfaction of the prototype. The part dedicated to interface elements design asks for feedback on the interface design and the affordance of each of the elements. The map features section obtains evaluators' perceptions of the map features.

The prototype was published online, thus became accessible for remote user evaluation, and the link together with the evaluation form was sent to EUA's Interim Head for consultation.

The approach proposed in this thesis can only be validated by conducting pertinent user studies. However, as the obtained feedback is valuable and already suggests improvements that could be implemented, EUA's Interim Head suggestions are discussed in the following chapter.

5 Results and Discussions

This chapter outlines the principal findings of this research, analyzes how the research objectives were addressed, and answers the research questions formulated in Section 1.3.2. The first section examines the interdisciplinary aspects of the project. The second, third, and fourth sections approach the three sub-objectives by discussing the proposed data model, evaluating the outcome of implementing a geographic network visualization method, and reviewing the most prominent aspects of the designed prototype, respectively. The following section is dedicated to the project limitations and open challenges that inspired the recommendations that the last section offers.

5.1 Interdisciplinary Aspects

A research project is considered interdisciplinary when it integrates data, methods, tools, concepts, and theories from different disciplines that are interconnected and combined, thus provide a better understanding of a complex issue, question, or problem (Wagner et al., 2011). This thesis considers an interdisciplinary approach since it implements information and methods acquired from different scientific domains, such as economics, data visualization, and cartography.

As Keena et al. (2017) have pointed out, projects involving multi-scalar research problems should be addressed from experts in each of the individual disciplines involved, so they can provide different points of view that are relevant for the project. The advantage of doing so is that the knowledge exchange and collaboration among experts in diverse related fields can generate new insights into the research problems. An interdisciplinary approach usually involves the challenges of working with large amounts of multivariate data and of interpreting the possible relationships among it and their corresponding relevance to the problem.

This research was conducted from the cartographic point of view and focused on data visualization. Although it is necessary to establish a closer collaboration with the researchers in the field of economics and innovation management, the results of this thesis can initiate a discussion on how Innovation ecosystems can be visualized to stakeholders (education, research and business experts). In this regard, a persistent challenge is to identify information relevant for decision-makers working in the domain of innovation and entrepreneurship.

5.2 The Data Model

The first sub-objective of this thesis was to identify the elements that can best describe the complexity of spatial and non-spatial relations among clusters based on a selected case study. The first research question that was formulated in accordance to this goal was: "**Which kind of**

relations among clusters need to be depicted to facilitate data exploration and decision making?" After conducting a thorough literature review on the topic of innovation ecosystems, a data model presenting the relations that can best describe universities' innovation ecosystems was proposed (see Fig 3.2).

The proposed data model contains all those elements that are considered relevant to the evolution of such ecosystems. Entities that could help to interpret the driving forces and impacts of innovation within a university environment together with their most prominent attributes are included. Analyzing and crossing data from different entities results in the revelation of patterns that can contribute to providing a complete description of these kinds of ecosystems.

Socio-economic databases, as well as the database developed within this prototype, involve heterogeneous data, coming from different sources, using different formats, and presenting diverse levels of quality and resolution. The proposed model successfully integrates and connects this data and succeeds in showing interconnectivity between the material resources and human capital that compose those ecosystems.

Even though the model was inspired in the EUA case study, reusability was a key aspect of its design. Therefore, emphasis was put on contributing with a model that could be implemented for similar applications in the future, without requiring significant changes. This data model aims to establish a basic framework and become a prototype for further improvement.

5.3 The Visualization Method

The second sub-objective of this thesis was to compare network visualization techniques and determine a suitable method that could emphasize the connectivity of science and technology across European boundaries. The second research question formulated in line with it was "**How can innovation ecosystems be presented using a geospatial network visualization approach?**".

Innovation ecosystems are invisible phenomena, but visualization techniques can make them visible and understandable to people. As previously mentioned, the literature review exposed the tendency of treating innovation ecosystems as networks. Therefore, when proposing a visualization method to test within this thesis, the research of possible methods was confined to network visualization approaches. Section 2.2 discusses their classification, focusing on the two most relevant for this project: the geographic and the abstract topological networks.

The data that describes innovation ecosystems is composed of spatial and non-spatial components. After studying the data model, the importance of the spatial components in the development of innovation became obvious. After analyzing the results of the previously mentioned comparison, the geographic network visualization method was chosen to depict the innovation ecosystems of the universities from EUA. The decision was based on one of their strengths: the possibility of proving spatial context. Heavy cluttering due to co-existence of spatial and network clustering was among the weaknesses of these visualization approaches. However, as the EUA is composed of only five European universities, the chance of encountering this problem was unlikely (see Table 2.1).

