Masters Program in Geospatial Technologies

Exploring the Spatio-Temporal Variation of Sense of Place in Situ

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Declaration of Authorship

I hereby declare that this thesis **"Exploring the Spatio-Temporal Variation of Sense of Place in Situ"** is solely my own work and that I have used no sources or aids other than the ones stated. All passages in my thesis and assistance I have received from other people is duly acknowledged and the sources cited. I agree to have my thesis checked in order to rule out potential similarities with other works and to have my thesis stored in a database for this purpose.

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Abstract

The study of people-place relationships has always been important in understanding urban environments. In the context of non-native residents adjusting to new urban environments, the development of relationships with the surrounding environments emerge differently transitioning from mere functional bonds, to emotional and to more deeper bonds of belonging. The subjective perception among individuals of the objective world is studied in the fields of environmental psychology and urban studies as a multidimensional construct of sense of place that varies in both space and time and influenced by perceptions and experiences happening in situ. In existing literature little attention has been paid on the influence of low-level timestamp and in-situ experienced in the variation of sense of place. This study brings together the fields of environmental psychology and urban studies to explore the spatial and temporal variation of three dimensions of sense of place namely; place dependence, place attachment, and urban sentiment by exploring in-situ low-level timestamped data collected from non-native students in the cities of Castellón (Spain) and Lisbon (Portugal). We designed and implemented a comprehensive and improved methodological framework from suggestions in existing literature to include in-situ data collection through developing a context-aware mobile app that generates questionnaires in situ, data processing that integrates contextual data, exploratory analysis of the spatial, temporal, and contextual dataset and visualization of the spatial and temporal variation of the dimensions of sense of place in the dataset. Results revealed areas that represent a consistent positive sense of place. The city center of Castellón and neigborhoods in Lisbon exhibit consistent positive place dependence, where as place attachment exhibit neutral to positive values across the two cities, and urban sentiment exhibit mere variation across the two cities. For the contextual factors influence in the variation of the three dimensions, only weather exhibit a statistical significance. The methodological framework developed and implemented in this study allowed to create and explore the spatial, temporal, and contextual dataset on sense of place and can be used for further exploration or other longitudinal studies.

Keywords

Sense of Place

Place dependence

Place attachment

Urban sentiment

In-situ data

Spatio-temporal variation

Acronyms

API: Application Programming Interface

APK: Android Application Package

GEOTEC: Geospatial Technologies

GPS: Global Positioning System

iOS: iPhone Operating System

JSON: JavaScript Object Notation

LABPSITEC: Laboratory of Psychology and Technology

NTD: NativeScript Task Dispatch

SOP: Sense of Place

STWR: Spatial-Temporal Weighted Regression

UI: User Interface

UUID: Universally Unique Identifier

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1 Introduction

1.1 Context and Rationale

The study of places, spaces, and people's perceptions, feelings and experiences about them has been receiving increasing attention in recent years in various disciplines such as environmental psychology, sociology, geography [30, 32, 26, 36], and more recently in the fast-growing field of platial research based on social media data, user-generated content, and location-based services [35, 13, 24]. Although space is a more objective concept and place is more subjective and socially constructed from physical spaces, both are closely intertwined concepts that can portray different facets from mere spatial relationships to the human connotation and meaning attached to places [35, 1]. In literature, the concept of place is expanded to include peoples' bonds, attachments, experiences, and relationships to locations, hence the combined set introduces the functional definition of sense of place [30, 27].

Sense of place has become an intriguing topic of study due to the increase in globalisation, immigration and interconnectedness around the world, which consequently threaten the person-place bond, particularly for non-native residents who move to new urban areas [26, 30, 32]. These studies contributed to a better understanding of how individuals, especially non-natives, form and experience a sense of place in the context of contemporary global dynamics. They also paved the way for further exploration and understanding of sense of place as a subjective, multifaceted, and holistic concept that encompasses various notions [1, 30] and, most importantly, develops differently among diverse populations that exhibit variations in both space and time.

