Effects of Urban Expansion in Real Estate Ecosystems: Identification and Analysis of Neutrosophic Causal Dynamics

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Master in Management

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ISCTE Business School

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EFEITOS DA EXPANSÃO URBANA NO ECOSSISTEMA IMOBILIÁRIO: IDENTIFICAÇÃO E ANÁLISE DA DINÂMICA CAUSAL NEUTROSÓFICA

ABSTRACT

O ecossistema imobiliário resulta da simbiose entre diferentes tipos de imobiliário, sejam residenciais, comerciais ou industriais, sendo o seu equilíbrio fundamental para o bom funcionamento desse ecossistema. O imobiliário é um produto da expansão urbana criada devido ao aumento da população e ao afastamento da mesma do setor primário. O crescimento não-planeado das áreas urbanas pode ter graves consequências na saúde da população e no meio ambiente. No entanto, quando bem estruturado, pode ter consequências positivas para o bem-estar da sociedade. A relação entre esta expansão e os seus efeitos no ecossistema imobiliário é um tema subjetivo e de grande complexidade, onde não é possível encontrar apenas uma solução aquando da tomada de uma decisão. Desta forma, esta dissertação propõe a criação de um modelo de análise multicritério de apoio à tomada de decisão que ajude a estruturar o problema e fazer face à sua subjetividade e complexidade. A presença de decisores com experiência profissional na área foi fundamental para a sua criação. O modelo, criado através de mapeamento cognitivo e da técnica *DEcision MAking Trial and Evaluation Laboratory* (DEMATEL) em ambiente neutrosófico, tem como objetivo combater as limitações de outros estudos sobre a expansão urbana. Estas metodologias incorporam a incerteza associada à tomada de decisão, tornando o modelo mais realista, completo e capaz de dar respostas informadas durante a tomada de decisão. O modelo criado foi validado por uma entidade externa ao processo, com o objetivo de analisar o seu potencial em possíveis aplicações práticas.

Palavras-Chave: Apoio à Tomada de Decisão Multicritério; DEMATEL; Ecossistema Imobiliário; Expansão Urbana; Lógica Neutrosófica; Mapeamento Cognitivo.

Códigos JEL: C60; M10; O18; O21.

EFFECTS OF URBAN EXPANSION IN REAL ESTATE ECOSYSTEMS: IDENTIFICATION AND ANALYSIS OF NEUTROSOPHIC CAUSAL DYNAMICS

ABSTRACT

Real estate ecosystems result from the symbiosis between different types of real estate, whether residential, commercial or industrial, and their balance is essential for proper functioning. Real estate is a product of urban expansion due to population increase and distance from the primary sector. Unplanned growth of urban areas can have profound consequences for the population's health and the environment. However, when well structured, it can have positive implications for the well-being of society. The relationship between this expansion and its impact on real estate ecosystems is a subjective and overly complex topic, where it is not possible to find just one solution when making a decision. The present dissertation presents a multi-criteria analysis model to support decision-making that helps structure the effects of urban expansion in real estate ecosystems and deal with the inherent subjectivity and complexity. Cognitive mapping and DEcision MAking Trial and Evaluation Laboratory (DEMATEL) are combined in a neutrosophic environment to incorporate uncertainty and make the model more realistic and complete, overcoming some limitations of previous studies on urban expansion. The collaboration of decision-makers with professional experience in the area was essential for creating this model. An external entity validated the results, showing the model's potential for real-life applications.

Keywords: Cognitive Mapping; Decision-making Support; DEMATEL; Neutrosophic Logic; Real Estate; Urban Expansion.

JEL Codes: C60; M10; O18; O21.

EXECUTIVE SUMMARY

Real estate is a system of relationships between a seller and a buyer that intends to produce new real estate units or commercialise existing ones. The existing types of real estate units can be rented or sold according to people's needs, influenced by economic, geographic, juridical or even social factors and affect property prices or likeability. The balance between these elements create a real estate ecosystem and its equilibrium is essential to the good functioning of this ecosystem. Real estate is a product of the expansion of urban areas, and the present dissertation intends to analyse how this expansion affects real estate. The agglomeration of people in urbanised areas emerged due to technological developments leading to the need for fewer workers in the primary sector and their consequent shift to the secondary and third sectors. Population increase has further contributed to this process and, nowadays, more than half of the world's population lives in urban areas. This expansion affects both the population and the environment. People who live in urban areas have better access to higher employment rates, better infrastructures and higher incomes, leading people to prefer urban centres or areas closer to them. Moreover, urban expansion is often an uncontrolled process with various environmental consequences that include land and agriculture degradation, urban heat islands, air and water pollution, climate change, an increase in the consumption of food and energy and loss of biodiversity, which also have harmful consequences in the physical and mental health of the citizens living in those areas. The complexity and subjectivity of the effects of urban expansion in real estate ecosystems created the need to find a model that will help structure and understand the topic without looking for optimal solutions. Creating a multicriteria analysis model that helps in the decision-making process is the main objective of this dissertation. The analysis of previous studies allowed us to understand the main contributions to the topic and the main limitations found in those studies. It was possible to conclude that there are not many studies that can relate urban-expansion effects and real estate ecosystems, and the ones closer to the problem use mathematical models that make it difficult to obtain relevant data or find any relationship between variables. The model created intends to overcome these limitations using two methodologies to identify qualitative determinants and understand their cause-and-effect relationship, both used in a neutrosophic environment to consider the uncertainty present in any decision made, thus making the model more transparent. To achieve the dissertation's primary goal, a panel of specialists in the field of study identified the main effects/impacts of urban expansion on real estate ecosystems. Through cognitive mapping, which originated from the panel members' opinions and knowledge, it was possible to determine the main areas of concern (*i.e.*, *Tourism*, *Mobility*, *Society*, *Sustainability* and *Economy*), and the consequent factors that link them. The application of the DEcision MAking Trial and Evaluation Laboratory (DEMATEL) technique allowed for the study of the cause-and-effect relationship between the clusters mentioned above (*i.e.*, main areas of concern) and the criteria of each cluster. It was possible to conclude that society is the most relevant cluster. It was also possible to analyse other clusters and their determinants. Neutrosophic logic was used in the study by asking the panel members their beliefs regarding the truthiness, indeterminacy, and falsity of their judgements, thus bringing transparency and more realistic values to the model-building process. A crispification formula permitted the incorporation of the values obtained into one single value. The last part presents the recommendations regarding the results. In a consolidation session, Lisbon City Hall personnel provided their recommendations and opinions, validating the model and debating its practical applicability. It was concluded that this model combines different methodologies (*i.e.*, cognitive mapping, DEMATEL and neutrosophic logic), and is a valuable tool for studying urban expansion in real estate ecosystems.

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MAIN ABBREVIATIONS USED

DEMATEL − DEcision MAking Trial and Evaluation Laboratory
GDP – Gross Domestic Product
IRM – Influential Relations Map
JOURNEY − JOint Understanding, Reflection, and NEgotiation of strategY
MCDA – Multiple Criteria Decision Analysis
NCM – Neutrosophic Cognitive Map
PSM – Problem Structuring Method
OR – Operational Research
SC – Subcriterion/a
SCA – Strategic Choice Approach
SODA – Strategic Options Development and Analysis
SSM – Soft Systems Methodology

CHAPTER 1

INTRODUCTION

1.1. Initial Background

Urbanisation emerged due to technological development and population increase (Tisdale, 1942), leading to population flows from the countryside to cities, consequent agglomeration in cities and expansion of urban areas. This expansion can positively affect populations by providing infrastructures, more employment and higher salaries. However, there are also many environmental disadvantages associated with urban expansion, such as pollution, damage to the ecosystem and higher consumption of natural resources (Firozjaei, Sedighi, Argany, Jelokhani-Niaraki, & Arsanjani, 2019). Real estate is a product of urbanisation and its expansion, and it divides into three different categories: residential, industrial and commercial (Fonseca, Ferreira, Fang, & Jalali, 2018). Real estate is a system that interconnects the seller and the buyer that trade new real estate units and explore new ones (Rybak & Shapoval, 2011). The commerce of real estate units can be done by renting properties or buying them. The real estate ecosystem is the symbiosis between different real estate types and how they interconnect.

There is a lack of connection between both topics in several previous studies regarding urban expansion and real estate. The problem under analysis links the effects of urban expansion in real estate ecosystems, making it a complex case that is difficult to analyse and resolve. The existing research recognises many limitations that can compromise the study, including a lack of data describing population features and the dependency on mathematical models. This dissertation intends to overcome these limitations and create a multi-criteria model that will support decision-making processes regarding urban expansion and its effects on real estate. Identifying the most relevant factors and studying their cause-and-effect relationship makes is possible to structure the decision problem at hand without concern for optimal solutions and overcome some limitations identified in previous studies.

1.2. Research Objectives

Analysing the effects of urban expansion in real estate ecosystems is a complex and subjective topic, as demonstrated by previous studies and their respective limitations. Thus, there is a need to include new approaches to understand the problem. In this dissertation, ***two different methodologies are used to develop a multi-criteria model that analyses the effects of urban expansion, namely cognitive mapping and the DEcision MAking Trial and Evaluation Laboratory (DEMATEL) technique, both combined in a neutrosophic context***. This model is assembled with the decision-makers' experience to obtain the data needed, adopting a constructive logic that allows for a better understanding of urban-expansion effects.

After forming an expert panel, two online group sessions will take place, allowing for discussion and a better understanding of the topic. These sessions will also lead to creating a group cognitive map and the use of the DEMATEL technique to identify the cause-and-effect relationship between factors. The neutrosophic logic will incorporate uncertainty and be essential for value crispification and aggregation. After obtaining the results, these will be presented to an external entity to comment on the model's practical applicability.

1.3. Epistemological Stance and Methodological Aspects

The combined use of cognitive mapping, DEMATEL and neutrosophic logic attempts to model the subjectivity present in real estate ecosystems and understand how it is affected by urban expansion and the complexity associated with the topic. This methodological combination is based on a constructive epistemological approach (Belton & Stewart, 2010).

The methodological process adopted in this study is divided into two phases. First, the structuring phase uses cognitive mapping to identify the decision criteria and group them in clusters defined by experts with professional knowledge of urbanisation and real estate. Second, the DEMATEL technique analyses the cause-and-effect relationship between the factors integrated into the model. The neutrosophic logic includes uncertainty associated with decision-making instead of only considering the truthiness or falsity of a statement. There will be values attributed to each level of truthiness, indeterminacy and falsity, creating a realistic model.

Group sessions will be performed online due to the pandemic situation. Still, it will be possible to promote collective discussion and share the panel members' opinions, points of view and, most crucially, specialised knowledge on the topic. With the help of the expert panel, the methodologies proposed will provide decision-makers with a reliable tool to analyse urban-expansion effects in real estate ecosystems.

1.4. Structure

This dissertation is divided into five chapters that include the present introduction and the conclusions of this study. It also includes the list of references used as the basis for the study and appendices with the necessary calculations to support the results.

The present chapter (*i.e.*, *Chapter 1*) shows the primary purpose of the dissertation. It presents the background on urban-expansion effects in real estate ecosystems and the methodologies used to structure and analyse the topic. *Chapter 2* presents the study's literature review and enables us to understand better the real estate ecosystem and how it relates to urbanisation and the effects of urban expansion. After investigating the models used by other authors and the main contributions and limitations of their studies, it was defined which methodological approach to use. *Chapter 3* deepens the literature on the methodologies. It addresses: (1) the structuring phase of complex decision problems, including explanations of the *JOint Understanding, Reflection, and NEgotiation of strategY* (JOURNEY making) approach and cognitive mapping in a neutrosophic environment; (2) the evaluation phase with a neutrosophic-environment DEMATEL, including the aggregation of values to better evaluate urban expansion. The advantages and disadvantages of these methodologies are also analysed. *Chapter 4* regards the empirical development and result analysis. It presents the study's practical component, showing the steps to get the results. Two group sessions were carried out to obtain the information needed. The development of a group cognitive map and crispification of neutrosophic values for a DEMATEL application allowed us to analyse decision criteria. The results were later presented and validated by an external organisation that provided us with some recommendations. Lastly, *Chapter 5* presents the dissertation's conclusions, principal results obtained, limitations found, and the overall contribution to the analysis of urban expansion and its impact on real estate ecosystems. This last chapter also provides a roadmap for future research.

1.5. Expected Results

This dissertation presents a multi-criteria analysis model that helps structure the analysis of urban expansion and its impact on real estate ecosystems. By combining constructivist techniques, the model is expected to provide increased simplicity and transparency in the process of analysing and understanding how urban expansion impacts real estate ecosystems.

The model allows for qualitative and quantitative analyses of the problem. It includes the uncertainty associated with the decision-making process and permits the identification of cause-and-effect relationships between determinants. Thus, it is expected that our framework can help overcome the limitations of previous studies. To support its dissemination among the practitioner community, the model was presented to a governmental organisation for consolidation. Publishing the results in an international journal is another expected result.

CHAPTER 2

LITERATURE REVIEW

In this chapter, we intend to explore the baseline concepts for the study of urban expansion and, with an interdisciplinary outlook, ascertain its impact on real estate ecosystems. We will achieve this by performing an in-depth analysis of the concepts of *real estate*, *urbanisation*, and *urban expansion*, followed by the most relevant perceptions on why an urban expansion should be studied and what the expected observable effects are. We will also review previous studies with the help of various methodologies and establish their different limitations and contributions to the overall objective of this dissertation, identifying the research gap presented along with the need to use a different methodology. The results of this study will enable the understanding of urban-expansion effects in real estate ecosystems.

2.1. Real Estate Ecosystem and Urban Expansion: Baselines Ideas and Trends

The real estate market is characterised as *"the trade of real estate"*, and it differs from all others since *"its 'product' is not portable"* (Case, Goetzmann, & Rouwenhorst, 2000, p. 2), making it unique. The trade of real estate properties is not limited to individuals who wish to acquire shelter but is also an activity where other organisations such as corporate firms or governmental organisations participate. Real estate plays an essential role in a country's economy and impacts individuals' wealth, thus influencing other economic sectors. *"A reduction in real estate sales may eventually lead to a decline in real estate prices"* (Maier & Herath, 2009, p. 2), that includes the value of people's houses, which is usually their most expensive asset, whether they are trying to sell them or not. This decline can also lead to a decline in other sectors and, consequently, unemployment can increase. *"A number of academics and housing market commentators claim that housing markets are characterised by excess speculation during real estate market upswings"* (Clayton, 1998, p. 41). Since the market's volatility can affect both individuals and countries, the reasons for market change are often analysed.

"Real estate" can be defined as a system of relations between seller and buyer connected both with the production of new real estate units and with trade and exploitation of available ones, thus acting based on a pricing mechanism that considers geographic, economic, judicial, and social features of real estate units (Rybak & Shapoval, 2011). According to Fonseca *et al*., (2018), there are three main types of real estate: (1) commercial; (2) industrial; and (3) residential. Real estate includes several properties within its primary forms, such as factories, warehouses, mines, farms, retail stores, houses, undeveloped land, or even town homes. There are also two main options in the real estate market (*i.e.*, sale or rent). The decision to buy or rent a real estate property depends on many factors. These are not necessarily financial but weigh on a household's decisions and lifestyle. Nevertheless, real estate is difficult to analyse since, in *"economic terms, it can be seen as the market where the supply of and demand for real estate meet and where real estate is traded"* (Maier & Herath, 2009, p. 7). The real estate market varies widely in the two dimensions of space and time and is also divided into the submarkets of sale or rent, so the value of a property can vary over the years, and the value of distinct properties can differ.

The real estate ecosystem is the symbiosis between the diverse types of real estate and how these interconnect with each other. According to Zhang, Lu, Wing-Yan Tam and Feng (2018, p. 428), *"there are multiple industrial ecosystems within a city or a region, which differ from one another in influencing the overall urban ecosystem"*. The same applies to the real estate industry since it connects to most industries. Once there is a disruption in real estate, other industries can also be disrupted and, consequently, affect other real estate properties, positively or negatively. Thus, it is essential to guarantee that all work together to ensure the survival and better function of the industry.

"Construction is crucial for the total urban ecosystem, as it is responsible for materialising the urban" (Zhang *et al*., 2018, p. 428). Thus, real estate is crucial for urbanisation since it stands for the output of urbanisation. *"The production of urban space is highly tied to the rationality and stage of development of the means of production and reproduction of life"* (Ramos, 2019, p. 1), which means that real estate and urbanisation are strongly interconnected since the real estate industry can be a product of urbanisation.

"Urbanisation is a process of population concentration. It proceeds in two ways: the multiplication of the points of concentration and the increase in the size of individual concentrations" (Tisdale, 1942, p. 311). The concept of urbanisation is challenging to define since it varies between different regions and over time. According to Davis and Henderson (2003), urbanisation translates the shift from agricultural activity into urban-industrial activity. Urbanisation or urban agglomeration can also be defined as a complex process of transforming rural or natural landscapes into urban, industrialised areas (Pinto *et al.*, 2021). According to

Champion (2001), urbanisation can be seen in the physical sense, as the increase of land area used for urban areas. It is also a social process because people traditionally embrace behaviours and lifestyles associated with city and town. The urbanisation process leads to an increase in the concentration of population into towns, large cities, and the surrounding ring.

The origin of urban agglomeration (or urbanisation) is not known. However, according to Hauser and Schnore (1975), the necessity of urban agglomerations can arise due to four major factors, namely: (1) size of the global population; (2) control of the natural environment; (3) technological development; and (4) progress of the social organisation. Davis and Henderson (2003) suggest that the driver of urbanisation is the transfer of the population from the primary sector to the secondary or tertiary sectors, characterised by the emergence of industries and services. The advances of technology in agriculture, releasing labour from agriculture to work in services and manufacturing, lead to urbanisation, as firms and workers cluster in cities (Davis and Henderson, 2003). Although the theories of what is necessary for urbanisation to emerge diverge, Tisdale (1942, p. 315) notes that *"two conditions appear to be necessary for urbanisation. One is people and the other is technology. Population increase and surplus feed the process; technology gives it form and focus. All three of them, population increase, technology, and urbanisation, work along together"*.