The implementation of methods that place the nodes in its geographical location need to make use of a cartographic representation. These approaches not only provide spatial context but also situate the map in a central position of the visualization. The map, employed to add meaningful spatial information, reveals spatial patterns that would otherwise go unnoticed.

Nevertheless, another visualization method was necessary to effectively display non-spatial data, so the proposed methodology integrates two recognized forms of data visualization: statistical graphics and thematic web cartography. Even though both approaches aim to serve as visual representation tools that allow exploration and discovery, they are employed to depict different kinds of information: cartographic visualization deals mainly with spatial data, while the graphs are generally used to depict quantitative data in statistical forms. (Friendly, 2009)

As explained in Chapter 4, throughout the prototype design, the emphasis was given to depicting different information in the Map View and the Statistics View, to use the available space efficiently and to avoid showing overlapping data. Both views are then complementing one another and instead of showing the same information in different forms: The Map View presents spatial data using a geographic network visualization approach, while the Statistics View provides non-spatial data in the form of charts. The integration of both methods results in a user-friendly and well-arranged interface. Presenting the different types of data (spatial and non-spatial) in separate views avoids overwhelming the user with information.

5.4 The Prototype

The third sub-objective of this thesis was to build a prototype of an interactive thematic web map enabled to visually represent scientific and technological networks and clusters based on a selected case study. The third research question "**Which map elements and user interactions can be used to convey relations among clusters?**" was formulated in accordance with that sub-objective. Thus, this thesis presents a prototype containing a thematic interactive web map introducing a new approach to the visualization of the EUA innovation ecosystem that can be accessed at https://zarinaacero.github.io/EuroTechProject/.

Workflow

Figure 5.1 summarizes the stages that a prototype like the one developed in this thesis needs to go through before being implemented. Within the context of this investigation, it was not possible to perform the user studies that would confirm or reject the need for redesigning some parts of the proposed model. Instead, the goal of this thesis was to develop a data model and a first mockup following the steps that Figure 5.1 highlights.

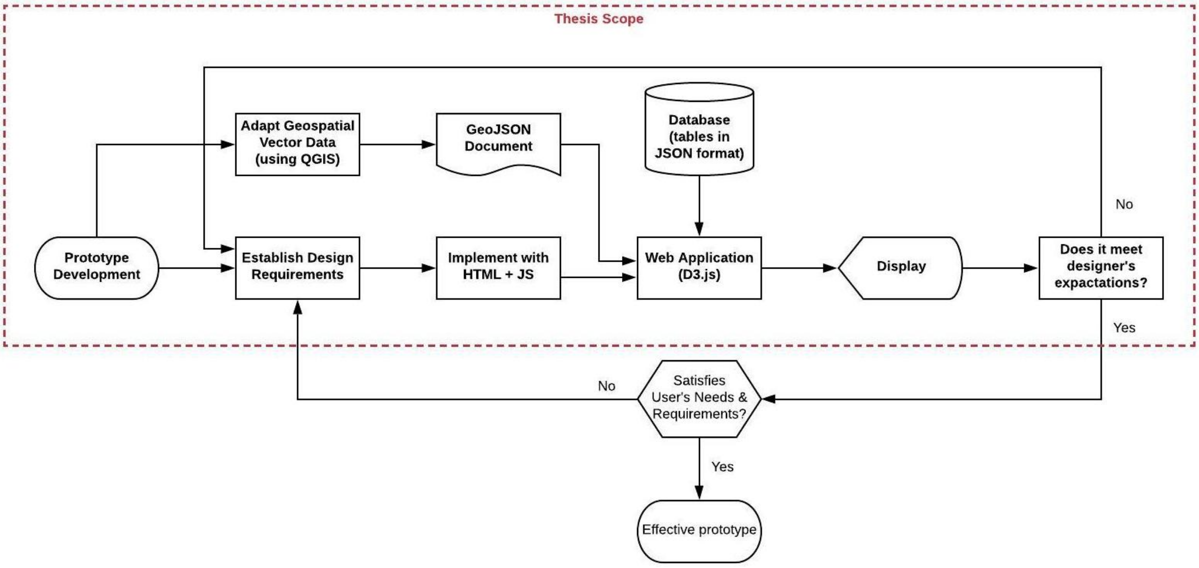


Figure 5.1. Prototype development workflow

Before starting to develop the prototype, potential target users were identified to guarantee that their needs and goals were covered. Currently, the prototype fulfills the designer's expectations and is ready to be tested by possible users for improvement.

Functionalities

The review performed in Section 2.5 inspired the features and functionalities that the prototype should include. Table 5.1 compares the reviewed projects with the prototype designed in this thesis, according to offered functionalities for data visualization.

Providing information not only on nodes but also on links was a priority since the literature has revealed that innovation ecosystems are better described by their relationships rather than by their entities. The prototype provides this information by updating the charts when users click on the lines connecting each pair of universities. By interacting with the tabs on the Statistics View, the user can explore the nature of those relationships.

	Prototype	Startup Heatmap Europe	Startup Hubs Europe	Startup Cartography Project	MIT World
Provides information on nodes	✓	✓	✓	✓	✓
Provides information on links	✓	✗	✗	✗	✓
Uses animation effects for transitions	✓	✗	✗	✗	✓
The map provides not only locations, but also additional relevant information	✓	✗	✗	✓	✓
Charts are linked to the map: changes on the map update the statistic charts	✓	✓	✗	No charts	✗
User can look at the map and the charts simultaneously	✓	✗	✗	No charts	✓

Table 5.1. Comparison of offered functionalities for data visualization between reviewed projects and the prototype

Heer & Robertson (2007) demonstrated that with careful design, animated transitions could improve users' graphical perception of transitions between statistical data graphics. Additionally, Bederson & Boltman (1999) proved that if a task requires users to know something about entities' spatial position, and the viewpoint is changed, animating that change in viewpoint can help users. Exploiting the potential of D3.js, animation effects were added to provide smooth transitions. Animation effects take place when zooming in and out, when changing parameters of the "Add Layer" panel, when updating the radius and colors of the proportional circles, just to mention a few.

The possibility to provide spatial context is one of the main reasons to choose a geographical network visualization over an abstract topological one. Integrating a map representation must add meaningful relevant information to the model. Otherwise, there is no reason to adopt this method over others. Some of the reviewed projects were only providing the map as a tool to filter the data, which could be easily accomplished by adding simple programming tools such as dropdowns or checkboxes. Having the filtering option together with the charts would even result in a less complex interface.

To give the map a purpose and support the choice of adopting a geographic visualization approach, the Map View of the prototype supplies information that complements the data presented in the Statistics View. Additionally, both views are interconnected, and charts update when the user interacts with the map. Introducing both views in the interface improves the learnability of the prototype, since users can immediately realize the connection between both views.

Website Programming

The prototype code was written focusing on providing all the map elements and user interactions that can convey relations among the components of the EUA innovation ecosystem.

The programming code is responsible for converting the data into visual representations. Not only is the code in charge of building and manipulating all the interface elements but also of performing the calculations to find the necessary data displayed in each of the charts. Figure 5.2 presents the prototype's interactive application, showing the states of each layer at every step of the process that users go through to gain knowledge.