The continuous economic progress, political and social evolution, and technological improvement, lead to urban developments. The dissemination of urbanisation has increased in the last century. In 1950, less than one-third of the world's population lived in urban areas. This number is currently close to 56% worldwide and is forecasted to increase to more than 68% in 2050 (United Nations, 2018). All around the globe, the percentage of the population that lives in urban areas differs from continent to continent. The continents with a higher population percentage residing in urban areas are the American continent (North and South America) and Europe, with more than three-quarters of their population living in urban areas. However, the continents with the most significant growth in this percentage are Asia and Africa (United Nations, 2018). It is possible to understand that urban areas are expanding in the 70 years analysed and will expand even further until 2050. The necessity to expand urban areas is evident in every continent. Thus, the study of urban expansion seems to be extremely important.

A method to measure urban agglomeration is necessary to understand urban expansion better. The urbanisation measurement method should be well defined since the most common past method used was calculating the portion of a national population that lives in "urban places". However, nowadays, this measure has no value to the study of urban change (Champion, 2001). According to Champion (2001), we should consider the measure of urbanisation based on the distribution of the population between different sizes of urban places. Following this, urban expansion is a phenomenon that occurs when population increases and, thus, the need for settlement also rises and increases spatial expansion, making urban expansion happen in two dimensions (*i.e.*, a demographic and a spatial dimension). Given the increase of the world population and the consequent expansion of urban areas, we will next analyse urban-expansion effects and understand why they should be analysed.

2.2. Urban-Expansion Effects: Reasons for Analysis

Throughout the world's history, the advance in urban expansion has been a process with many advances and setbacks. However, it appears to be a rapid process in today's world. Nowadays, the percentage of residents in urban areas is increasing. This boost is fundamental and of utmost importance since the expansion of urban areas increases the *"GDP per capita and a decrease in agriculture's share in the economy"* (Davis & Henderson, 2003, p. 99).

Several factors can influence a given region's urbanisation and expansion, including government restrictions and the degree of "democratisation" in the region. Some regions around the globe set restrictions on their citizens' freedom of movement, which influences the country's level of urbanisation and urban expansion. The policies mentioned can have an important role in the country's urban expansion since these can directly influence the movement of the population from rural areas to urbanised regions. For example, *"as the largest emerging country in the world, China is experiencing rapid urbanisation since the implementation of reforms and the 'opening up' policy"* (Cui *et al.*, 2019, p. 1), and the effects of urban expansion in China are widely noticed and studied.

"The concentrations of population and socioeconomic activities in urban areas have led to fast urban expansion all around the world in recent decades" (Yang, Li, & Lu, 2019, p. 1). The increase of the urban population predicted by the United Nations (2018) in 2050 shows 6.7 billion people living in an urban centre compared to the 4.2 billion presently occupying the same urban centre, showing the expected degree of expansion that the urban centre can still face. According to Yang *et al*. (2019, p. 1), *"urban expansion is rather an uncontrolled process leading to numerous environmental problems including shaping slums in the fringe of cities"*, and it can have some benefits but at times uncontrollable consequences. The effects studied by different authors are very similar. Cui *et al*. (2019, p. 1), for example, mention that *"urban expansion directly affects the croplands surrounding cities and indirectly impacts farmers'*

welfare, food systems, and the natural environment", and there are many other studies that support and analyse this phenomenon such as Getu and Bhat (2021) and Jiang, Zhang, Ren, Wei, Xu and Liu (2021).

Urban expansion can be associated with various benefits for the population, such as better infrastructures, higher employment rates and higher income. Jansen (2020) analyses the types of preferred residential environments and concludes that the population prefers smaller municipalities and city edge urban centres since they offer the benefits of living in urban areas. Adding to these benefits, we can mention the increase in mobility and self-employment opportunities (Jansen, 2020). It is worth noting, however, that according to Firozjaei *et al*. (2019, p. 1), *"the urban expansion phenomenon turns into urban sprawl, which refers to an unplanned urban development that moves beyond urban expansion boundaries"*, and this phenomenon has negative consequences for the population, the environment, and the natural resources. Unmeasured urban expansion not only leads to the loss of biodiversity, urban heat islands (Myronidis & Ioannou, 2019), air and water pollution, climate change, an increase in the consumption of food and energy, land and agricultural degradation, but also to losses in the physical and mental health of the citizens living in urban areas (Firozjaei *et al.*, 2019), as well as an increase in CO_2 emissions (Yang *et al.*, 2019).

Studying the expansion of urban areas enables us to understand its powerful effects on populations and their environment. These effects can be beneficial but can also have negative consequences. The latter mainly occurs when the expansion is unplanned and does not account for different concerns. Over time, urbanisation and urban expansion improve, increasing the population's opportunities for higher salaries and better working conditions. This process will simultaneously influence populations' mental and physical health, raising added concerns about environmental issues and the increased usage of natural resources. Next, we will analyse previous studies that have contributed to the topic, referencing the respective research methods and their contributions and limitations.

2.3. Previous Studies: Contributions and Limitations

The analysis of urban expansion has several variables to consider. However, the variables highlighted as most relevant diverge from author to author. The increased population living in urban areas has led to an increase in the studies regarding different effects of urban expansions, and these studies stem from different regions of the world and, thus, observe several different types of urbanisations. The exponential increase of urban areas has also led to several studies on the planning for sustainable growth, the effects on the environment and the population. *Table 2.1* summarizes different studies on the topic, including their contributions and limitations.

Table 2.1. Methodologies for Analysis of Urban Expansion and Real Estate Effects: Contributions and Limitations

Author	Method	Contributions	Authors' Recognized Limitations
Cui *et al*. (2019)	Markovian chain model	▪ The model helps the study of three main points: (1) variations in urban expansion and cropland areas; (2) contribution of croplands to urban expansion areas; and (3) predicted impacts of urban expansion on croplands.	▪ The model used is a mathematical problem and does not consider the impact of other factors in the study.
Ramos (2019)	Statistical methods	▪ The model allows for a better understanding of contemporary urbanization and its socio-environmental. ▪ The methodology combines industry ecology, urban political ecology, and urban political economy analytical tools. ▪ Helps urban socio-environmental policies, providing monitoring and evaluation tools with a more successful, multi-scale, multi-dimension, and inclusive urban transformation.	▪ The implementation of the methodology created requires data that is difficult to obtain due to delays in responses. ▪ The quality and quantity of the data used differed across sources and can harm the conclusions.
Jansen (2020)	Statistical methods	▪ The incorporated methods enable the forecasting of preferences related to the characteristics of the environment and motivations regarding the choice of preferred urban areas to inhabit.	▪ As a statistical method, the sample used does not represent the entire universe of residents. ▪ Separation of residents according to their preferences (and not according to objective measures of urbanization) also limited the study.
Varna *et al.* (2020)	Case study method	▪ The methodology used evaluates and analysis the development in networks and urban growth in small cities.	▪ The research used data collected throughout seventeen years, and, thus, it involved significant planning applications.
Maturana *et al.* (2021)	Simulation model for the city of Temuco	▪ The study developed allows the analysis of 2 points: (1) the trends in land use and cover between 1985 and 2017; and (2) the changes in land use and cover for the city of Temuco.	▪ There was a lack of transparency and information available for the research, compromising the final result.
Prada-Trigo *et al*. (2021)	Spatial statistics and case study method	▪ The study shows how the real estate sector has prevailed over the indigenous way of life.	▪ There were difficulties in building a close relationship with the community leaders.

According to *Table 2.1*, it is possible to observe the urban expansion study dynamics during several decades, but there is a lack of correlating studies that indicate the convergence of data. Most of the analysed studies evaluate, for example, the effects of urban expansion in the cropland, the land used for urbanisation, the consequences of urban expansion on land use, the types of properties that people prefer and how people's choices affect urbanisation, and the creation of policies that help control the effects of urban expansion. However, there is no perfect methodological approach and the analysed studies all present limitations. Even though no study comprehensively analyses the effects of urban expansion in real estate ecosystems, it is important to understand what their limitations are, and what methodological approach should be followed to address those limitations.

2.4. General Limitations and Research Gaps

Our literature review collected various contributions made in the last decades about the topic of this dissertation. Many of the studies considered have adopted statistics in their methodology, and one of the most significant limitations is the quality of the available data for analysis. The data may be difficult to obtain, samples can be too small and not representative of the population. The models can also focus heavily on the mathematical side of the problems considered, neglecting some qualitative variables and leading to an absence of analyses on cause-effect relationships between criteria.

There is no perfect methodology, and previous studies mention some limitations grouped into two major categories. The first regards the unclear method of identifying the analysis criteria used in most cases, and the second concerns the lack of analysis regarding cause-and-effect relationships among criteria, which should be carried out dynamically. The identification of these two broad categories of limitations represents a research opportunity for the present research to apply cognitive mapping in order to address the first category of limitations (Eden, 1988), and DEcision MAking Trial and Evaluation Laboratory (DEMATEL) technique to address the second category (Trivedi, 2018). In addition, there is a need to use neutrosophic logic due to the subjective nature of the analysis (Smarandache, 2007). Following these limitations, this dissertation will use cognitive mapping and DEMATEL in a neutrosophic context to overcome some pitfalls that have limited previous studies.

This second chapter presented a brief theoretical explanation of real estate ecosystem, urbanisation and urban expansion. It intended to show the possible effects of urban expansion and why these should be studied. It also presented methods that evaluate urban-expansion effects, including their contributions and limitations. Lastly, some general methodological limitations of previous research are exposed to provide the reader with reasons to use the proposed methodology. Real estate is essential for a country's economy since it affects individuals' wealth and various economic sectors with its unique "no portable" product. This market is categorised by the trade of commercial, industrial or residential real estate properties and is associated with two primary market forms of "sale" or "rent", which influence the real estate property trade. Financial reasons are not the only influencer of this decision. The real estate concept is difficult to analyse since it varies in two dimensions (*i.e.*, space and time), which influence the value of commercialised properties depending on their location and period of time. The real estate ecosystem is the interconnection between the different players in this industry, and the disruption of any variable will lead to a change in this ecosystem that can be of a positive or negative character. The existence of a complex real estate market occurs due to urbanisation. Urbanisation occurs due to a complex process that transforms rural areas into industrialised and urban ones. This change has social implications since people embrace attitudes and behaviours associated with an urban lifestyle. We have found that urban expansion is an event that occurs due to population increase, which leads to a need for settlement and spatial expansion increase. The increase in the world's population leads to an increase in urban areas. This urban expansion can affect population, the environment and natural resources positively (*e.g.*, higher salaries, more employment and better infrastructures), but also negatively (*e.g.*, increased environmental pollution, higher concentration of CO_2 in the atmosphere, increased consumption of natural resources and, consequently, harm to the physical and mental health of the residents). By analysing previous studies and their methodologies, we have identified different limitations and concluded that there is no perfect methodology. However, the combined use of cognitive mapping and DEMATEL in a neutrosophic context can overcome some of these limitations. In the next chapter, we will explore the methodological background of the present research in more detail.

CHAPTER 3

METHODOLOGICAL BACKGROUND

To study the effects of urban expansion in real estate ecosystems, it is necessary to create a model that will help structure and evaluate those effects. This need results from observing previous studies on the same topic and presenting their limitations. This dissertation will use cognitive mapping and DEcision MAking Trial and Evaluation Laboratory (DEMATEL) in a neutrosophic context to overcome previous studies' constraints and accurately establish the cause-and-effect relationships between variables. This chapter deepens the methodologies' characteristics and application and the advantages their use will bring to the study topic.

3.1. Problem Structuring Methods

Problem structuring methods (PSMs) emerged in the mid-1960s. However, only in the late 1980s these were recognised as a family of methods (Rosenhead, 2006). The complexity of real-life decision problems and the difficulty of modelling these problems in mathematical terms gave origin to the development of PSMs (Gomes-Júnior & Schramm, 2021). It came as an answer to the shortcomings of traditional, optimisation-based operational research (OR) methods to approach complex decision problems (Belton & Stewart, 2010).

A movement for re-evaluation within the *"OR community in Britain, followed by some American researchers"* (Gomes-Júnior & Schramm, 2021, p. 2), showed that "Hard OR" approaches, characterised by optimisation-based methods, did not follow the change in management needs (Gomes-Júnior & Schramm, 2021). This phenomenon led to the development of a new category of OR methods (*i.e.*, the PSMs), also known as "Soft OR" (Gomes-Júnior & Schramm, 2021). According to (Rosenhead, 1996, p. 119), *"problem structuring methods provide a more radical response to the poor fit of the traditional OR approach for wicked problems"* and *"there is a greater need for decision-making systems that can learn and adapt effectively than there is for optimising systems that cannot"* (Ackoff, 1979, p. 103). Unlike "Hard OR", PSMs are simple and transparent, conceptualising people as active subjects and facilitating process planning while accepting the uncertainty that qualitative analysis can generate (Belton & Stewart, 2010).

PSMs can be defined *"as flexible mechanisms for addressing complex problems"* (Lami, Abastante, Bottero, Masala, & Pensa, 2014, p. 282) through the development of a structured way of representing a situation to produce an original solution (Mingers & Rosenhead, 2004). Franco (2007, p. 760) argues that PSMs are *"a family of methods for decision support that assist a group of stakeholders to gain a better understanding of a problematic situation"*. These problematic situations are characterised by *"the presence of multiple actors often with different perspectives and objectives, conflicting interests and uncertainties"* (Lami *et al.*, 2014, p. 282). These problems are more strategic since they lay the foundations of well-structured problems (Mingers & Rosenhead, 2004).

Different PSMs present different models that offer alternative means of representing the decision problem by permitting the participants to clarify the situation under analysis, potentially agree on the problem or issue, and acknowledge a potential commitment that can partially or fully solve the problem (Mingers & Rosenhead, 2004). To achieve this, a PSM should *"enable alternative perspectives to be considered with each other; be transparent to a range of participants; operate iteratively; allow contingent solutions"* (White, 2006, p. 842). According to Dewey (*in* Hickman & Alexander, 1998, p. 190), *"it is a familiar and significant saying that a problem well put is half solved"*. Thus, there is a need to structure the *"different experiences/perceptions of the problem"* (Shaw, Edwards, & Collier, 2006, p. 942) and later develop a solution. The main difference between PSM and other approaches that involve group workshops, such as focus groups, is *"the modelling process and the emphasis on taking action"* (Shaw *et al.*, 2006, p. 832).

PSMs operate in a context involving a complex decision problem with the characteristics mentioned above. Thus, PSMs are designed for use in a group format, which allows considering various perspectives simultaneously, and the application process should be interactive, with critical communication between the participants and facilitator and among participants (Rosenhead, 2006). PSMs allow for *"closure when participants are satisfied with the progress achieved, rather than requiring commitment to a comprehensive solution of all the interacting strands that make up the problematic situation"* (Rosenhead, 2006, p. 762).

PSMs include Soft Systems Methodology (SSM) (Checkland 1981); Strategic Choice Approach (SCA) (Friend & Hickling 2005); and Strategic Options Development and Analysis (SODA) (Ackermann and Eden, 2001). According to Lami *et al.* (2014, p. 284), *"in all these approaches, visual representation is fundamental to support the process"*. The next topic presents the JOint Understanding, Reflection, and NEgotiation of strategY (JOURNEY Making) approach. JOURNEY Making is a cognitive mapping-based PSM.

3.1.1. JOURNEY Making and Cognitive Mapping

JOURNEY Making was selected as a PSM due to its computer-supported group workshops as a research tool (Paiva *et al.*, 2021). It *"offers a process that aims to help stakeholders to think through complex problems"* (Shaw, 2006, p. 832). To better understand what it stands for, this PSM *"encourages JOint Understanding among the group members through their individual and collective Reflection on important issues, enabling more informed NEgotiation on defining the problem and agreeing on actions to be included in the strategY which emerges"* (Shaw *et al.*, 2006, p. 940).

Research data collection can be conducted through: (1) a course of interventions in a single organisation; or (2) interventions with a diverse collection of organisations (Shaw, 2006). The last will lead to an abundance of data due to the range of people within different organisations (Shaw *et al.*, 2006). The groups usually comprise four to fifteen people who gather for a maximum of three days, aiming to agree on an outcome to address the complex problem, and the facilitator will help to accomplish that using a range of activities (Shaw, 2006). The role of the facilitator is to support this process so that the participants can demonstrate their opinions and explore, as a group, the differences between the points of view, looking for possible similarities and divergences and allowing to learn how the views connect and affect each other (Shaw, 2006). It is also essential that the facilitator encourages the participants to critically evaluate the causes and consequences of the situation to improve the group's knowledge of the situation and select a collection of complementary actions that will be impactful when implemented (Shaw, 2006).

As the baseline tool for JOURNEY Making applications, cognitive mapping is a term that describes *"the task of mapping persons thinking about a problem or issue"* (Eden, 2004, p. 673). Thus, it allows for representing cause-and-effect relationships between variables through a system of nodes and arrows, where the arrows show the causality between variables/criteria (Marques, Ferreira, Zopounidis, & Banaitis, 2020).

According to Eden, (2004, p. 673), a cognitive map is a *"network of nodes and arrows as links* [...] *where the direction of the arrow implies believed causality"* organised as a hierarchy divided into three levels. The first level is at the top and represents the objectives. At the middle, are represented the strategic issues. Lastly, at the bottom, are the potential actions that approach the main problems (Rosário, Ferreira, Çipi, Ilander, & Banaitienė, 2021). The arrows can imply causality *"with a positive sign (+), when the influence between concepts is positive, and a minus sign (–) when a factor influences the higher-order concept in a negative way"* (Ferreira, Jalali, Zavadskas, & Meidutė-Kavaliauskienė, 2017, p. 175).