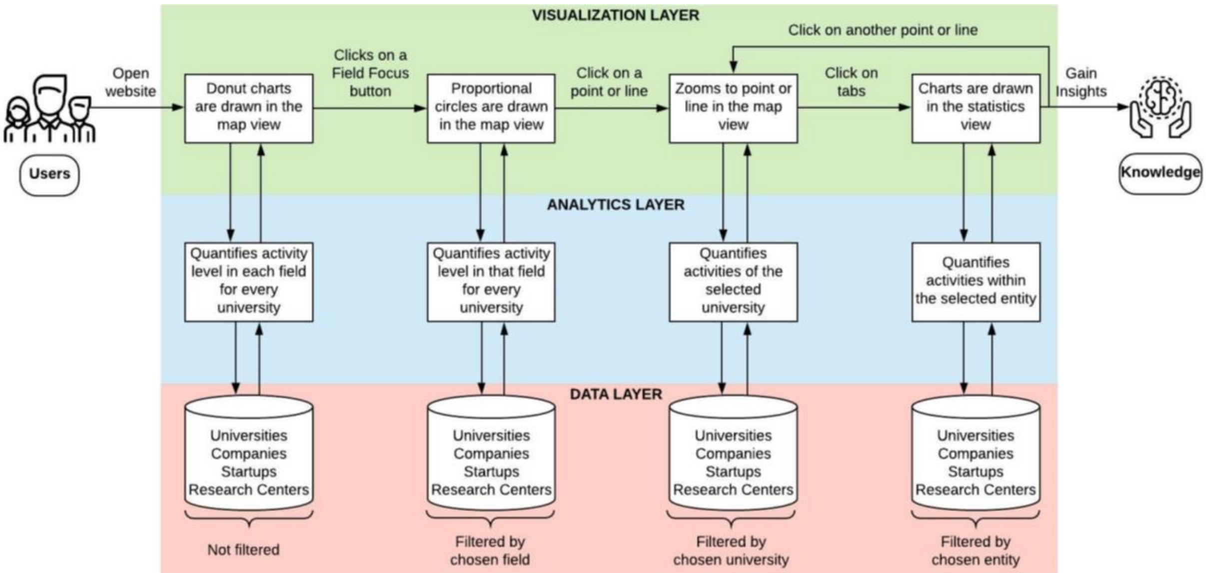


Figure 5.2. Prototype's interactive application overview – Icons from www.flaticon.com

The end of Section 4.1 introduces the three scenarios that were used to illustrate the target user's needs and set as the tasks that the prototype should be able to fulfill. Hereunder each of the scenarios is reviewed and the schema of the prototype's interactive application is used to explain how each of those potential users can interact with the prototype to solve those tasks and gain knowledge.

<u>Scenario 1</u> describes the need for a EuroTech employee to propose universities that are well prepared to participate in a new project concerning healthcare devices that the EUA is planning to carry out. When opening the prototype, he would first notice the donut charts that would make him realize that each color represents a field of interest. Since healthcare devices fall in the category of Health & Bio Engineering (H&BE), he would notice in which of the universities this field stands out by analyzing the presence of green in the donuts. After getting familiar with the interface, the user would identify the need for clicking on the button that corresponds to

H&BE to get the information he needs. The proportional circles would appear indicating which universities are doing better in that field and would make him inspect them by clicking on their logos or the lines connecting them. By clicking on the tab dedicated to research centers in the Statistics View, he would discover the performance of universities in the field of healthcare devices. After clicking on several points and lines and analyzing the charts, he could draw conclusions to propose the universities that could participate in the EUA project. The interactive process is explained in Figure 5.3.

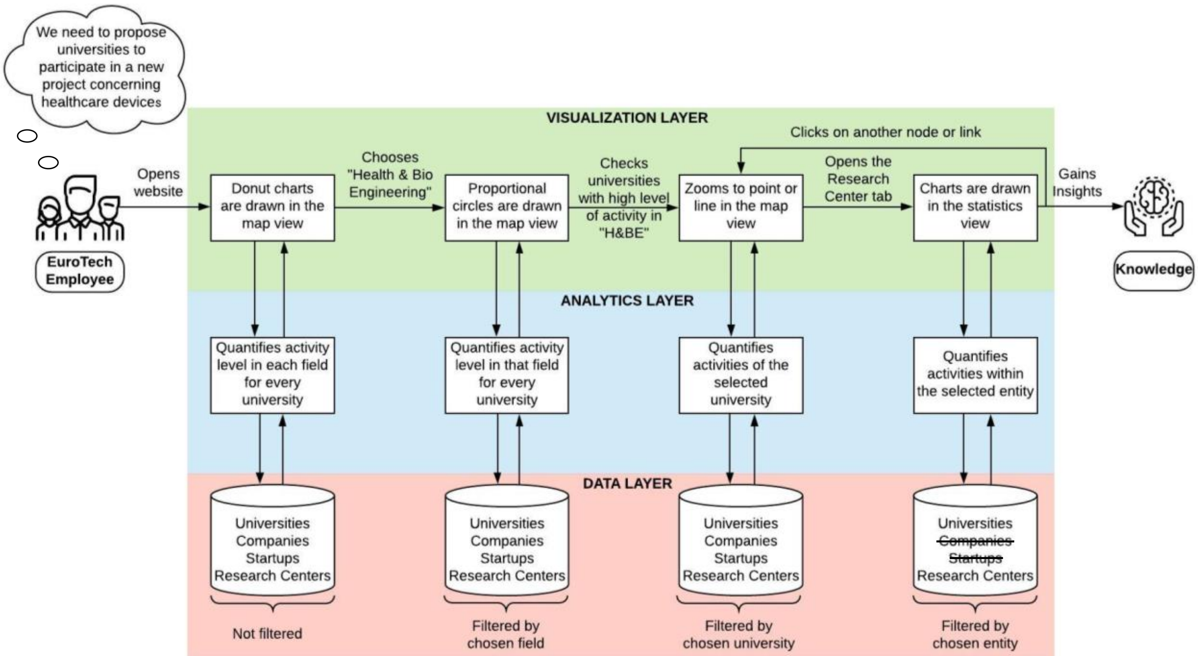


Figure 5.3. Prototype's workflow applied to Scenario 1

Scenario 2 illustrates an electronic engineer that wants to initiate a start-up and needs to identify the most profitable business sector within her field of study. Additionally, she would like to find out which universities are strong in that business sector in case of needing help, advice or a partnership. When opening the prototype, she would first notice the donut charts that would make her realize that each color represents a field of interest. Since electronic engineering falls in the category of Data Science & Engineering (DS&E), she would notice in which of the universities this field stands out by analyzing the presence of orange in the donuts. After getting familiar with the interface, she would identify the need for clicking on the button that corresponds to DS&E to get the information she needs. The proportional circles would appear indicating which universities are doing better in that field and would make her inspect them by clicking on their logos or the lines connecting them. By clicking on the Startups tab in the Statistics View, she would discover the annual turnover of each of the fields related to DS&E for different universities. After clicking on several points and lines and analyzing the charts, she could draw conclusions regarding the most profitable business sectors, and in which environment she should develop the start-up. The interactive process is explained in Figure 5.4.

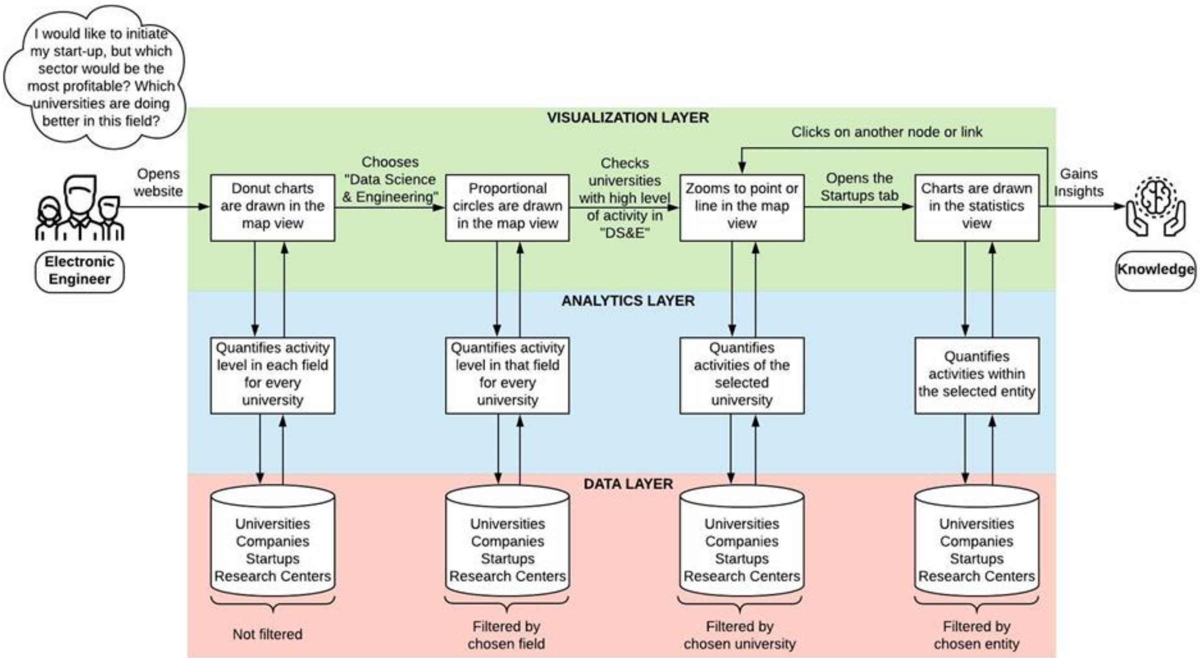


Figure 5.4. Prototype's workflow applied to Scenario 2

Scenario 3 describes a private research company in need for partnering up with universities that have competences in the field of microchips. When opening the prototype, the user would first notice the donut charts that would make him realize that each color represents a field of interest. Since microchips fall in the category High Performance Computing (HPC), he would notice in which of the universities this field stands out by analyzing the presence of dark cyan in the donuts. After getting familiar with the interface, he would identify the need for clicking on the button that corresponds to HPC to get the information he needs. The proportional circles would appear indicating which universities are doing better in that field and would make him inspect them by clicking on their logos or the lines connecting them. By clicking on the tab dedicated to Companies and Research Centers in the Statistics View, he would discover which universities have been actively working in the field of microchips. After clicking on several points and lines and analyzing the charts, he could draw conclusions regarding the potential partnerships that could be established. The interactive process is explained in Figure 5.5.