The policy-makers' system trust and their relationship with the topic in question define the confidence in the map. Therefore, the answer will depend on the policy-makers having faith in the model and *"coming to the view that the software provided a fast way of briefing others about the complexity of the issue"* (Eden & Ackermann, 2004, p. 621). The introduction of neutrosophic logic in cognitive mapping will allow uncertainty to be modelled, as discussed in the next topic.

3.1.2. Principles of Neutrosophic Logics

As previously discussed, cognitive mapping is an important tool that helps structure complex decision problems and analyse causal relationship between variables. Neutrosophic logic will bring the concept of uncertainty. Thus, it will be possible to estimate the level of truthiness in a statement and admit that there is more than true or false in a decision problem (Smarandache, 2007).

The world has much uncertainty and information that cannot be managed by sharp values (Uluçay & Sahin, 2019). The use of fuzzy set theory has been an effective tool to deal with information uncertainty, but it can only be used in a random process. Therefore, there have been several developments in the decision-making theories (Uluçay & Sahin, 2019). However, these theories do not account for *"all types of uncertainties, such as indeterminate and inconsistent information some decision-making problems"* (Uluçay & Sahin, 2019, p. 1). Thus, Smarandache (2007) presented the neutrosophic logic as an extension of fuzzy logic.

According to Schweizer (2020, p. 100), *"neutrosophy began as a branch of philosophy that considered neutrality in addition to the positive and negative"*, complementing the classical logic of true or false by adding a neutral state. Smarandache (2007, p. 91) defines "neutrosophic logic" as *"a logic in which each proposition is estimated to have the percentage of truth in a subset T, the percentage of indeterminacy in a subset I, and the percentage of falsity in a subset F, where T, I, F are defined above"*. In other words, instead of intervals, subsets are *"any sets (discrete, continuous, open or closed or half-open/half-closed interval, intersections or unions of the previous sets, etc.) by the given proposition"* (Smarandache, 2007, p. 91). Thus, statistically, T, I, and F are considered subsets. The value of (T, I, F) can also be designated as functions that are susceptible to known or unknown parameters. The neutrosophic logic makes the distinction between relative and absolute truth. Thus, *T*, *I*, *F* have the unitary non-standard interval of]-0, 1+[. This is the only restriction of the neutrosophic logic and $0 \leq T + I + F \leq 3^{+}$ when the components are independent (Smarandache, 2007).

Cognitive maps rely on experts' opinions to do the representation. However, when questioned, an expert can determine the level of truthiness, indeterminacy and falsity of his/her statements (Uluçay & Sahin, 2019). The neutrosophic logic portray is identical to the human mind (Shadrach & Kandasamy, 2021). Thus, it is possible to construct a neutrosophic cognitive map that captures indeterminacy, closely representing human thinking. In this sense, a neutrosophic cognitive map (NCM) can be defined as *"a directed graph that represents the causal relationships between the features"* (Shadrach & Kandasamy, 2021, p. 3).

In an NCM, it is possible to consider two vertices of a map as indeterminate, meaning that the effect of C*i* on C*j* is indefinite and represents the neutrality between the criteria (Ramalingam, Vasantha Kandasamy, & Broumi, 2019). All nodes are considered features in the graph with a weight associated with every direction edge and the weight that fits in the set {-1, 0, 1, I} (Shadrach & Kandasamy, 2021), where the value gives the relationship between the criteria. The arrows of the map can have a certain weight (w_{ij}), where: (1) $w_{ij} = 0$ shows no effect between the nodes; (2) $w_{ij} = 1$ demonstrates that the effect between the criteria is directly proportional (C*i* increases or decreases in the same proportion as C*j*); and, on the contrary, (3) $w_{ij} = -1$ shows that it is indirectly proportional. $w_{ij} = I$ stands for an undefined relationship between criteria (Ramalingam *et al.*, 2019).

A neutrosophic matrix N(E) based on the NCM is originated, and to each node is assigned an input vector that $A = (a_1, a_2, \ldots, a_n)$, where $a_i \in \{0, 1, I\}$. The matrix will have the values of the neutrosophic evaluations that result from the cause-and-effect relationship between the n variables, with the diagonal always equal to zero since the concepts do not affect themselves. The use of NCM is beneficial since it allows to represent neutral criteria without effect between them. It also gives decision-makers the freedom to determine if the criteria can have an indeterminate effect between them, adding to the previous choices of positive, negative casual or null effect (Smarandache, 2007).

Neutrosophic logic can be incorporated into cognitive maps and support other methodologies. This dissertation will also use the DEMATEL technique. Thus, the use of neutrosophic logic can reflect the indeterminacy of the decision-makers' choices. To use this logic in the DEMATEL technique, it is necessary to convert the values (*T*, *I*, *F*) associated with the neutrosophic logic into a single number (*i.e.*, crisp value) (Abdel-Basset, Manogaran, Gamal, & Smarandache, 2018). To find this value, *r* decision-makers define neutrosophic weights, each expressed by $w_k = (T_k, I_k, F_k)$. Equation (1) makes it possible to obtain the crisp weights (Pramanik, Banerjee, & Giri, 2016).

$$w_k = \frac{1-\sqrt{((1-T_k)^2+(I_k)^2+(F_k)^2)/3}}{\sum_{k=1}^{r}\left\{1-\sqrt{((1-T_k)^2+(I_k)^2+(F_k)^2)/3}\right\}} \quad (1)$$

The combined use of neutrosophic logic and DEMATEL will allow for the presentation of information that is unknown to the experts who are unsure about their preferences, *"depicts the disagreement of decision-makers and experts"*, and considers the truthiness, indeterminacy, and falsity associated with the nature of decision making (Abdel-Basset *et al.*, 2018, p. 263). The next topic will present the contributions of the methodologies previously presented for the analysis of urban-expansion effects.

3.1.3. Potential Contributions for Urban Expansion Analysis

The effects of urban expansion in real estate ecosystems are complex since these involve several variables of different nature. It is subjective topic, given that it can be studied from different perspectives. JOURNEY making and cognitive mapping help structure the topic, whilst neutrosophic logic allows for more proximity to human reality.

PSMs are simple, transparent and contextualise people as active subjects. These characteristics are fundamental to facilitating the planning process of the decision problem in question. The use of PSMs in this dissertation will allow for a transparent approach to the analysis of urban expansion. The objective is to structure the effects of urban expansion as a complex decision problem rather than answer what these effects are.

The use of cognitive mapping to study decision problems enables the organisation and synthesis of the decision-makers' ideas, easing their visualisation. It can also facilitate the reformulation of the group's perspective, making it easier to compare those ideas (Vaz, Ferreira, Pereira, Correia & Banaitis, 2022). The use of cognitive maps assists the understanding of basic integrated assumptions and illustrates the linkage between decision criteria. According to Vaz *et al.* (2022, p. 919), *"visualization can be a powerful tool for managers in the development of strategic plans and all the decisions involved in different phases"*. Thus, cognitive mapping has the potential to make the analysis of urban-expansion effects more structured and organised through its visualisation.

The neutrosophic logic will be included in the map construction, admitting the existence of vagueness, uncertainty, inconsistency or incompleteness in the experts' value judgments. The use of this logic will complement the study since it will bring a closer portrait of human mind. Hence, it recognises the indeterminacy of the decision-makers' opinions, allowing them to recognise that there is a level of truthiness, indeterminacy and falsity in every statement and determine that level.

The previously presented methodologies will facilitate the analysis of urban expansion. The study of urban population phenomena with the assistance of field experts and the use of PSMs incorporating neutrosophic logic will provide structure to the decision problem at hand. DEMATEL will be presented next.

3.2. DEMATEL

DEMATEL is used to address complex decision problems by identifying cause-and-effect relationships between factors (Braga, Ferreira, Ferreira, Correia, Pereira, & Falcão, 2021). Researchers use it to analyse the variables that affect the decision-support system and use decision-maker knowledge to better understand the factors' interdependency through the development of a matrix that evaluates the cause-and-effect relationship among the criteria. For that purpose, a structural model is developed that produces an impact-relation diagram. The DEMATEL process includes finding *"the average matrix, calculate the normalized initial direct-relation matrix, compute the total relation matrix, set a threshold value and obtain the impact-relation map (IRM)"* (Costa, Ferreira, Spahr, R., Sunderman, & Pereira 2021, p. 5).

3.2.1. Background and Processual Steps

DEMATEL was developed by Gabus and Fontela (1972) at the Battelle Memorial Institute to analyse the relationships between criteria and structure complex decision problems (Abdel-Basset *et al.*, 2018). The application of this technique in various areas has increased in recent years due to the widely recognised advantages of solving highly complex decision problems (Braga *et al.*, 2021). The application of the DEMATEL methodology can be organized into six different steps (Sivakumar, Jeyapaul, Vimal, & Ravi, 2018):

Step 1: Calculate the group direct influence matrix *Z* to determine the relationship between *n* factors *F* considering that the study will use *l* experts in the decision group *E* to establish the direct influence existing between the analysed factors. Using a scale from 0 to 4 (where 0 = no influence; 1 low influence; 2 = medium influence; 3 = high influence; and 4 = very-high influence), the decision-makers attribute a value to the degree of influence that factor F_i projects on *Fj*, allowing to generate the individual direct-influence matrix *Z* = [*zij*] *n* × *n*, where all diagonal elements are equal to zero, and the value of *zij* represents the decision of the experts. The matrix for *l* experts can be obtained through *Equation* (2):

$$z_{ij} = \frac{1}{l} \sum_{k=1}^{l} z_{ij}^{k}, i, j = 1, 2, \dots, n \tag{2}$$

Step 2: Compute the normalised direct-influence matrix *X* that results from the normalised direct-influence matrix *Z* using *Equation* (3). The value of *k* is computed in *Equation* (4), representing the normalised constant that corresponds to the maximum effect of the sum of *i* row on other factors on the matrix *Z*. Likewise, column *j* sums the maximum effect on the other factors. Due to the application of the normalised constant in *k*, each element of matrix *X* should have values within the interval [0,1].

$$X = \frac{Z}{k} \tag{3}$$

$$k = \max\left(\max_{1 \le i \le n} \sum_{j=1}^{n} z_{ij}, \max_{1 \le j \le n} \sum_{i=1}^{n} z_{ij}\right) \tag{4}$$

Step 3: Generate the total-influence matrix *T* using the matrix of normalised direct-influence *X*. The total influence matrix *T n* × *n* is the sum of all direct and indirect effects using *Equation* (5). Thus, matrix *T* describes the relationship between each factor.

$$\mathrm{T} = \lim_{k \to \infty} (X^1 + X^2 + \cdots + D^h) = X(\mathrm{I} - X)^{-1} \tag{5}$$

Step 4: Calculate the sum of the rows and columns of total-influence matrix *T* to create vectors *R* and *C*, according to *Equations* (6) and (7), respectively.

$$\mathrm{R} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n \times 1} = [r_i]_{n \times 1} \tag{6}$$

$$C = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} = \left[c_j\right]'_{1\times n} \tag{7}$$

The values of r_i represent the sum of the i^{th} row in matrix T and show the sum of the indirect and direct effect of factor F_i transferred to the other factors. Likewise, the sum of the j^{th} column is equal to c_j and illustrates the sum of the direct and indirect effect that factor F_j is getting from other factors. Given $i = j \in \{1, 2, \ldots n$, the value of (R+C) is called "prominence". It is presented on the horizontal axis, represents the degree of importance that a criterion has on the system, and shows the power of influence that a factor gives or receives. The value of (R–C) is called "relation". It is presented on the vertical axis, and provides the level of influence of a given factor. Therefore, there are two possible situations. If $(r_i - c_j)$ is positive, F_i has a net influence on the other factors, and it can be allocated to the group of causes. If $(r_i - c_j)$ is negative, the F_j is influenced by other factors. Thus, it belongs to the group of effects.

Step 5: Calculate the limit α – also known as threshold value – according to *Equation* (8). This limit allows to identify the system's critical factors and is defined by the average value of all matrix T elements. It allows to remove the less significant elements from the analysis.

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[t_{ij}]}{N} \tag{8}$$

Step 6: Create an IRM by mapping the dataset of (R+C, R–C). As previously mentioned, (R+C) is represented in the horizontal axis and (R–C) is shown in the vertical one. Therefore, the diagram representing the cause-and-effect relationships is divided into four quadrants where factors/criteria are allocated (see *Figure 3.1*).

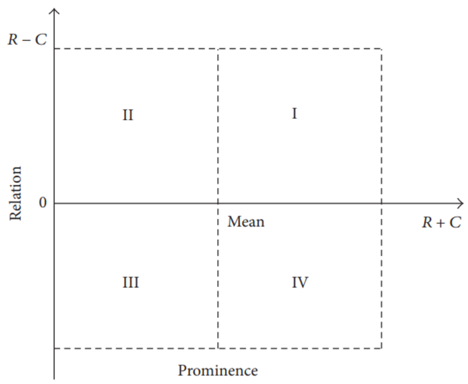

Figure 3.1. Four-Quadrant IRM

Source: Si, You, Liu and Zhang (2018).

In *Figure 3.1*, QI represents the core factors (*i.e.*, cause factors of perceived values). QII holds the driving factors (*i.e.*, cause factors of perceived risks). QIII portrays the independent factors (*i.e.*, effects factors of perceived risks). Lastly, QIV presents the impact factors (*i.e.*, effect factors of perceived benefits) (Si *et al.*, 2018).

When compared to other MCDA methods, DEMATEL *"effectively analyses the mutual influences (both direct and indirect effects) among different factors and understands the complicated cause and effect relationships in the decision-making problem"* (Si *et al.*, 2018, p. 12). Thus, it provides a picture of the relationships between factors identified by the decision-makers through IRM to understand the influence that one factor has over the others (Yazdi, Khan, Abbassi, & Rusli, 2020). DEMATEL's advantages and shortcomings are presented in the next topic, which is important to legitimate the technique's use in the present dissertation.

3.2.2. Advantages and Shortcomings

DEMATEL presents several advantages. It analyses the relationships between decision criteria and allows decision-makers to prioritise them based on the type of relationship or level of influence identified (Trivedi, 2018; Tseng & Lin, 2009). According to Trivedi (2018, p. 725), DEMATEL *"is employed as a solution methodology since it is best suited for analysing interrelationships by neglecting sample size limitations"*, and it allows to determine the influence that occurs among the different factors, whether directly or indirectly (Si *et al.*, 2018). The technique is supported by a diagram that helps establish the relationship's impact between factors, offering a visual representation of this relationship (Si *et al.*, 2018).

Even though DEMATEL presents many advantages, no methodology is free from limitations. DEMATEL is not an exception. One significant limitation is the fact that expert opinions can be biased and imprecise. Thus, there is the possibility that decision-makers try to manipulate criteria to obtain desired results (*cf.* Luthra, Govindan, & Mangla, 2017; Bhatia & Srivastava, 2018; Kumar & Dixit, 2018; Dalvi-Esfahani, Niknafs, Kuss, Nilashi, & Afrough, 2019; Chen, Lu, Ming, Zhang, & Zhou 2020). Nevertheless, the advantages of using the DEMATEL methodology seem to surpass its limitations. Some of the reasons why DEMATEL was selected to analyse the effects of urban expansion are presented in the next topic.

3.2.3. Potential Contributions for Urban Expansion Analysis

Urban expansion has increased effects on different real estate dimensions. Thus, it is of extreme importance that its analysis will include several criteria with different levels of interconnection between them. DEMATEL allows contextualising and evaluating the decision criteria associated with the experts' decisions. Urban-expansion effects in real estate ecosystems will be identified and evaluated to promote solutions that can associate benefits of the expansion.

The DEMATEL methodology addresses complex decision problems such as urban-expansion effects, describing the cause-and-effect relationships between criteria that decision-makers define within a specific range. This technique will further create a diagram that reveals the variables' cause or effect behaviours with image support. This technique has several advantages that can potentiate its use in the research for urban expansion analysis. Overall, DEMATEL allows the interdependency within criteria to be determined, providing a visual representation of the relationships between criteria, which can also be prioritised according to their level of influence. The advantages of DEMATEL in this dissertation context will allow for the analysis of urban expansion through a model created by field experts.

This third chapter presents the methodology used to study urban-expansion effects in real estate ecosystems. These effects should be structured and analysed through PSMs, such as JOURNEY Making, cognitive mapping and DEMATEL. PSMs address complex decision problems and assist stakeholders with decision support to better understand the situation. PSMs have specific characteristics such as multiple actors, different perspectives and objectives, conflicting interests and uncertainty. The PSM used in this study is JOURNEY Making, with the intent to gather a group of between four and fifteen people to address the complex problem with the help of a facilitator. The baseline tool of this PSM is cognitive mapping, which allows for the mapping a person's thinking regarding a decision problem. A cognitive map allows cause-and-effect relationship between variables to be visually represented, and causality links are usually accompanied by a plus sign (+) if the relationship is positive or a minus sign (–) if it is negative. This dissertation will use neutrosophic logic to incorporate and represent human thinking. This logic brings the concept of uncertainty, and it estimates the level of truthiness in a statement. Neutrosophic logic will be incorporated into cognitive mapping through the consideration of indeterminacy and into DEMATEL through the calculus of crisp values (*i.e.*, numbers that will include the percentage of truthiness, indeterminacy and falsity into one single value). The DEMATEL methodology also addresses complex problems and identifies the causality among different factors. DEMATEL is a 6-step methodology that intends to create an IRM that will graphically represent the relationship between the factors identified by the decision-makers. It will be necessary to find the average matrix, calculate the normalised initial direct-relation matrix, compute the total relation matrix, set a threshold value and obtain the IRM. There are several advantages and disadvantages in the use of the DEMATEL methodology. The benefits include the visual representation of the cause-and-effect relationship between different factors. However, there are some shortcomings, since the decision-makers' opinions can be biased and imprecise. Even though there are some disadvantages, the benefits seem to surpass them. Thus, DEMATEL will be combined with cognitive mapping and neutrosophic logic and used in this dissertation to study urban-expansion effects in real estate ecosystems.