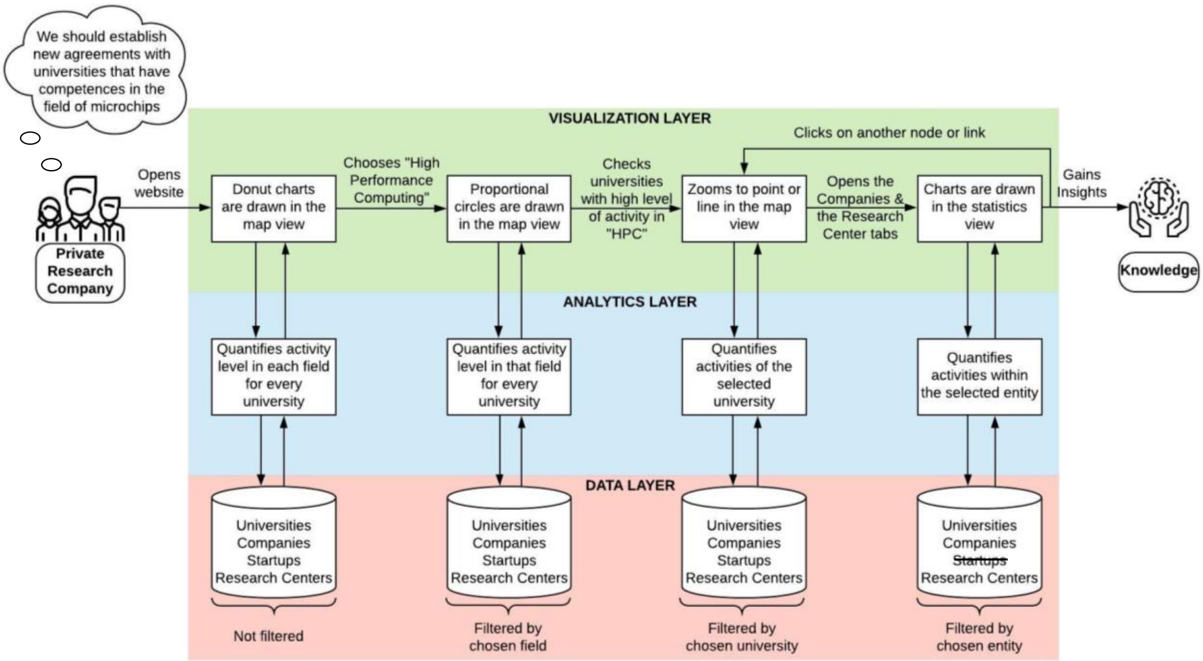


Figure 5.5. Prototype's workflow applied to Scenario 3

Reusability

During the last decade, the EU Commission has acknowledged the benefits of Open Data (OD) for society and economy, supporting and encouraging the opening up of public sector information. The EU Commission has implemented an OD policy which is linked with the open research data policy, both addressing publicly funded data and their data results from public funding. (EU Commission, 2019)

Not only is OD saving time, money, and effort to several organizations by allowing communities to collaborate on data products, but it is also an innovation booster. OD can stimulate entrepreneurs to create new innovative products and services.

Since reusability was a priority for this project, the prototype was fully developed in an open-source environment, following the trends in Information Technology. All the data involved in this project is free to access for everybody, and the file format and its content are not restricted to a particular non-open source software tool. By only using OD and publishing the prototype as an open-source project in Github, the door is left open for others to continue working on its development. Additionally, it enables non-experts in programming to adapt the prototype for another usage by making small changes in the code.

The project resources and how to reuse them

Derived from Figure 5.1, the program needs the following files to run:

- An HTML file containing the functionality of the website, programmed with JS. This file is responsible for the structure of the website, putting its layout and skeleton together.
- A CSS file that specifies the style rules and the layout of the web page.
- A GeoJSON document containing the geospatial vector data, so D3 can create SVG elements out of it. As D3 can convert JSON files into SVG elements as well, the input file could also have a JSON format, or be directly an SVG file, although that will mean that more lines in the code had to be changed.
- As many JSON files as tables in the database

Additionally, in this case, two extra JS files are needed: one to run TaffyDB and the other one to draw the radar chart. The image files containing the map markers used for the universities are also in the directory.

Therefore, if the prototype was implemented for another set of universities, it would only be necessary to change the content of the JSON tables. If the names of the attributes and the format remain the same, the prototype should run smoothly. It is crucial to replace the images that will serve as the map markers for each university to the directory. The name given to each image needs to match the attribute "image" for its corresponding university in the table called "universities".

To display other types of data within the Statistics View, changes can be made in the HTML file. First step is to import the tables containing such data. Then, as the code offers separate functions for preparing the data to build a chart and for building it, it is simple to change the variables that the statistical graphs must show. As the functions that prepare the data only need parameters concerning the name of the table containing such data and the attributes that should be displayed on the graph, only those parameters have to be changed. Finally, the tabs should be renamed after the new entities, and chart titles should be updated.

The previous explanation is only valid if the proposed fields of interest were kept. If using different ones, the new fields should be specified in the variable called "fields" and icons for the buttons should be updated.

2.5 Open Challenges

The study of innovation ecosystems is relatively new, and it involves invisible phenomena of several disciplines. As could be expected, developing a methodology to visualize such a complex subject posed several challenges.

The data model

As previously mentioned, the proposed data model is based on the literature review. Even though innovation ecosystems have certainly gained ground in the field of economic research, the topic is still on an early stage, and the literature is still scarce on the components of such ecosystems. If the project was to be continued or implemented for another case study, a consultation with specialists in innovation and entrepreneurship to validate the data model would be required.

The visualization method

Considering that the subject of innovation ecosystems is recent to the cartographic field and no map representations were depicting entire ecosystems at the time of proposing a visualization method to the author's knowledge, proposing an appropriate data visualization approach was particularly challenging.

The prototype

The prototype is a potential to be improved by adding additional features discussed down below:

- When the user clicks on a point or a line and triggers the zoom effect, the donut charts and proportional circles on the Map View should resize just like map markers do. As a temporary solution to avoid overlapping disproportional circles in the Map View, they currently become invisible when the user zooms in the lines or points.
- The info button in the prototype should provide the users with information concerning the project, either by opening a new tab or presenting it in a modal window.
- Data sources should appear somewhere in the prototype. Possible solutions might be: (a) mentioning them where the project would be explained (see previous item) or (b) including them in the corresponding legends.
- Currently, only two types of data visualization charts are implemented to show statistics. However, more graphs could be added to visualize all the relevant aspects of innovation ecosystems. Research to determine which chart types would be appropriate to add would be needed. This study only considered quantitative data, but charts for qualitative data could be tested as well.
- The map legends in the prototype are static. However, dynamic legends could be implemented to test if there is a navigation improvement.

5.6 Future Work Recommendations

One or several appropriate user studies must be conducted to validate the approach. The adopted methodology suggests that a mixed method of quantitative and qualitative data could be suitable for the user evaluation (see Appendix 1). Further investigation needs to be done to define the participants that should be recruited for the study, the products that need evaluation, the evaluation process that the participants will need to complete and how data will be collected and interpreted.

Even though running the user studies was not within the objectives of this thesis, the prototype was sent to the EUA's Interim Head. When being consulted about her preference regarding data visualization, she explicitly acknowledged her inclination for visual representations of data over the use of numerical or textual formats. Furthermore, she revealed that she currently works with Excel charts for basic PowerPoints and that she would like to have visual illustration tools showing the interconnectedness of ecosystems. However, she emphasized that such tools would require a "thorough concept of indicators".

Additionally, derived from the remote consultation with the EUA's Interim Head, the need for giving special attention to the following issues in the further development of the prototype have aroused:

- While solving the tasks, she would have liked to distinguish for each university, the number of start-ups/companies/research centers of each field of interest over the total number.
- She has not interacted with the lines, but only with the points. Thus, she found it hard to compare universities' information. Aligned to the abovementioned, when asked about the learnability of the prototype after finishing the tasks, she stated that she did not find the prototype easy to learn, and that she would like to get instructions on the interface elements.
- She would have liked to go back to the home page. Since the home page hosting the donut charts aimed to provide a quick overview of each university's ecosystem, the possibility of users wanting to go back to it was not contemplated.
- She found the information provided by the "Add layer" panel relevant and useful for solving the tasks.
- She was satisfied with the zooming options
- She felt the interface was user-friendly.

- She thought the prototype could be implemented to depict real data concerning the EUA.

Considering these issues, and only after running adequate user studies, the improvements that the prototype requires could be identified. Implementing them would result in a successful interface, where users could efficiently complete their desired objectives.

6 Conclusion

The main objective of this thesis was to visualize clusters and networks among European innovation ecosystems and to map European competences as well as facilities that support technological advances.