CHAPTER 4

EMPIRICAL DEVELOPMENT AND RESULT ANALYSIS

After presentation of the methodological background, the procedural steps followed to create a model to analyse the effects of urban expansion in real estate ecosystems are explained in this chapter. Thus, the empirical part of the study is presented based on the creation a group cognitive map and an application of the DEMATEL technique as part of the structuring and evaluation phases of the study. The resulting model was analysed and interpreted for consistency purposes. A final consolidation session validated the results and allowed to discuss the model's practical applicability.

4.1. Group Cognitive Map

The methodologies presented in *Chapter 3* allowed for the creation of a model that analyses the effects of urban expansion in real estate ecosystems. The *"structuring* [phase] *is an essential phase of MCDA"* (Bana e Costa, Stewart, & Vansnick, 1997, p. 34), and structuring procedures were followed to create a transparent model and understand the problem under analysis.

A panel of specialists is usually composed of *"human experts who operate, supervise, or 'know' the system and how it behaves under different circumstances"* (Yaman & Polat, 2009, p. 386). According to Salmeron (2009), an expert panel should include between five to eighteen members. Following this recommendation, our panel was composed of eight specialists in the study topic, namely: (1) an investment consultant specialised in hotel investments; (2) an architect who owns a company; (3) a real estate consultant who has been working in one of the largest real estate companies operating in Portugal over the past 11 years; (4) a civil engineer; (5) a real estate constructor specialised in sustainable construction; (6) another real estate consultant who owns a real estate agency; (7) another architect with several years of experience in sustainable construction; and (8) a sustainable energy production and distribution specialist.

Due to the pandemic situation and the rising number of Covid-19 cases in Portugal in January 2022, the group sessions took place online to guarantee a safe environment for all the participants. The first session started with a short presentation of the panel members and an explanation of what the session consisted of. Brief explanations of the baseline concepts and methodologies were also provided to avoid misunderstanding among the panel members. The meeting was coordinated by a facilitator – *i.e.*, the author of the present dissertation – who promoted group interaction and negotiation. In addition, two technical assistants provided logistical support and were responsible for recording the sessions. The use of the MIRO platform (www.miro.com) allowed the participants to complete the first-session tasks.

The following trigger question was presented to the panel members: *"Based on your experience/professional knowledge, what effects/impacts can urban expansion have on real estate ecosystems?"*. To support the panel members' answers, the "post-its technique" (Ackermann & Eden, 2001) was applied using virtual post-it notes provided by the MIRO platform. The participants were invited to write *"on post-it* [notes] *what they consider to be relevant criteria"* (Azevedo & Ferreira, 2019, p. 687). They were informed that each post-it note could only contain one idea or concept, and that they should add a plus (+) or minus (–) sign according to the type of causal relationship identified between concepts (Faria, Ferreira, Jalali, Bento, & António, 2018). If the criteria positively influences urban expansion, the post-it note should include a plus sign. If, on the contrary, an urban-expansion effect harms real estate ecosystems, a negative sign should be added to the post-it note. The decision-makers presented several criteria that they found related to the trigger question and study topic. According to Eden (2004, p. 674), *"cognitive maps of problem situations are reasonably large– – over 100 nodes on the map"*. In our case, over 150 criteria were identified by the group.

The second phase of the first session started with the analysis of the criteria defined in stage one. The objective was to group *"the criteria most closely related to each other"* (Castanho, Ferreira, Carayannis, & Ferreira, 2019, p. 6). Five clusters – or "areas of concern" – were created regarding urban-expansion effects in real estate ecosystems, which were labelled as follows: (1) *Tourism*; (2) *Mobility*; (3) *Society*; (4) *Sustainability*; and (5) *Economy*.

The final stage of the first group session regarded the hierarchy of criteria in each cluster. The participants organised the criteria in each cluster by levels of importance. The most significant criteria were placed at the top of their respective cluster, while the least important were placed at the bottom. Any intermediate factors were situated somewhere in between these extremes. *Figure 4.1* shows some moments of the first group session.

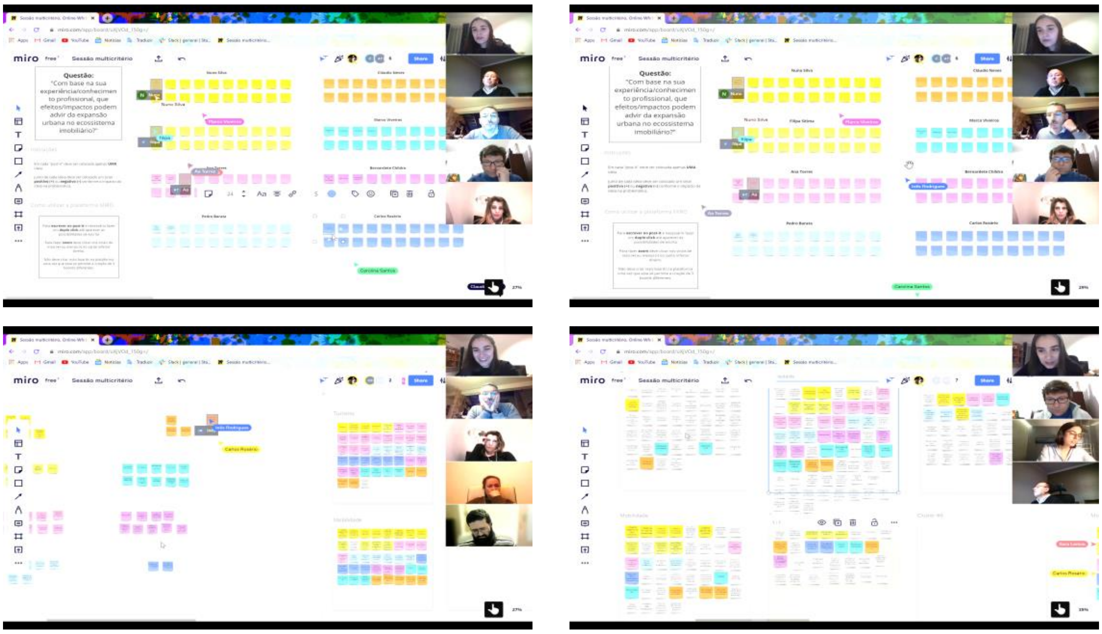

Figure 4.1. First Group Session

The data obtained during the first group session allowed for the creation of a group cognitive map. The construction of the map was support by the *Decision Explorer* software (www.banxia.com). At the beginning of the second group session, which took place online via Zoom platform, the group cognitive map was presented to the panel members for analysis, discussion and validation. This allowed the decision-makers to give their opinion on what was previously done and reformulate what they considered necessary (Brito, Ferreira, Pérez-Gladish, Govindan, & Meidutė-Kavaliauskienė, 2019). *Figure 4.2* presents the map's approved and final version.

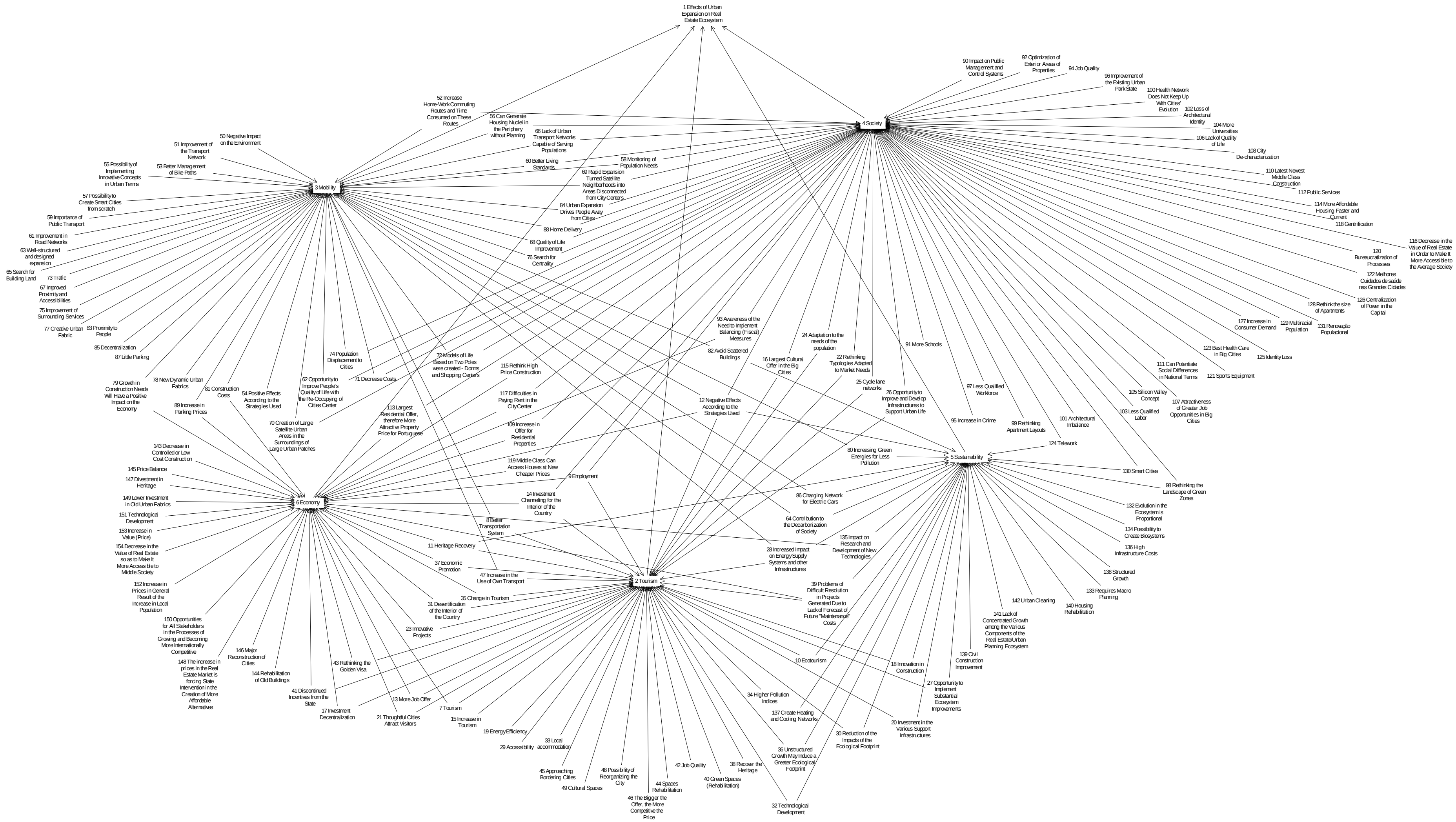

Figure 4.2. Group Cognitive Map

As shown in *Figure 4.2.*, each arrow in the map represents a cause-and-effect relationship between two criteria/clusters. Some criteria belong to more than one cluster, and the criteria that negatively influence urban expansion include a negative sign at the head of the corresponding arrow. After completing the cognitive map, it was possible to apply the DEMATEL technique in a neutrosophic context and proceed to the quantitative component of the study.

4.2. Neutrosophic Logics, Crispification and DEMATEL Application

Neutrosophic DEMATEL incorporates neutrosophic logic into the DEMATEL scale to measure cause-and-effect relationships between variables. *"Indeterminacy is part of daily life, which is why the neutrosophic DEMATEL allows the study of complex cause-effect relationships, which includes indeterminacy and the use of linguistic terms, which is the natural form of communication for human beings"* (Díaz, López, & Castro, 2020, p. 24). Thus, the presentation of the techniques and the advantages they bring to the model-building process were explained to the panel members at the beginning of the second group meeting.

The second meeting accounted for five out of the eight initial participants. This situation is contemplated in the literature and it does not jeopardize the results because the minimum number of participants is respected (*cf.* Azevedo & Ferreira, 2019; Salmeron, 2009). At the beginning of the session, the panel members cast votes to define which criteria were more relevant inside each cluster. This was accomplished using nominal group and multi-voting techniques and was a key step in the process due to the vast number of criteria in each cluster. The application of these techniques benefited from the interaction among the participants during the meeting, allowing for knowledge sharing. *Figure 4.3* shows relevant moments of the second group session, where nominal group and multi-voting techniques were applied.

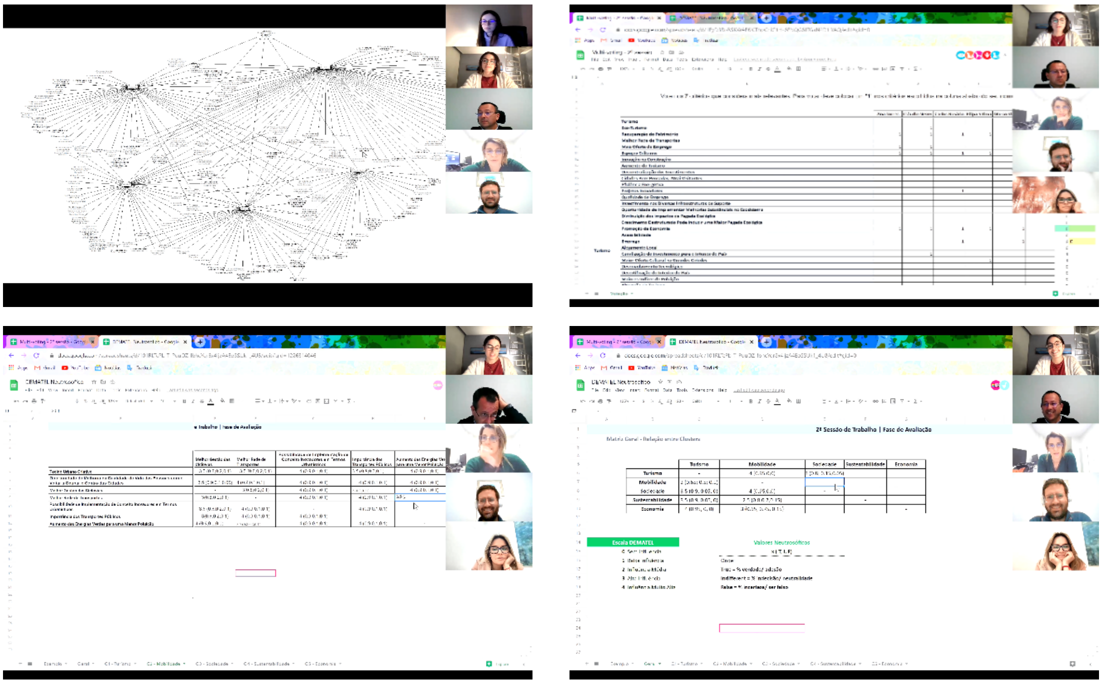

Figure 4.3. Second Group Session

The second group session resulted in six matrices (*i.e.*, one inter-cluster matrix and five intra-cluster matrices), where each cell contains four values (*i.e.*, the DEMATEL value (x) and the degrees of truthiness (T), uncertainty (I) and falsity (F)). To apply the DEMATEL technique, it was necessary to aggregate the neutrosophic values received by the panel members into a single/crisp value according to the levels of T, I and F.

The first matrix presents the inter-relationship between clusters (see *Table 4.1*) and leads to *Table 4.2*. *Table 4.3* presents the values after crispification. With the values of *Table 4.3*, it was possible to complete the final DEMATEL matrix and obtain an IRM. *Table 4.4* shows the DEMATEL matrix with crisp values. After this step, the use of *Equations* (3) and (4) in *Chapter 3* allowed for auxiliary calculi (see *Table 4.5*) and the normalised direct matrix presented in *Table 4.6*. The remaining calculi supporting Matrix T are presented in *Tables 4.7* and *4.8*, respectively.