To accomplish the objective, an interdisciplinary methodology was proposed and applied to the case study of EuroTech Universities Alliance. Firstly, a solid data model enabled to identify the relations among the most significant components of universities' innovation ecosystems was designed. Secondly, and based on the data model, a suitable visualization method that could effectively convey the connectivity of science and technology across European boundaries was chosen. Finally, an interactive prototype adopting the data model and the proposed visualization method was developed to depict universities' innovation ecosystems. The combination of statistical graphics and thematic web cartography introduces a new approach for the visualization of these complex ecosystems.

This thesis is a step forward towards the study of innovation ecosystems from a cartographic point of view. Additionally, this project is in line with European policies. On one hand, the prototype designed within this thesis is in accordance with the measures that encourage the development of European innovation ecosystems through the integration of education, research, and entrepreneurship (EU Commission - Directorate-General for Research, 2018). On the other hand, the entire project was fully developed in an open-source environment following the trends of Open Data, which is supported by the EU Commission with projects like the Digital Single Market and the FAIR Data Principles (Association of European Research Libraries, 2016; EU Commission, 2019).

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Appendix 1– Proposed questionnaire for user study

Department of Civil, Geo and Environmental Engineering
Chair of Cartography

Master Thesis Questionnaire

This survey is part of a study that presents innovation ecosystems using a geographic network visualization approach. The proposed prototype of an interactive web map aims to enable non-experts in complex network visualization to explore and manipulate data in an interactive way, to gain insights into how European innovation clusters are related, and to draw conclusions that would ultimately lead to better decision-making.

As the EuroTech Universities Alliance was chosen as the case study, it would be really helpful if you could provide some feedback regarding the effectiveness of the prototype. To do so, you will be presented with three tasks, and some questions regarding the problems you might have had to accomplish them. This survey should take you no more than 30 minutes.

The results of this study will only be used to test and eventually improve the functionality of the prototype and its features, so your responses will be kept anonymous. Your time and effort are greatly appreciated.

Before you start…

1. Which is your current position at EuroTech Universities?

2. Do you feel that it is easier for you to understand data when it is (a) visually presented or (b) presented in numerical or textual formats? (**a** / **b**)
3. Do you use any kind of data visualization tool at work? (**Yes** / **No**)
4. If your previous answer was "**Yes**": For which kind of data? Do you find it useful?

   If your previous answer was "**No**": Do you think it would be a helpful tool? For which kind of task?

Go to https://zarinaacero.github.io/EuroTechProject/ and take some time to get familiar with the prototype. Once you feel ready, please try to perform the proposed tasks down below.

Remarks:

a. The datasets used in the prototype were randomly generated, so the data is not real.
b. As datasets regarding companies has not been integrated yet, you should avoid using the tab "Companies" to complete the tasks.

Task 1

You are an electronic engineer and you would like to initiate your own start-up.

5. As you have not decided your business sector yet, you would like to know which area within your field of study is the most profitable one among start-ups.

   My answer is based on (name interface elements or graphs):

6. Either to get help and advice from them, or to establish partnerships you would like to find out which universities are doing better in those fields.

   My answer is based on (name interface elements or graphs):

Task 2

The EuroTech Universities Alliance is planning to carry out a new project concerning healthcare devices and needs you to find out which universities should take part in it.

7. Which two universities would you suggest?

   My answer is based on (name interface elements or graphs):

Task 3

A private research company specialized in the study of microchips wants to establish a new agreement with a university that is also currently working on that field.

8. Which universities could be appropriate partners for them?

   My answer is based on (name interface elements or graphs):

9. To what extent do you agree with the following sentences?

	Strongly Disagree	Disagree	Agree	Strongly Agrees
The prototype				
It was easy to learn how to use it	◯	◯	◯	◯
It was easy to find the information I was looking for	◯	◯	◯	◯
I was able to efficiently complete the tasks with it	◯	◯	◯	◯
I believe EuroTech could implement it to depict some kind of information	◯	◯	◯	◯
Interface elements				
The interface is user friendly	◯	◯	◯	◯
The interface is intuitive	◯	◯	◯	◯
Functionality of elements is clear	◯	◯	◯	◯
If not, please specify which elements were not:				
I would like to have instructions on the interface elements	◯	◯	◯	◯
Map features				
Legends were clear	◯	◯	◯	◯
Legends were enough	◯	◯	◯	◯
If not, please specify what was missing:				
I have used the “Add layer” panel (top left) to perform at least one of the tasks	◯	◯	◯	◯
I feel the “Add layer” panel provides meaningful information	◯	◯	◯	◯
I am satisfied with the zooming options (clicking on lines and points)	◯	◯	◯	◯

10. I find confusing that…

11. Any other remarks?