Table 4.1. Clusters of Criteria Resulting from the First Group Session

Clusters	
C1	Tourism
C2	Mobility
C3	Society
C4	Sustainability
C5	Economy

Table 4.2. Inter-Cluster Matrix Obtained in the Second session with the Neutrosophic Values

	C1	**C2**	**C3**	**C4**	**C5**
C1	--	2(0.65;0.5;0.1)	3.5(0.9,0.05,0)	3.5(0.9,0.05,0)	4(0.95,0,0)
C2	4(0.95,0,0)	--	4(0.95,0,0)	2.5(0.8,0.2,0.15)	3(0.65,0.75,0.15)
C3	3(0.8,0.15,0.05)	3(0.9,0.05,0)	--	3.5(0.9,0.05,0)	4(0.95,0,0)
C4	2.5(0.7,0.2,0.15)	2.5(0.8,0.2,0.15)	3(0.8,0.15,0.05)	--	3(0.8,0.15,0.05)
C5	3(0.7,0.2,0.15)	3(0.7,0.2,0.15)	3(0.7,0.2,0.15)	2.5(0.8,0.15,0.1)	--

Table 4.3. Inter-Cluster Crispification of Neutrosophic Values

	Relationship Under Analysis	**DEMATEL Scale (x)**	**Neutrosophic Values (T, I, F)**			**Neutrosophic Crispification**		
			T	I	F	Crispification Formula Numerator	Neutrosophic Weight *w* Crispified	Final Value at DEMATEL Matrix x(T,I,F)→x
Inter-Cluster Matrix	C1-C2	2.0	0.65	0.50	0.10	0.6429	0.0380	1.29
	C1-C3	3.5	0.90	0.05	0.00	0.9355	0.0553	3.27
	C1-C4	3.5	0.90	0.05	0.00	0.9355	0.0553	3.27
	C1-C5	4.0	0.95	0.00	0.00	0.9711	0.0574	3.88
	C2-C1	4.0	0.95	0.00	0.00	0.9711	0.0574	3.88
	C2-C3	4.0	0.95	0.00	0.00	0.9711	0.0574	3.88
	C2-C4	2.5	0.80	0.20	0.15	0.8152	0.0482	2.04
	C2-C5	3.0	0.65	0.75	0.15	0.5144	0.0304	1.54
	C3-C1	3.0	0.80	0.15	0.05	0.8528	0.0504	2.56
	C3-C2	3.0	0.90	0.05	0.00	0.9355	0.0553	2.81
	C3-C4	3.5	0.90	0.05	0.00	0.9355	0.0553	3.27
	C3-C5	4.0	0.95	0.00	0.00	0.9711	0.0574	3.88
	C4-C1	2.5	0.70	0.20	0.15	0.7745	0.0458	1.94
	C4-C2	2.5	0.80	0.20	0.15	0.8152	0.0482	2.04
	C4-C3	3.0	0.80	0.15	0.05	0.8528	0.0504	2.56
	C4-C5	3.0	0.80	0.15	0.05	0.8528	0.0504	2.56
	C5-C1	3.0	0.70	0.20	0.15	0.7745	0.0458	2.32
	C5-C2	3.0	0.70	0.20	0.15	0.7745	0.0458	2.32
	C5-C3	3.0	0.70	0.20	0.15	0.7745	0.0458	2.32
	C5-C4	2.5	0.80	0.15	0.10	0.8445	0.0499	2.11
If Σ=1, the conditions of the formula are respected.					Crispification Formula Denominator	**16.9151**	**1.0000**	

Table 4.4. Inter-Cluster Group Direct Influence Matrix

	C1	C2	C3	C4	C5	**SUM**
C1	0.0	1.3	3.3	3.3	3.9	11.7
C2	3.9	0.0	3.9	2.0	1.5	11.3
C3	2.6	2.8	0.0	3.3	3.9	12.5
C4	1.9	2.0	2.6	0.0	2.6	9.1
C5	2.3	2.3	2.3	2.1	0.0	9.1
SUM	10.7	8.5	12.0	10.7	11.9	

Table 4.5. Auxiliary Calculations

Max	12.0	12.5
1/max	0.083126	0.079872
1/s	**0.079872204**	

Table 4.6. Normalised Direct-Influence Matrix X

	C1	C2	C3	C4	C5
C1	0.0000	0.1030	0.2612	0.2612	0.3099
C2	0.3099	0.0000	0.3099	0.1629	0.1230
C3	0.2045	0.2244	0.0000	0.2612	0.3099
C4	0.1550	0.1629	0.2045	0.0000	0.2045
C5	0.1853	0.1853	0.1853	0.1685	0.0000

Table 4.7. Auxiliary Calculations for Matrix T

Matriz I

	C1	C2	C3	C4	C5
C1	1.0000	0.0000	0.0000	0.0000	0.0000
C2	0.0000	1.0000	0.0000	0.0000	0.0000
C3	0.0000	0.0000	1.0000	0.0000	0.0000
C4	0.0000	0.0000	0.0000	1.0000	0.0000
C5	0.0000	0.0000	0.0000	0.0000	1.0000

I-D

	C1	C2	C3	C4	C5
C1	1.0000	-0.1030	-0.2612	-0.2612	-0.3099
C2	-0.3099	1.0000	-0.3099	-0.1629	-0.1230
C3	-0.2045	-0.2244	1.0000	-0.2612	-0.3099
C4	-0.1550	-0.1629	-0.2045	1.0000	-0.2045
C5	-0.1853	-0.1853	-0.1853	-0.1685	1.0000

(I-D)^-1

	C1	C2	C3	C4	C5
C1	2.0823	1.0195	1.4046	1.3258	1.4771
C2	1.3541	1.9339	1.4707	1.2848	1.3760
C3	1.3261	1.1599	2.2759	1.3899	1.5432
C4	1.0304	0.8970	1.1577	1.9166	1.1803
C5	1.0562	0.9134	1.1497	1.0643	2.0136

Table 4.8. Matrix T

	C1	C2	C3	C4	C5	R
C1	1.0823	1.0195	1.4046	1.3258	1.4771	6.3094
C2	1.3541	0.9339	1.4707	1.2848	1.3760	6.4195
C3	1.3261	1.1599	1.2759	1.3899	1.5432	6.6950
C4	1.0304	0.8970	1.1577	0.9166	1.1803	5.1821
C5	1.0562	0.9134	1.1497	1.0643	1.0136	5.1971
C	5.8491	4.9237	6.4586	5.9813	6.5902	

Table 4.9. Inter-Cluster Interaction

	R	C	R+C	R-C
C1	6.3094	5.8491	12.1585	0.4603
C2	6.4195	4.9237	11.3432	1.4957
C3	6.6950	6.4586	13.1536	0.2363
C4	5.1821	5.9813	11.1634	-0.7992
C5	5.1971	6.5902	11.7873	-1.3931

Table 4.9 presents the values of R and C and the sum of R+C and subtraction of R-C that will serve as IRM axes. The factors are divided into two groups: (1) if (R-C) < 0, the factor will belong to the effects group and will have a low relationship with the other clusters; and (2) if (R-C) > 0, the factor will be part of the causes group and directly influence the remaining clusters. The value of (R+C) will allow knowing the total effect a cluster receives or gives to another and it is illustrated in the horizontal axis of the IRM. The vertical axis will be (R-C), which reveals the degree of influence a given cluster has on the map.

The level of importance of a cluster can be measured by (R+C) because it represents the total impact of that cluster in the model. In this specific case, the cluster with higher importance is *Society* (C3). With the lowest value, *Sustainability* (C4) is the least important cluster. The clusters' order of importance according to the (R+C) value is: C3 > C1 > C5 > C2 > C4. *Figure 4.4* presents the respective IRM for the inter-cluster analysis.

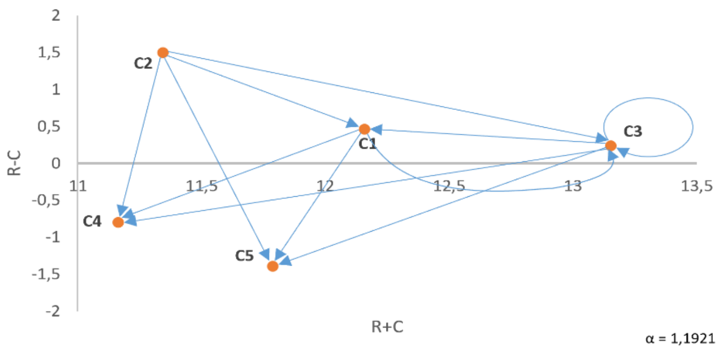

Figure 4.4. Inter-Cluster Influential Relationship Map

According to *Figure 4.4*, it is possible to conclude that C4 and C5 have a negative (R-C) and belong to the effects group. C1, C2 and C3 (*i.e.*, *Tourism*, *Mobility* and *Society*) are part of the causes group with a positive (R-C). Through the analysis of the IRM, it is also possible to divide the clusters into three different groups: (1) C1 and C3 are core factors (QI); (2) C2 is a driving factor (QII); and (3) C4 and C5 are independent factors (QIII).

An individual analysis of each cluster was carried out to perform a better evaluation and have more conclusive results. This analysis used the sub-criteria (SC) that the panel chose during the second group session to complete the DEMATEL matrix. Because the formulas and auxiliary calculi are the same used for the inter-cluster analysis, most of the tables that support the intra-clusters analyses are presented in *Appendix*.

The first cluster selected by the decision-makers is *Tourism* (C1). *Table 4.10* presents the SC chosen by the group as the most relevant for C1 (see also *Appendices A1* to *A6*).

Table 4.10. Selected Criteria for the First Cluster Analysis

Sub-Criteria in C1	
SC11	Heritage recovery
SC13	More job offer
SC23	Innovative projects
SC37	Promotion of the economy
SC39	Problems that are difficult to solve in the projects generated due to the lack of forecast of future costs of “maintenance”
SC44	Space rehabilitation
SC49	Cultural spaces

Considering the information in *Table 4.11*, it is possible to analyse the most relevant SC in C1. The SC with the highest R is SC11 – *heritage recovery*. The SC with the highest C value is SC37 – *promotion of the economy*, which is also the most relevant in this cluster due to its (R+C) value of 7.9565. The least relevant is SC49 – *cultural space*, with the lowest (R+C). Overall, the ranking for C1 is as follows: SC37 > SC11 > SC39 > SC23 > SC13 > SC49 > SC44. *Figure 4.5* presents the respective IRM.

Table 4.11. Cluster 1: Interaction Between Criteria

	R	C	R+C	R-C
SC11	4.4048	3.1777	7.5825	1.2271
SC13	1.7050	3.9398	5.6448	-2.2348
SC23	3.5458	2.9637	6.5095	0.5820
SC37	3.8257	4.1308	7.9565	-0.3051
SC39	3.6269	3.0145	6.6413	0.6124
SC44	3.9829	0.0000	3.9829	3.9829
SC49	3.5160	0.0000	3.5160	3.5160

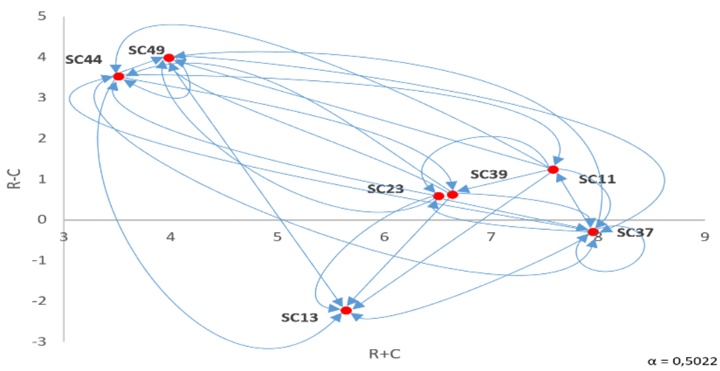

Figure 4.5. Cluster 1 – Influential Relations Map

As can be seen in *Figure 4.5*, SC11, SC23, SC39, SC44 and SC49 present positive (R-C) values and belong to the causes group. SC13 and SC37 are part of the effect group and more influenced by others. The subdivision of *Figure 4.5* in quartiles allow SC11, SC23 and SC39 to be allocated to QI. As driving factors (QII) are SC44 and SC49. As independent factor (QIII) is SC13. Lastly, SC37 is considered as impact factor (QIV).

The second cluster – *Mobility* (C2) – was analyse based on the SC presented in *Table 4.12*. *Appendices B1 to B6* present the intermediary calculi.

Table 4.12. Selected Criteria for the Second Cluster Analysis

Sub-Criteria in C2	
SC51	Improvement of the transport network
SC53	Better management of bike paths
SC55	Possibility of implementing innovative concepts in urban terms
SC59	Monitoring of population needs
SC62	Opportunity to improve people's quality of life with the re-occupying of cities centre
SC77	Creative urban fabric
SC80	Increasing green energies for less pollution

Table 4.13 allows us to evaluate the most relevant SC. Considering the results presented, the SC that has the most significant influence on others is SC55, with R = 10.6641. It also has the highest C, meaning that it receives more influence from the others.

Table 4.13. Cluster 2: Interaction Between Criteria

	R	C	R+C	R-C
SC51	9.6046	9.5077	19.1123	0.0969
SC53	8.9127	9.3303	18.2430	-0.4175
SC55	10.6641	10.3389	21.0030	0.3252
SC59	9.6046	9.7097	19.3143	-0.1051
SC62	9.8947	10.3113	20.2060	-0.4166
SC77	9.9013	9.5733	19.4746	0.3281
SC80	10.0665	9.8775	19.9440	0.1890

As shown in *Figure 4.6*, the most important SC is SC55 – *possibility of implementing innovative concepts in urban terms* – with (R+C) = 21.0030. According to (R+C) axis, the ranking of importance is as follows: SC55 > SC62 > SC80 > SC77 > SC59 > SC51 > SC53. The SC with highest values are those that give and receive more influence. The SC that have positive (R-C) values are part of the causes group, which is divided into: (1) core factors (*i.e.*, SC55 and SC80) in QI; and (2) driving factors (*i.e.*, SC51 and SC77) in QII. The effects group (R-C) < 0 is also divided into: (1) independent factors (*i.e.*, SC53 and SC59) in QIII; and (4) impact factors (*i.e.*, SC62) in QIV.

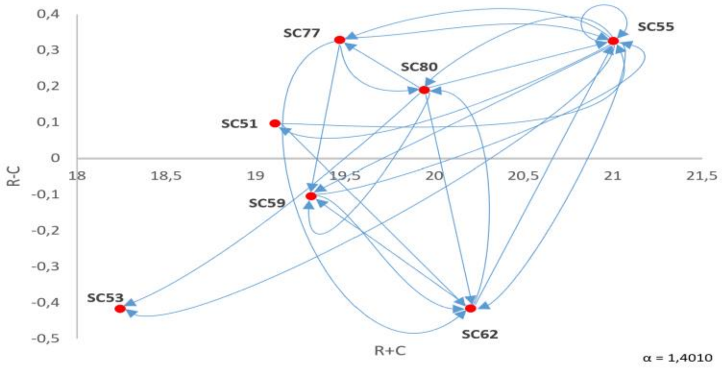

Figure 4.6. Cluster 2 – Influential Relations Map

The SC chosen for C3 – *Society* – are presented in *Table 4.14*. The respective calculi are presented in *Appendices C1* to *C6*.

Table 4.14. Selected Criteria for the Third Cluster Analysis

Sub-Criteria in C3	
SC9	Employment
SC22	Rethinking typologies adapted to market needs
SC68	Quality-of-Life improvement
SC93	Awareness of the need to implement balancing (fiscal) measures
SC112	Public services
SC113	Largest residential offer, therefore more attractive property price for portuguese
SC131	Smart cities

The cause-and-effect relationship of the criteria selected for C3 and presented in *Table 4.15* shows the influence of the different factors.

Table 4.15. Cluster 3: Interaction Between Criteria

	R	C	R+C	R-C
SC9	3.3631	3.2596	6.6227	0.1035
SC22	3.2256	3.0086	6.2343	0.2170
SC68	1.6923	3.5438	5.2361	-1.8515
SC93	2.4074	2.0621	4.4695	0.3453
SC112	1.6650	1.6528	3.3177	0.0122
SC113	2.9096	2.6105	5.5201	0.2991
SC131	3.5438	2.6694	6.2133	0.8744

The SC that most influence others is SC131 (R=3.5438). SC68 – *quality-of-Life improvement* – is the most influenced by others, with the highest value of C. SC9 – *employment* – is the one that gives and receives more influence in total, and thus is the most important one in C3 with the highest (R+C). As shown in *Figure 4.7*, the most important SC are on the right side of the diagram and, when organized by level of importance, the ranking is as follows: SC9 > SC22 > SC131 > SC113 > SC68 > SC93 > SC112. The IRM division into quadrants includes: (1) SC9, SC22, SC113 and SC131as a core factors (Q1); (2) SC93 and SC112 as a driving factors in QII; and (3) SC68 as independent factor in QIII.

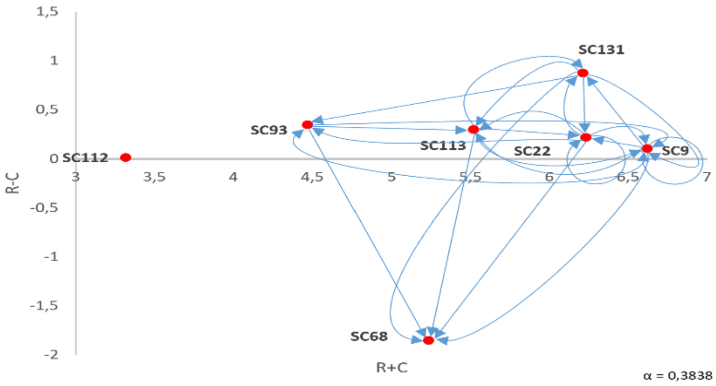

Figure 4.7. Cluster 3 – Influential Relations Map

Table 4.16 presents the SC chosen for C4 – *Sustainability*. The respective calculi are presented in *Appendices D1* to *D6*.

Table 4.16. Selected Criteria for the Fourth Cluster Analysis

Sub-Criteria in C4	
SC18	Innovation in construction
SC30	Reduction of the impacts of the ecological footprint
SC64	Contribution to the decarbonization of society
SC82	Avoid scattered buildings
SC138	Structured growth

Table 4.17. Cluster 4: Interaction Between Criteria

	R	C	R+C	R-C
SC18	2.0717	1.3720	3.4437	0.6997
SC30	0.9317	2.6860	3.6177	-1.7543
SC64	1.6689	2.6860	4.3549	-1.0171
SC82	2.0717	0.7372	2.8089	1.3345
SC138	2.6860	1.9488	4.6348	0.7372

SC138 presents the highest R value (*i.e.*, R=2.6860). On the contrary, SC30 and SC64 are the most influenced ones, with C=2.6860. As can be seen in *Figure 4.8*, SC138 is the most important SC in this cluster. The ranking of importance is as follows: SC138 > SC64> SC30 > SC18 > SC82. From the division in quartiles, resulted that: (1) SC138 is a core factor (QI); (2) SC18 and SC82 are driving factors (QII); (3) SC30 is an independent factor (QIII); and (4) SC64 is an impact factor (Q4).

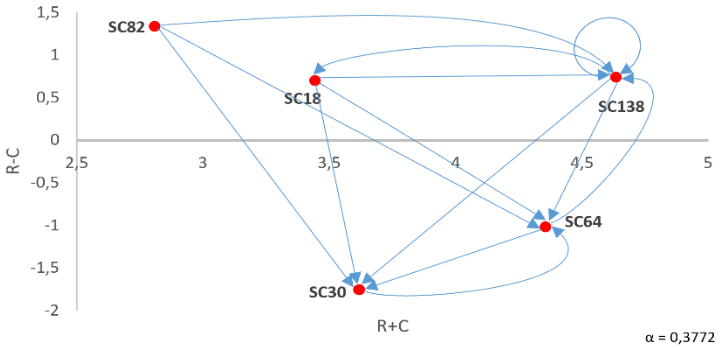

Figure 4.8. Cluster 4 – Influential Relations Map

The last cluster is C5 – *Economy*. *Table 4.18* presents the SC selected for this cluster. The respective calculi are presented in *Appendices E1* to *E6*.

Table 4.18. Selected Criteria for the Fifth Cluster Analysis

Sub-Criteria in C5	
SC13	More job offer
SC17	Investment decentralization
SC37	Economic promotion
SC93	Awareness of the need to implement balancing (fiscal) measures
SC154	Decrease in the value of real estate so as to make it more accessible to middle society

In this cluster, SC37 and SC93 present the highest value for R and C (see *Table 4.19*). The order of importance is: SC37 = SC93 > SC17 = SC13 > SC154. As shown in *Figure 4.9*, there are only two factors in the causes group (*i.e.*, SC13 and SC17). SC37 and SC93 do not belong to either of the groups because their relation is 0 (*i.e.*, R-C=0).

Table 4.19. Cluster 5: Interaction Between Criteria

	R	C	R+C	R-C
SC13	9.3976	7.4847	16.8823	1.9129
SC17	8.7563	8.1436	16.8999	0.6127
SC37	9.3976	9.3976	18.7952	0.0000
SC93	9.3976	9.3976	18.7952	0.0000
SC154	6.0389	8.5645	14.6034	-2.5256

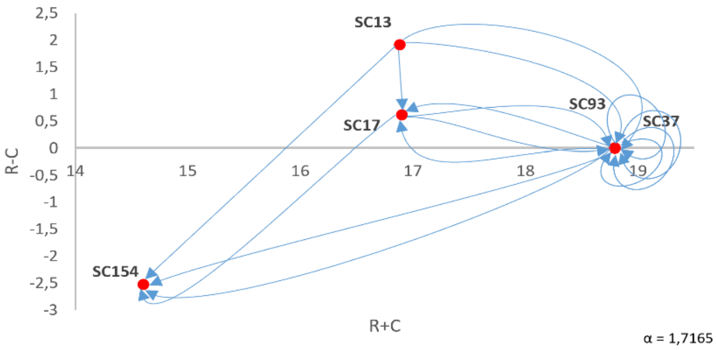

Figure 4.9. Cluster 5 – Influential Relations Map

The end of the evaluation phase led to the need to consolidate the results with an impartial entity. The results of the consolidation session and final recommendations will be presented in the next topic.

4.3. Consolidation of Results, Limitations, and Recommendations

The results previously presented allow us to analyse the effects of urban expansion in real estate ecosystems. The model developed in this study provides a hierarchy of determinants and prioritises where to act and how to improve. In addition, the methodology used to support the decision-making process allowed for the creation of a realistic and transparent model that integrates uncertainty and provides objective measures resulting from the combination of qualitative and quantitative approaches.

To strengthen the results obtained, a consolidation session was organised with two representatives of the Lisbon City Council Centre for Management and Urban Intelligence. These two experts were considered neutral/independent because they did not participate in the previous group sessions. The session started with a brief explanation of the study topic, followed by an explanation of the methodologies used and the results obtained. The session allowed both experts to analyse the results and express their opinion on the advantages and limitations of the proposed model. *Figure 4.10* illustrates this meeting.

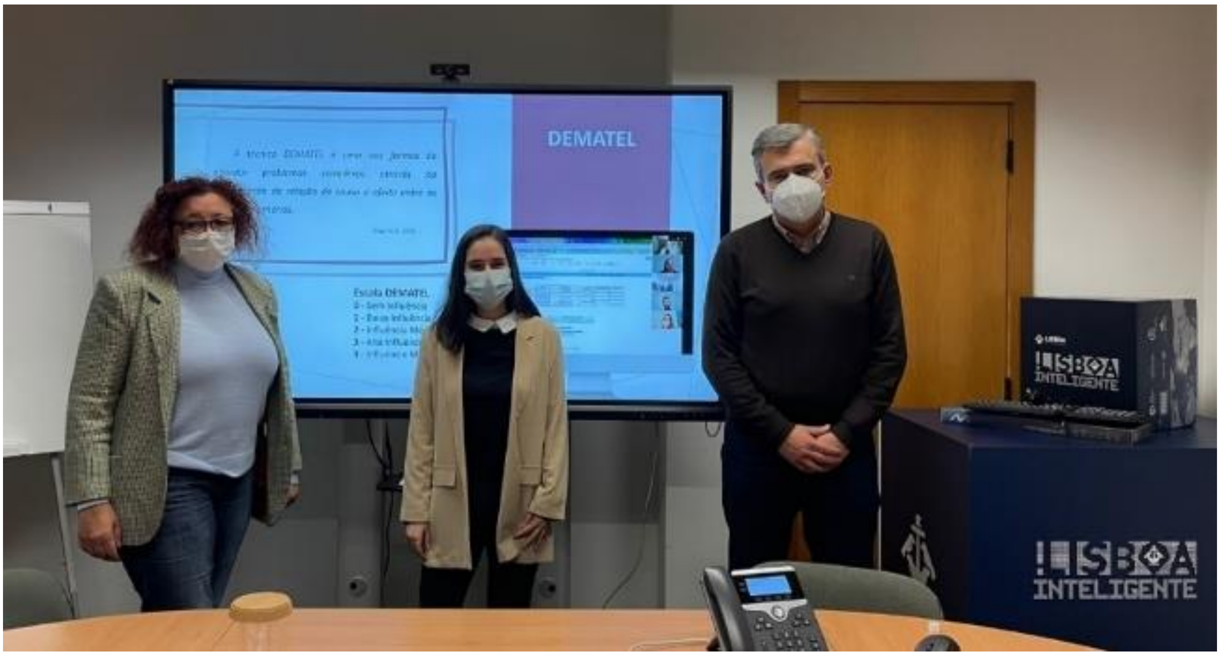

Figure 4.10. Study Consolidation Session

The meeting had an approximate duration of 30 minutes and, after the presentation of the results, the experts expressed their opinions. They were surprised by the amount of information included in the map and stated that it was very detailed. However, they also considered the information too general and not specific to any city. Since each city is unique, the experts expressed that the results could be more valuable if the methodologies used were applied on a casuistic basis. Still, the experts noticed that the map's base rely significantly on the decision-makers' professional experience. Both experts considered the DEMATEL analysis a valuable tool to analyse the clusters' importance, and agreed with the results obtained. However, their opinion regarding the intra-cluster results was different. For each cluster, the experts found the SC chosen very specific and, sometimes, with very similar meanings, leading to less essential results in their opinion. They also mentioned that the developed model could have better applicability if the methodologies used and the panel chosen could capture the reality of a single city. At this point, the interviewer reiterated that this study is process-oriented and constructivist in nature, and both experts agreed with the advantages resulting from this methodological option.

SYNOPSIS OF CHAPTER 4

Chapter 4 presented the empirical component of the present dissertation with the application of the methodologies described in *Chapter 3*. The main goal of using these methodologies is to create a model of analysis and support decision-making processes regarding the effects of urban expansion in real estate ecosystems. A group of eight experts applied the methodologies in two group sessions carried out online using the Zoom and Miro platforms. The first session intended to start the structuring phase and, through brainstorming activities, the experts identified different criteria that impact the study topic. During the first session, those criteria were grouped into five clusters and, later on, were organised hierarchically inside the respective cluster. The first session allowed us to develop a group cognitive map, which was validated by the experts in the second session and reflect the group perception of the problematic under analysis. The second group session intended to do the evaluation phase using the DEMATEL technique and neutrosophic logic. First, nominal group and multi-voting techniques were applied in each cluster to select sub-criteria for the cause-and-effect relationship analysis. The choice of sub-criteria was followed by the definition of neutrosophic values for truthiness, indeterminacy and falsity, allowing DEMATEL matrices to be completed after crispification of values. The process was repeated for each matrix during the intra-cluster analyses. The second session allowed us to obtain the cause-and-effect relationship of the different factors, the importance of each factor, and their level of influence on others. The next step was to interpret the results, which allowed us to understand the urban-expansion determinants that most impact real estate ecosystems. The model's potential for practical applicability led to its presentation at the Lisbon City Council Centre for Management and Urban Intelligence. The experts pointed out some benefits and limitations to the model. The most relevant limitation is its general character, without focusing on a specific reality. However, due to its constructivist and process-oriented nature, the methodologies have associated benefits if applied to specific situations. Overall, the techniques applied were considered valuable and can be used in more cases.

CHAPTER 5

CONCLUSION

5.1. Results and Limitations

The study of urban-expansion effects in real estate ecosystems is very complex due to the number of variables that influence the topic and the subjectivity that comes with it. Studying the topic from multiple perspectives makes it almost impossible the search for a single answer. The problem's complexity urges the need to find a model that can structure, evaluate and generate solutions and recommendations with the knowledge on how and where to act in each area. This dissertation aimed to create a model that supports the decision-making process and analyses urban-expansion effects in real estate ecosystems.

This dissertation adopted a constructive logic and is divided into five chapters. In the first chapter (*i.e., Chapter 1* – Introduction), it is possible to find the study context together with research objectives and methodologies chosen. The second chapter (*i.e., Chapter 2* – Literature Review) introduced a review of the theoretical knowledge already reported in the literature, assessed the limitations found, and analysed the need to use a different methodology. After researching previous studies, a methodological background on PSMs, cognitive mapping, DEMATEL and neutrosophic logic was presented (*i.e., Chapter 3* – Methodological Background). With the results described in *Chapter 4* – Empirical Development and Result Analysis – it was possible to acknowledge the critical determinants to consider in this study context. The last chapter (*i.e., Chapter 5* – Conclusions) presents the main results and limitations of the study and its key contributions to the field.

A model was created using cognitive mapping and neutrosophic DEMATEL to study the cause-and-effect relationship between urban-expansion effects. Combining these methodologies leaded to a holistic, complete model that benefits from expert professional knowledge. Using this combination of methodologies allowed the decision-making process to incorporate subjective and less-quantifiable criteria, since it accounts for the opinion of several experts with different backgrounds. As such, the use of cognitive mapping helps overcome some of the main limitations of previous studies, including the lack of data and the dependency on numerical variables. DEMATEL, in turn, allows for the quantitative evaluation of the cause-and-effect relationships between variables, making it possible to know each factor's level of importance in the model. The neutrosophic logic brings to the model the concept of uncertainty, which eases the decision-making process and simplifies the interpretation topic.

The model-building process was supported by experts who developed a transparent model and validated it after its conclusion. Based on the experts' opinion, the results highlight five main areas of interest (*i.e.*, *Tourism*, *Mobility*, *Society*, *Sustainability* and *Economy*). Within those main areas, it is possible to determine causality relationships between determinants. Therefore, the clusters were organised by order of relevance: (1) *Society* (C3), which has *employment, rethinking technologies adapted to the market needs* and *smart cities* as the most relevant criteria; (2) *Tourism* (C1), which includes *heritage recovery*, *promotion of the economy* and *problems that are difficult to solve in the projects generated due to the lack of forecast of the future cost of "maintenance"* as the most important criteria; (3) *Economy* (C5), which presents two equally important factors (*i.e.*, *economic promotion* and *awareness of the need to implement balancing (fiscal) measures*); (4) *Mobility* (C2), where the most relevant factors are *the possibility of implementing innovative concepts in urban terms*, *the opportunity to improve people's quality of life with the re-occupying of cities centre* and *increasing green energies for less pollution and lastly*; and (5) *Sustainability* (C4), where the dominant factors are *innovation in construction*, *avoiding scattered buildings* and *structured growth*.

All studies present limitations. Ours is no exception. The online group sessions led to a few problems that include connection issues and difficulties accessing the tools used. This was coupled with some fatigue on the participants' part due to the meetings' length. The panel members' answers and opinions influence the results obtained. Therefore, choosing other panel members with different backgrounds could have had different results. Lastly, the presentation of the study to an external entity led to conclude that the study is context-dependent. In this case, the decision-makers brought to the study different realities from within the Portuguese context. Thus, conclusions cannot be generalised. However, this has been acknowledged from the beginning and relates to the present study's constructivist and process-oriented nature. Even though there are limitations to the study, the results are promising and help better understand urban-expansion effects in real estate ecosystems.

5.2. Managerial Implications and Concluding Remarks

The effects of urban expansion in real estate ecosystems is a complex and subjective topic. Other studies were analysed to understand the present dissertation topic, and it was possible to identify their main limitations, which include: (1) difficulties in obtaining relevant data; (2) sample size, which is usually too small and not representative of the entire population; and (3) methodologies used, which are excessively dependent on mathematical models and do not analyse causality relationships between factors.

Given the limitations found in the extant literature, the use of cognitive mapping in our study allowed qualitative variables to be considered during the model-building process, while DEMATEL allowed cause-and-effect relationship between factors to be quantitatively analysed. In addition, the neutrosophic logic incorporated different levels of truthiness, indeterminacy and falsity in the experts' statements. As such, the resulting model has many contributions, which include: (1) consideration of uncertainty; (2) crispification of neutrosophic values that allows for more realistic results; (3) consideration of different opinions from several experts; and (4) methodological innovation.

One of the most significant innovations of the present study is the use of neutrosophic logic. It was recently introduced in the literature and its use to address real estate topics is very scarce, especially when combined with other methodologies such as DEMATEL. The model created presents promising and positive results for the analysis of urban-expansion effects.

5.3. Future Research

The results obtained in the present dissertation highlight the importance of the methodological combination used to analyse urban-expansion effects in real estate ecosystems. Specifically, the incorporation of the decision makers' opinions and experiences allows the analysis system to be robust, transparent and realistic. For this reason, real estate stakeholders can benefit from the combined use of cognitive mapping, DEMATEL and neutrosophic logic because it can improve the strategic planning of their activities. As such, future inquiry and research may explore and highlight the advantages of carrying out similar studies resorting to different MCDA methods, as well as doing comparative studies.

The need to expand the methodological approach used in this dissertation to other contexts is another interesting future course of action. It would also be advisable to improve the model created within the framework of this study or its adaptation for online platforms, thus enabling the decision makers to evaluate, in a quicker, transparent and intuitive way, the effects of urban expansion. Any adjustment in the model will be seen as a step forward to support the analysis of urban-expansion effects in real estate ecosystems.

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APPENDICES

Appendix A – Cluster 1 – Tourism

Table A1. Cluster 1 Matrix Obtained in the Second Session with the Neutrosophic Values

	SC11	SC13	SC23	SC37	SC39	SC44	SC49
SC11	--	3(0.9,0.1,0.1)	2(0.70,0.3,0.15)	3.5(0.9,0.1,0.1)	3(0.8,0.1,0.1)	4(0.9,0.1,0.1)	4(0.9,0.1,0.1)
SC13	1.5(0.7,0.7,0.15)	--	1.5(0.7,0.7,0.15)	3(0.9,0.1,0.1)	0(1,0,0)	1.5(0.7,0.7,0.15)	1.5(0.7,0.7,0.15)
SC23	2.5(0.7,0.1,0.1)	2.5(0.7,0.1,0.1)	--	3(0.8,0.2,0.15)	2.5(0.7,0.1,0.1)	2.5(0.7,0.1,0.1)	3.5(0.8,0.2,0.1)
SC37	3(0.7,0.2,0.15)	4(0.95,0.05,0)	3.5(0.8,0.2,0.1)	--	2(0.75,0.2,0.15)	3(0.7,0.2,0.15)	3(0.7,0.2,0.15)
SC39	3(0.8, 0.2, 0.15)	3(0.8,0.2,0.15)	2(0.75,0.2,0.2)	3(0.8,0.2,0.15)	--	3(0.8,0.2,0.15)	3(0.8, 0.2, 0.15)
SC44	3(0.8, 0.2, 0.15)	3.5(0.9,0.1,0.1)	1.5(0.8,0.2,0.15)	3.5(0.9,0.1,0.1)	3.5(0.9,0.1,0.1)	--	3(0.8, 0.2, 0.15)
SC49	3.5(0.7,0.7,0.15)	1.5(0.7,0.7,0.15)	3.5(0.8,0.2,0.1)	2.5(0.8,0.15,0.1)	2.5(0.8,0.15,0.1)	3.5(0.8,0.2,0.1)	--

Table A2. Cluster 1 Crispification of Neutrosophic Values

	Relationship Under Analysis	**DEMATEL Scale (x)**	**Neutrosophic Values (T, I, F)**			**Neutrosophic Crispification**		
			T	I	F	Crispification Formula Numerator	Neutrosophic Weight w Crispified	Final Value at DEMATEL Matrix x(T,I,F)→x
MATRIX Cluster 1 – Tourism	SC11-SC13	3.0	0.90	0.10	0.10	0.9000	0.0268	2.70
	SC11-SC23	2.0	0.70	0.30	0.15	0.7402	0.0221	1.48
	SC11-SC37	3.5	0.90	0.10	0.10	0.9000	0.0268	3.15
	SC11-SC39	3.0	0.80	0.10	0.10	0.8586	0.0256	2.58
	S11-SC44	4.0	0.90	0.10	0.10	0.9000	0.0268	3.60
	SC11-SC49	4.0	0.90	0.10	0.10	0.9000	0.0268	3.60
	SC13-SC11	1.5	0.70	0.70	0.15	0.5519	0.0165	0.83
	SC13-SC23	1.5	0.70	0.70	0.15	0.5519	0.0165	0.83
	SC13-SC37	3.0	0.90	0.10	0.10	0.9000	0.0268	2.70
	SC13-SC39	0.0	1.00	0.00	0.00	1.0000	0.0298	0.00
	SC13-SC44	1.5	0.70	0.70	0.15	0.5519	0.0165	0.83
	SC13-SC49	1.5	0.70	0.70	0.15	0.5519	0.0165	0.83
	SC23-SC11	2.5	0.70	0.10	0.10	0.8085	0.0241	2.02
	SC23-SC13	2.5	0.70	0.10	0.10	0.8085	0.0241	2.02
	SC23-SC37	3.0	0.80	0.20	0.15	0.8152	0.0243	2.45
	SC23-SC39	2.5	0.70	0.10	0.10	0.8085	0.0241	2.02
	SC23-SC44	2.5	0.70	0.10	0.10	0.8085	0.0241	2.02
	SC23-SC49	3.5	0.80	0.20	0.10	0.8268	0.0247	2.89

	SC37-SC11	3.0	0.70	0.20	0.15	0.7745	0.0231	2.32
	SC37-SC13	4.0	0.95	0.05	0.00	0.9592	0.0286	3.84
	SC37-SC23	3.5	0.80	0.20	0.10	0.8268	0.0247	2.89
	SC37-SC39	2.0	0.75	0.20	0.15	0.7959	0.0237	1.59
	SC37-SC44	3.0	0.70	0.20	0.15	0.7745	0.0231	2.32
	SC37-SC49	3.0	0.70	0.20	0.15	0.7745	0.0231	2.32
	SC39-SC11	3.0	0.80	0.20	0.15	0.8152	0.0243	2.45
	SC39-SC13	3.0	0.80	0.20	0.15	0.8152	0.0243	2.45
	SC39-SC23	2.0	0.75	0.20	0.20	0.7821	0.0233	1.56
	SC39-SC37	3.0	0.80	0.20	0.15	0.8152	0.0243	2.45
	SC39-SC44	3.0	0.80	0.20	0.15	0.8152	0.0243	2.45
	SC39-SC49	3.0	0.80	0.20	0.15	0.8152	0.0243	2.45
	SC44-SC11	3.0	0.80	0.20	0.15	0.8152	0.0243	2.45
	SC44-SC13	3.5	0.90	0.10	0.10	0.9000	0.0268	3.15
	SC44-SC23	1.5	0.80	0.20	0.15	0.8152	0.0243	1.22
	SC44-SC37	3.5	0.90	0.10	0.10	0.9000	0.0268	3.15
	SC44-SC39	3.5	0.90	0.10	0.10	0.9000	0.0268	3.15
	SC44-SC49	3.0	0.80	0.20	0.15	0.8152	0.0243	2.45
	SC49-SC11	3.5	0.70	0.70	0.15	0.5519	0.0165	1.93
	SC49-SC13	1.5	0.70	0.70	0.15	0.5519	0.0165	0.83
	SC49-SC23	3.5	0.80	0.20	0.10	0.8268	0.0247	2.89
	SC49-SC37	2.5	0.80	0.15	0.10	0.8445	0.0252	2.11
	SC49-SC39	2.5	0.80	0.15	0.10	0.8445	0.0252	2.11
	SC49-SC44	3.5	0.80	0.20	0.10	0.8268	0.0247	2.89
If Σ=1, the conditions of the formula are respected.					Crispification Formula Denominator	**33.5374**	**1.0000**	

Table A3. Cluster 1 Group Direct Influence Matrix

	SC11	SC13	SC23	SC37	SC39	SC44	SC49	**SUM**
SC11	0.00	2.70	1.48	3.15	2.58	3.60	3.60	17.1
SC13	0.83	0.00	0.83	2.70	0.00	0.83	0.83	6.0
SC23	2.02	2.02	0.00	2.45	2.02	2.02	2.89	13.4
SC37	2.32	3.84	2.89	0.00	1.59	2.32	2.32	15.3
SC39	2.45	2.45	1.56	2.45	0.00	2.45	2.45	13.8
SC44	2.45	3.15	1.22	3.15	3.15	0.00	2.45	15.6
SC49	1.93	0.83	2.89	2.11	2.11	2.89	0.00	12.8
SUM	12.0	15.0	2.4	16.0	11.5	14.1	14.5	

Table A4. Auxiliary Calculations I

Max	16.0	17.1
1/max	0.062461	0.058445
1/s	**0.058445354**	

Table A5. Normalised Direct-Influence Matrix X

	SC11	SC13	SC23	SC37	SC39	SC44	SC49
SC11	0.0	0.2	0.1	0.2	0.2	0.2	0.2
SC13	0.0	0.0	0.0	0.2	0.0	0.0	0.0
SC23	0.1	0.1	0.0	0.1	0.1	0.1	0.2
SC37	0.1	0.2	0.2	0.0	0.1	0.1	0.1
SC39	0.1	0.1	0.1	0.1	0.0	0.1	0.1
SC44	0.1	0.2	0.1	0.2	0.2	0.0	0.1
SC49	0.1	0.0	0.2	0.1	0.1	0.2	0.0

Table A6. Auxiliary Calculations II for Matrix T and Matrix T

Matriz I

	SC11	SC13	SC23	SC37	SC39	SC44	SC49
SC11	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SC13	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SC23	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
SC37	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
SC39	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
SC44	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
SC49	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

I-D

	SC11	SC13	SC23	SC37	SC39	SC44	SC49
SC11	1.0000	-0.1578	-0.0865	-0.1841	-0.1508	-0.2104	-0.2104
SC13	-0.0485	1.0000	-0.0485	-0.1578	0.0000	-0.0485	-0.0485
SC23	-0.1181	-0.1181	1.0000	-0.1432	-0.1181	-0.1181	-0.1689
SC37	-0.1356	-0.2244	-0.1689	1.0000	-0.0929	-0.1356	-0.1356
SC39	-0.1432	-0.1432	-0.0912	-0.1432	1.0000	-0.1432	-0.1432
SC44	-0.1432	-0.1841	-0.0713	-0.1841	-0.1841	1.0000	-0.1432
SC49	-0.1128	-0.0485	-0.1689	-0.1233	-0.1233	-0.1689	1.0000

(I-D)^-1

	SC11	SC13	SC23	SC37	SC39	SC44	SC49
SC11	1.4583	0.7041	0.5091	0.7510	0.5671	0.7042	0.7109
SC13	0.2234	1.2257	0.2168	0.3670	0.1704	0.2489	0.2529
SC23	0.4741	0.5598	1.3467	0.6024	0.4553	0.5303	0.5772
SC37	0.5114	0.6798	0.5134	1.5165	0.4550	0.5699	0.5797
SC39	0.5017	0.5933	0.4352	0.6153	1.3569	0.5590	0.5656
SC44	0.5377	0.6730	0.4535	0.6942	0.5451	1.4738	0.6056
SC49	0.4712	0.5041	0.4890	0.5844	0.4647	0.5692	1.4335

Matrix T

	SC11	SC13	SC23	SC37	SC39	SC44	SC49	R
SC11	0.4583	0.7041	0.5091	0.7510	0.5671	0.7042	0.7109	4.4048
SC13	0.2234	0.2257	0.2168	0.3670	0.1704	0.2489	0.2529	1.7050
SC23	0.4741	0.5598	0.3467	0.6024	0.4553	0.5303	0.5772	3.5458
SC37	0.5114	0.6798	0.5134	0.5165	0.4550	0.5699	0.5797	3.8257
SC39	0.5017	0.5933	0.4352	0.6153	0.3569	0.5590	0.5656	3.6269
SC44	0.5377	0.6730	0.4535	0.6942	0.5451	0.4738	0.6056	3.9829
SC49	0.4712	0.5041	0.4890	0.5844	0.4647	0.5692	0.4335	3.5160
C	3.1777	3.9398	2.9637	4.1308	3.0145	3.6553	3.7253	

Appendix B – Cluster 2 – Mobility

Table B1. Cluster 2 Matrix Obtained in the Second Session with the Neutrosophic Values

	SC51	SC53	SC55	SC59	SC62	SC77	SC80
SC51	--	3(0.8,0.2,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	3.5 (0.8,0.2,0.1)	3.5 (0.8,0.2,0.1)
SC53	3(0.8,0.2,0.1)	--	3.5 (0.8,0.2,0.1)	3(0.8,0.2,0.1)	3.5 (0.9,0.1,0.05)	3.5 (0.8,0.2,0.1)	4 (0.9,0.1,0.1)
SC55	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	--	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)
SC59	4 (0.9,0.1,0.1)	3 (0.8,0.2,0.1)	4 (0.9,0.1,0.1)	--	4 (0.9,0.1,0.1)	3.5 (0.8,0.2,0.1)	3.5 (0.8,0.2,0.1)
SC62	3.5 (0.9,0.1,0.1)	3.5 (0.9,0.1,0.1)	3.5 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	--	3.5 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)
SC77	3.5 (0.9,0.1, 0.1)	3.5 (0.9,0.1,0.1)	4 (1,0,0)	3.5 (0.9,0.1, 0.1)	3.5 (0.9,0.1, 0.1)	--	3.5 (0.9,0.1, 0.1)
SC80	3.5 (0.8,0.2,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	3.5 (0.8,0.2,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	--

Table B2. Cluster 2 Crispification of Neutrosophic Values

	Relationship Under Analysis	**DEMATEL Scale (x)**	**Neutrosophic Values (T, I, F)**			**Neutrosophic Crispification**		
			T	I	F	Crispification Formula Numerator	Neutrosophic Weight w Crispified	Final Value at DEMATEL Matrix x(T,I,F)→x
MATRIXZ Cluster 2 – Mobility	SC51-SC53	3.0	0.80	0.20	0.10	0.8268	0.0223	2.48
	SC51-SC55	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC51-SC59	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC51-SC62	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC51-SC77	3.5	0.80	0.20	0.10	0.8268	0.0223	2.89
	SC51-SC80	3.5	0.80	0.20	0.10	0.8268	0.0223	2.89
	SC53-SC51	3.0	0.80	0.20	0.10	0.8268	0.0223	2.48
	SC53-SC55	3.5	0.80	0.20	0.10	0.8268	0.0223	2.89
	SC53-SC59	3.0	0.80	0.20	0.10	0.8268	0.0223	2.48
	SC53-SC62	3.5	0.90	0.10	0.05	0.9134	0.0247	3.20
	SC53-SC77	3.5	0.80	0.20	0.10	0.8268	0.0223	2.89
	SC53-SC80	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC55-SC51	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC55-SC53	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC55-SC59	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC55-SC62	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC55-SC77	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC55-SC80	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC59-SC51	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60

	SC59-SC53	3.0	0.80	0.20	0.10	0.8268	0.0223	2.48
	SC59-SC55	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC59-SC62	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC59-SC77	3.5	0.80	0.20	0.10	0.8268	0.0223	2.89
	SC59-SC80	3.5	0.80	0.20	0.10	0.8268	0.0223	2.89
	SC62-SC51	3.5	0.90	0.10	0.10	0.9000	0.0243	3.15
	SC62-SC53	3.5	0.90	0.10	0.10	0.9000	0.0243	3.15
	SC62-SC55	3.5	0.90	0.10	0.10	0.9000	0.0243	3.15
	SC62-SC59	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC62-SC77	3.5	0.90	0.10	0.10	0.9000	0.0243	3.15
	SC62-SC80	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC77-SC51	3.5	0.90	0.10	0.10	0.9000	0.0243	3.15
	SC77-SC53	3.5	0.90	0.10	0.10	0.9000	0.0243	3.15
	SC77-SC55	4.0	1.00	0.00	0.00	1.0000	0.0270	4.00
	SC77-SC59	3.5	0.90	0.10	0.10	0.9000	0.0243	3.15
	SC77-SC62	3.5	0.90	0.10	0.10	0.9000	0.0243	3.15
	SC77-SC80	3.5	0.90	0.10	0.10	0.9000	0.0243	3.15
	SC80-SC51	3.5	0.80	0.20	0.10	0.8268	0.0223	2.89
	SC80-SC53	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC80-SC55	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC80-SC59	3.5	0.80	0.20	0.10	0.8268	0.0223	2.89
	SC80-SC62	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
	SC80-SC77	4.0	0.90	0.10	0.10	0.9000	0.0243	3.60
If Σ=1, the conditions of the formula are respected.					Crispification Formula Denominator	**37.0349**	**1.0000**	

Table B3. Cluster 2 Group Direct Influence Matrix

	SC51	SC53	SC55	SC59	SC62	SC77	SC80	**SUM**
SC51	0.0	2.5	3.6	3.6	3.6	2.9	2.9	19.1
SC53	2.5	0.0	2.9	2.5	3.2	2.9	3.6	17.5
SC55	3.6	3.6	0.0	3.6	3.6	3.6	3.6	21.6
SC59	3.6	2.5	3.6	0.0	3.6	2.9	2.9	19.1
SC62	3.2	3.2	3.2	3.6	0.0	3.2	3.6	19.8
SC77	3.2	3.2	4.0	3.2	3.2	0.0	3.2	19.8
SC80	2.9	3.6	3.6	2.9	3.6	3.6	0.0	20.2
SUM	18.9	18.5	20.8	19.3	20.8	19.0	19.7	

Table B4. Auxiliary Calculations I

Max	20.8	21.6
1/max	0.047985	0.046296
1/s	**0.046296296**	

Table B5. Normalised Direct-Influence Matrix X

	SC51	SC53	SC55	SC59	SC62	SC77	SC80
SC51	0.0	0.1	0.2	0.2	0.2	0.1	0.1
SC53	0.1	0.0	0.1	0.1	0.1	0.1	0.2
SC55	0.2	0.2	0.0	0.2	0.2	0.2	0.2
SC59	0.2	0.1	0.2	0.0	0.2	0.1	0.1
SC62	0.1	0.1	0.1	0.2	0.0	0.1	0.2
SC77	0.1	0.1	0.2	0.1	0.1	0.0	0.1
SC80	0.1	0.2	0.2	0.1	0.2	0.2	0.0

Table B6. Auxiliary Calculations II for Matrix T and Matrix T

Matriz I

	SC51	SC53	SC55	SC59	SC62	SC77	SC80
SC51	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SC53	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SC55	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
SC59	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
SC62	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
SC77	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
SC80	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

I-D

	SC51	SC53	SC55	SC59	SC62	SC77	SC80
SC51	1.0000	-0.1148	-0.1667	-0.1667	-0.1667	-0.1338	-0.1338
SC53	-0.1148	1.0000	-0.1338	-0.1148	-0.1481	-0.1338	-0.1667
SC55	-0.1667	-0.1667	1.0000	-0.1667	-0.1667	-0.1667	-0.1667
SC59	-0.1667	-0.1148	-0.1667	1.0000	-0.1667	-0.1338	-0.1338
SC62	-0.1458	-0.1458	-0.1458	-0.1667	1.0000	-0.1458	-0.1667
SC77	-0.1458	-0.1458	-0.1852	-0.1458	-0.1458	1.0000	-0.1458
SC80	-0.1338	-0.1667	-0.1667	-0.1338	-0.1667	-0.1667	1.0000

(I-D)^-1

	SC51	SC53	SC55	SC59	SC62	SC77	SC80
SC51	2.2246	1.3038	1.4734	1.3938	1.4701	1.3500	1.3889
SC53	1.2380	2.1153	1.3523	1.2623	1.3600	1.2618	1.3231
SC55	1.5011	1.4758	2.4770	1.5300	1.6159	1.5105	1.5539
SC59	1.3675	1.3038	1.4734	2.2509	1.4701	1.3500	1.3889
SC62	1.3877	1.3640	1.4979	1.4299	2.3670	1.3963	1.4521
SC77	1.3889	1.3654	1.5282	1.4156	1.4951	2.2703	1.4378
SC80	1.3999	1.4023	1.5368	1.4273	1.5331	1.4344	2.3328

Matrix T

	SC51	SC53	SC55	SC59	SC62	SC77	SC80	R
SC51	1.2246	1.3038	1.4734	1.3938	1.4701	1.3500	1.3889	9.6046
SC53	1.2380	1.1153	1.3523	1.2623	1.3600	1.2618	1.3231	8.9127
SC55	1.5011	1.4758	1.4770	1.5300	1.6159	1.5105	1.5539	10.6641
SC59	1.3675	1.3038	1.4734	1.2509	1.4701	1.3500	1.3889	9.6046
SC62	1.3877	1.3640	1.4979	1.4299	1.3670	1.3963	1.4521	9.8947
SC77	1.3889	1.3654	1.5282	1.4156	1.4951	1.2703	1.4378	9.9013
SC80	1.3999	1.4023	1.5368	1.4273	1.5331	1.4344	1.3328	10.0665
C	9.5077	9.3303	10.3389	9.7097	10.3113	9.5733	9.8775	

Appendix C – Cluster 3 – Society

Table C1. Cluster 3 Matrix Obtained in the Second Session with the Neutrosophic Values

	SC9	SC22	SC68	SC93	SC112	SC113	SC131
SC9	--	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	3.5 (0.8,0.2,0.15)	3.5 (0.8,0.2,0.15)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)
SC22	4 (0.9,0.1,0.1)	--	4 (0.9,0.1,0.1)	3.5 (0.8,0.2,0.15)	2.5 (0.7,0.5,0.3)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)
SC68	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	--	0 (1,0,0)	0 (1,0,0)	0 (1,0,0)	2 (0.7,0.5,0.3)
SC93	4 (0.9,0.1,0.1)	2 (0.7,0.5,0.3)	4 (0.9,0.1,0.1)	--	1 (0.7,0.5,0.3)	4 (0.9,0.1,0.1)	2 (0.7,0.5,0.3)
SC112	1 (0.9,0.1,0.1)	2 (0.7,0.5,0.3)	4 (0.9,0.1,0.1)	2 (0.7,0.5,0.3)	--	1 (0.9,0.1,0.1)	3.5 (0.9, 0.7, 0.1)
SC113	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	2 (0.7,0.5,0.3)	1 (0.7,0.5,0.3)	--	4 (0.9,0.1,0.1)
SC131	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	--

Table C2. Cluster 3 Crispification of Neutrosophic Values

	Relationship Under Analysis	**DEMATEL Scale (x)**	**Neutrosophic Values (T, I, F)**			**Neutrosophic Crispification**		
			T	I	F	Crispification Formula Numerator	Neutrosophic Weight w Crispified	Final Value at DEMATEL Matrix x(T,I,F)→x
MATRIX Cluster 3 – Society	SC9-SC22	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC9-SC68	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC9-SC93	3.5	0.80	0.20	0.15	0.8152	0.0233	2.85
	SC9-SC112	3.5	0.80	0.20	0.15	0.8152	0.0233	2.85
	SC9-SC113	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC9-SC131	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC22-SC9	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC22-SC68	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC22-SC93	3.5	0.80	0.20	0.15	0.8152	0.0233	2.85
	SC22-SC112	2.5	0.70	0.50	0.30	0.6214	0.0177	1.55
	SC22-SC113	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC22-SC131	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC68-SC9	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC68-SC22	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC68-SC93	0.0	1.00	0.00	0.00	1.0000	0.0286	0.00
	SC68-SC112	0.0	1.00	0.00	0.00	1.0000	0.0286	0.00
	SC68-SC113	0.0	1.00	0.00	0.00	1.0000	0.0286	0.00
	SC68-SC131	2.0	0.70	0.50	0.30	0.6214	0.0177	1.24
	SC93-SC9	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60

	SC93-SC22	2.0	0.70	0.50	0.30	0.6214	0.0177	1.24
	SC93-SC68	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC93-SC112	1.0	0.70	0.50	0.30	0.6214	0.0177	0.62
	SC93-SC113	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC93-SC131	2.0	0.70	0.50	0.30	0.6214	0.0177	1.24
	SC112-SC9	1.0	0.90	0.10	0.10	0.9000	0.0257	0.90
	SC112-SC22	2.0	0.70	0.50	0.30	0.6214	0.0177	1.24
	SC112-SC68	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC112-SC93	2.0	0.70	0.50	0.30	0.6214	0.0177	1.24
	SC112-SC113	1.0	0.90	0.10	0.10	0.9000	0.0257	0.90
	SC112-SC131	3.5	0.90	0.70	0.10	0.5877	0.0168	2.06
	SC113-SC9	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC113-SC22	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC113-SC68	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC113-SC93	2.0	0.70	0.50	0.30	0.6214	0.0177	1.24
	SC113-SC112	1.0	0.70	0.50	0.30	0.6214	0.0177	0.62
	SC113-SC131	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC131-SC9	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC131-SC22	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC131-SC68	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC131-SC93	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC131-SC112	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
	SC131-SC113	4.0	0.90	0.10	0.10	0.9000	0.0257	3.60
If Σ=1, the conditions of the formula are respected.					Crispification Formula Denominator	**35.0258**	**1.0000**	

Table C3. Cluster 3 Group Direct Influence Matrix

	SC9	SC22	SC68	SC93	SC112	SC113	SC131	**SUM**
SC9	0.0	3.6	3.6	2.9	2.9	3.6	3.6	20.1
SC22	3.6	0.0	3.6	2.9	1.6	3.6	3.6	18.8
SC68	3.6	3.6	0.0	0.0	0.0	0.0	1.2	8.4
SC93	3.6	1.2	3.6	0.0	0.6	3.6	1.2	13.9
SC112	0.9	1.2	3.6	1.2	0.0	0.9	2.1	9.9
SC113	3.6	3.6	3.6	1.2	0.6	0.0	3.6	16.3
SC131	3.6	3.6	3.6	3.6	3.6	3.6	0.0	21.6
SUM	18.9	16.9	21.6	11.8	9.2	15.3	15.3	

Table C4. Auxiliary Calculations I

Max	21.6	21.6
1/max	0.046296	0.046296
1/s	**0.046296296**	

Table C5. Normalised Direct-Influence Matrix X

	SC9	SC22	SC68	SC93	SC112	SC113	SC131
SC9	0.0	0.2	0.2	0.1	0.1	0.2	0.2
SC22	0.2	0.0	0.2	0.1	0.1	0.2	0.2
SC68	0.2	0.2	0.0	0.0	0.0	0.0	0.1
SC93	0.2	0.1	0.2	0.0	0.0	0.2	0.1
SC112	0.0	0.1	0.2	0.1	0.0	0.0	0.1
SC113	0.2	0.2	0.2	0.1	0.0	0.0	0.2
SC131	0.2	0.2	0.2	0.2	0.2	0.2	0.0

Table C6. Auxiliary Calculations II for Matrix T and Matrix T

Matriz I

	SC9	SC22	SC68	SC93	SC112	SC113	SC131
SC9	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SC22	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SC68	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
SC93	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
SC112	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
SC113	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
SC131	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

I-D

	SC9	SC22	SC68	SC93	SC112	SC113	SC131
SC9	1.0000	-0.1667	-0.1667	-0.1319	-0.1319	-0.1667	-0.1667
SC22	-0.1667	1.0000	-0.1667	-0.1319	-0.0718	-0.1667	-0.1667
SC68	-0.1667	-0.1667	1.0000	0.0000	0.0000	0.0000	-0.0574
SC93	-0.1667	-0.0574	-0.1667	1.0000	-0.0287	-0.1667	-0.0574
SC112	-0.0417	-0.0574	-0.1667	-0.0574	1.0000	-0.0417	-0.0954
SC113	-0.1667	-0.1667	-0.1667	-0.0574	-0.0287	1.0000	-0.1667
SC131	-0.1667	-0.1667	-0.1667	-0.1667	-0.1667	-0.1667	1.0000

(I-D)^-1

	SC9	SC22	SC68	SC93	SC112	SC113	SC131
SC9	1.4440	0.5543	0.6233	0.3963	0.3405	0.4978	0.5070
SC22	0.5733	1.3981	0.6037	0.3866	0.2833	0.4871	0.4936
SC68	0.3711	0.3583	1.2418	0.1556	0.1257	0.1938	0.2461
SC93	0.4669	0.3574	0.4868	1.1952	0.1859	0.3973	0.3179
SC112	0.2620	0.2594	0.3807	0.1876	1.1078	0.2076	0.2598
SC113	0.5338	0.5085	0.5585	0.3033	0.2306	1.3112	0.4637
SC131	0.6085	0.5727	0.6491	0.4374	0.3790	0.5158	1.3813

Matrix T

	SC9	SC22	SC68	SC93	SC112	SC113	SC131	R
SC9	0.4440	0.5543	0.6233	0.3963	0.3405	0.4978	0.5070	3.3631
SC22	0.5733	0.3981	0.6037	0.3866	0.2833	0.4871	0.4936	3.2256
SC68	0.3711	0.3583	0.2418	0.1556	0.1257	0.1938	0.2461	1.6923
SC93	0.4669	0.3574	0.4868	0.1952	0.1859	0.3973	0.3179	2.4074
SC112	0.2620	0.2594	0.3807	0.1876	0.1078	0.2076	0.2598	1.6650
SC113	0.5338	0.5085	0.5585	0.3033	0.2306	0.3112	0.4637	2.9096
SC131	0.6085	0.5727	0.6491	0.4374	0.3790	0.5158	0.3813	3.5438
C	3.2596	3.0086	3.5438	2.0621	1.6528	2.6105	2.6694	

Appendix D – Cluster 4 – Sustainability

Table D1. Cluster 4 Matrix Obtained in the Second Session with the Neutrosophic Values

	SC18	SC30	SC64	SC82	SC138
SC18	--	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	0 (1,0,0)	4 (0.9,0.1,0.1)
SC30	2 (0.7,0.5,0.3)	--	4 (0.9,0.1,0.1)	0 (1,0,0)	0 (1,0,0)
SC64	2 (0.7,0.5,0.3)	4 (0.9,0.1,0.1)	--	0 (1,0,0)	4 (0.9,0.1,0.1)
SC82	0 (1,0,0)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	--	4 (0.9,0.1,0.1)
SC138	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	4 (0.9,0.1,0.1)	--

Table D2. Cluster 4 Crispification of Neutrosophic Values

	Relationship Under Analysis	**DEMATEL Scale (x)**	**Neutrosophic Values (T, I, F)**			**Neutrosophic Crispification**		
			T	I	F	Crispification Formula Numerator	Neutrosophic Weight w Crispified	Final Value at DEMATEL Matrix x(T,I,F)→x
MATRIX Cluster 4 – Sustainability	SC18-SC30	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC18-SC64	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC18-SC82	0.0	1.00	0.00	0.00	1.0000	0.0557	0.00
	SC18-SC138	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC30-SC18	2.0	0.70	0.50	0.30	0.6214	0.0346	1.24
	SC30-SC64	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC30-SC82	0.0	1.00	0.00	0.00	1.0000	0.0557	0.00
	SC30-SC138	0.0	1.00	0.00	0.00	1.0000	0.0557	0.00
	SC64-SC18	2.0	0.70	0.50	0.30	0.6214	0.0346	1.24
	SC64-SC30	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC64-SC82	0.0	1.00	0.00	0.00	1.0000	0.0557	0.00
	SC64-SC138	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC82-SC18	0.0	1.00	0.00	0.00	1.0000	0.0557	0.00
	SC82-SC30	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC82-SC64	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC82-SC138	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC138-SC18	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC138-SC30	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC138-SC64	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60
	SC138-SC82	4.0	0.90	0.10	0.10	0.9000	0.0502	3.60

If Σ=1, the conditions of the formula are respected.	Crispification Formula Denominator	**17.9428**	**1.0000**

Table D3. Cluster 4 Group Direct Influence Matrix

	SC18	SC30	SC64	SC82	SC138	**SUM**
SC18	0.0	3.6	3.6	0.0	3.6	10.8
SC30	1.2	0.0	3.6	0.0	0.0	4.8
SC64	1.2	3.6	0.0	0.0	3.6	8.4
SC82	0.0	3.6	3.6	0.0	3.6	10.8
SC138	3.6	3.6	3.6	3.6	0.0	14.4
SUM	6.1	14.4	14.4	3.6	10.8	

Table D4. Auxiliary Calculations I

Max	14.4	14.4
1/max	0.069444	0.069444
1/s	**0.069444444**	

Table D5. Normalised Direct-Influence Matrix X

	SC18	SC30	SC64	SC82	SC138
SC18	0.0000	0.2500	0.2500	0.0000	0.2500
SC30	0.0861	0.0000	0.2500	0.0000	0.0000
SC64	0.0861	0.2500	0.0000	0.0000	0.2500
SC82	0.0000	0.2500	0.2500	0.0000	0.2500
SC138	0.2500	0.2500	0.2500	0.2500	0.0000

Table D6. Auxiliary Calculations II for Matrix T and Matrix T

Matriz I

	SC18	SC30	SC64	SC82	SC138
SC18	1.0000	0.0000	0.0000	0.0000	0.0000
SC30	0.0000	1.0000	0.0000	0.0000	0.0000
SC64	0.0000	0.0000	1.0000	0.0000	0.0000
SC82	0.0000	0.0000	0.0000	1.0000	0.0000
SC138	0.0000	0.0000	0.0000	0.0000	1.0000

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	SC18	SC30	SC64	SC82	SC138
SC18	1.0000	-0.2500	-0.2500	0.0000	-0.2500
SC30	-0.0861	1.0000	-0.2500	0.0000	0.0000
SC64	-0.0861	-0.2500	1.0000	0.0000	-0.2500
SC82	0.0000	-0.2500	-0.2500	1.0000	-0.2500
SC138	-0.2500	-0.2500	-0.2500	-0.2500	1.0000

(I-D)^-1

	SC18	SC30	SC64	SC82	SC138
SC18	1.2287	0.6143	0.6143	0.1229	0.4915
SC30	0.1727	1.1863	0.3863	0.0373	0.1491
SC64	0.2676	0.5338	1.3338	0.1068	0.4270
SC82	0.2287	0.6143	0.6143	1.1229	0.4915
SC138	0.4744	0.7372	0.7372	0.3474	1.3898

Matrix T

	SC18	SC30	SC64	SC82	SC138	R
SC18	0.2287	0.6143	0.6143	0.1229	0.4915	2.0717
SC30	0.1727	0.1863	0.3863	0.0373	0.1491	0.9317
SC64	0.2676	0.5338	0.3338	0.1068	0.4270	1.6689
SC82	0.2287	0.6143	0.6143	0.1229	0.4915	2.0717
SC138	0.4744	0.7372	0.7372	0.3474	0.3898	2.6860
C	1.3720	2.6860	2.6860	0.7372	1.9488	

Appendix E – Cluster 5 – Economy

Table E1. Cluster 5 Matrix Obtained in the Second Session with the Neutrosophic Values

	SC13	SC17	SC37	SC93	SC154
SC13	--	4 (0.9.0.1.0.1)	4 (0.9.0.1.0.1)	4 (0.9.0.1.0.1)	4 (0.9.0.1.0.1)
SC17	4 (0.9.0.1.0.1)	--	4 (0.9.0.1.0.1)	4 (0.9.0.1.0.1)	2.5 (0.7.0.2.0.1)
SC37	4 (0.9.0.1.0.1)	4 (0.9.0.1.0.1)	--	4 (0.9.0.1.0.1)	4 (0.9.0.1.0.1)
SC93	4 (0.9.0.1.0.1)	4 (0.9.0.1.0.1)	4 (0.9.0.1.0.1)	--	4 (0.9.0.1.0.1)
SC154	0 (1.0.0)	2(0.7.0.5.0.3)	4 (0.9.0.1.0.1)	4 (0.9.0.1.0.1)	--

Table E2. Cluster 5 Crispification of Neutrosophic Values

	Relationship Under Analysis	**DEMATEL Scale (x)**	**Neutrosophic Values (T, I, F)**			**Neutrosophic Crispification**		
			T	I	F	Crispification Formula Numerator	Neutrosophic Weight w Crispified	Final Value at DEMATEL Matrix x(T.I.F)→x
MATRIX Cluster 5 – Economy	SC13-SC17	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC13-SC37	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC13-SC93	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC13-SC154	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC17-SC13	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC17-SC37	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC17-SC93	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC17-SC154	2.5	0.70	0.20	0.10	0.7840	0.0443	1.96
	SC37-SC13	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC37-SC17	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC37-SC93	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC37-SC154	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC93-SC13	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC93-SC17	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC93-SC37	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC93-SC154	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC154-SC13	0.0	1.00	0.00	0.00	1.0000	0.0565	0.00
	SC154-SC17	2.0	0.70	0.50	0.30	0.6214	0.0351	1.24
	SC154-SC37	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60
	SC154-SC93	4.0	0.90	0.10	0.10	0.9000	0.0508	3.60

If Σ=1, the conditions of the formula are respected.	Crispification Formula Denominator	**17.7054**	**1.0000**

Table E3. Cluster 5 Group Direct Influence Matrix

	SC13	SC17	SC37	SC93	SC154	**SUM**
SC13	0.0	3.6	3.6	3.6	3.6	14.4
SC17	3.6	0.0	3.6	3.6	2.0	12.8
SC37	3.6	3.6	0.0	3.6	3.6	14.4
SC93	3.6	3.6	3.6	0.0	3.6	14.4
SC154	0.0	1.2	3.6	3.6	0.0	8.4
SUM	10.8	12.0	14.4	14.4	12.8	

Table E4. Auxiliary Calculations I

Max	14.4	14.4
1/max	0.069444	0.069444
1/s	**0.069444444**	

Table E5. Normalised Direct-Influence Matrix X

	SC13	SC17	SC37	SC93	SC154
SC13	0.0000	0.2500	0.2500	0.2500	0.2500
SC17	0.2500	0.0000	0.2500	0.2500	0.1361
SC37	0.2500	0.2500	0.0000	0.2500	0.2500
SC93	0.2500	0.2500	0.2500	0.0000	0.2500
SC154	0.0000	0.0861	0.2500	0.2500	0.0000

Table E6. Auxiliary Calculations II for Matrix T and Matrix T

Matriz I

	SC13	SC17	SC37	SC93	SC154
SC13	1.0000	0.0000	0.0000	0.0000	0.0000
SC17	0.0000	1.0000	0.0000	0.0000	0.0000
SC37	0.0000	0.0000	1.0000	0.0000	0.0000
SC93	0.0000	0.0000	0.0000	1.0000	0.0000
SC154	0.0000	0.0000	0.0000	0.0000	1.0000

I-D

	SC13	SC17	SC37	SC93	SC154
SC13	1.0000	-0.2500	-0.2500	-0.2500	-0.2500
SC17	-0.2500	1.0000	-0.2500	-0.2500	-0.1361
SC37	-0.2500	-0.2500	1.0000	-0.2500	-0.2500
SC93	-0.2500	-0.2500	-0.2500	1.0000	-0.2500
SC154	0.0000	-0.0861	-0.2500	-0.2500	1.0000

(I-D)^-1

	SC13	SC17	SC37	SC93	SC154
SC13	2.4969	1.8287	2.0795	2.0795	1.9129
SC17	1.6070	2.5256	1.9513	1.9513	1.7211
SC37	1.6969	1.8287	2.8795	2.0795	1.9129
SC93	1.6969	1.8287	2.0795	2.8795	1.9129
SC154	0.9869	1.1318	1.4078	1.4078	2.1047

Matrix T

	SC13	SC17	SC37	SC93	SC154	R
SC13	1.4969	1.8287	2.0795	2.0795	1.9129	9.3976
SC17	1.6070	1.5256	1.9513	1.9513	1.7211	8.7563
SC37	1.6969	1.8287	1.8795	2.0795	1.9129	9.3976
SC93	1.6969	1.8287	2.0795	1.8795	1.9129	9.3976
SC154	0.9869	1.1318	1.4078	1.4078	1.1047	6.0389
C	7.4847	8.1436	9.3976	9.3976	8.5645	