A wide range of terminologies are used to articulate and examine the concept of sense of place across its multiple dimensions. Terms such as place attachment, place identity, place dependence, place inherited, urban sentiment, to name a few examples, are used to characterise the sense of place in different dimensions and also to differentiate places and meaning attributed to them [32, 1, 30]. Under the lens of environmental psychology, increased mobility in urban societies shapes heterogeneity in the dimensions of sense of place, levels of dependence, attachments, identity development or belonging to the new society [4] and, consequently, the link between one's own experience and the dynamic and static contextual factors of a place, which trigger immediate emotions that influence satisfaction with valued places [24]. Thus, in the realm of inclusive and immersive urban environments, understanding the person-place relationship is pivotal to shaping people perception and attachment among non-native residents adapting to new urban environments.

To broaden the body of knowledge and understanding on the concept of sense of place, we start from the fact that sense of place is a dynamic construct that results from a variety of emotions and experiences, both positive and negative, as Trabka [32] pointed out. As some dimensions of sense of place develop faster than others [30], the emphasis is on the dimensions that unfold an immersive and inclusive urban experience among non-native residents referred to in this study as people who were not born or raised in the city of residence. Therefore, this study will focus on place dependence, place attachment and urban sentiment to capture the variation of sense of place from physical/functional, social/emotional, to the individual and perceptual experiences across different spatial extents in the city over time. In this work, sense of place acts as an umbrella construct where place dependence, place attachment, and urban sentiment are distinct components or facets, but with levels of complementarity to the development of sense of place.

1.2 Knowledge Gap Identification

Drawing from previous research on sense of place from the angle of environmental psychology, the development of different dimensions has been explored, revealing a strong correlation with time, in addition to exhibiting spatial variation [30, 36, 32]. Despite the existing body of research on sense of place and on the combination of different dimensions, there are significant gaps that need further attention.

- Primarily, there is still a need for more exploratory work that combines place dependence, place attachment and urban sentiment to understand to which extent a place satisfies an individual's behaviour goals. People's behaviour is driven by affordance and opportunities such as daily tasks, leisure, study, and working habits through place dependence [30]. Furthermore, these behaviour are driven by how a place foster engagement, exploration and emotional bond through place attachment [36, 1]. Lastly , by how a place is perceived contextually from in situ experiences through urban sentiment[8]. These 3 dimensions altogether frame the functional or physical, emotional, and more interestingly but least explored, the perceptual aspects of sense of place [33, 13].

- Secondly, some existing research works considered the temporal component of sense of place solely based on the length of residency [30, 32, 1], based on collecting data once and categorizing participants according to the time they have spent living in the area of interest. However, little is known about the temporal dynamics of sense of place, i.e. whether it changes on finer time scales, such as daily, weekly, biweekly, or monthly. Repeatedly capturing people's perceptions, in the moment and in situ, will open the door to evaluating the variation of sense of place over different timeframes and across places, and even analyze its dimensions to examine

which dimension exhibits consistency or variation.

- Lastly, in the course of exploring the multidimensional, dynamic sense of place, it is paramount to take into consideration the recall bias in collecting data on experiences and perceptions about places. One of the research gaps identified by Acedo et al. [1] is that most of the related studies analysed and interpreted data collected from questionnaires, structured and semi-structured interviews that are typically filled once by each participant[1]. Although these methods are well-established data surveying instruments, key contextual factors are often omitted and the reliability of the collected data is reduced since individuals need to recall experiences and events long after they occurred [1]. Therefore to explore sense of place more accurately, especially perceptual aspects, in-situ data collection instruments have been argued to be the best approach to capture individual's experiences about places[8, 24, 1, 13].

1.3 Objective and Research Questions

The above gaps raise the need for studies that explore how different facets of sense of place behave, interact and evolve over relatively short timeframes. In this sense, the overall research goal of this master thesis is to explore how the dimensions of sense of place related to place dependence, place attachment, and urban sentiment vary in space and time from in situ experiences of non-native residents. In line with this research objective, the following research questions are set:

- What are the spatial and temporal distribution, correlation and patterns of significant areas that represent a positive sense of place including place attachment, place dependence, and urban sentiment for non-native residents in Lisbon and Castellón?
- Do contextual factors, including time of the day and weather conditions gathered from in-situ data collection, affect o influence sense of place or associated dimensions?
- What are the spatial-temporal similarities or differences in the development of sense of place for non-native residents between Castellón and Lisbon?

By applying a novel methodological framework to explore the three dimensions of sense of place among non-native residents, this study seeks to expand the body of knowledge in two ways: (1) by creating a rich dataset that incorporates spatial, temporal, and contextual variables on the dimensions of place dependence, place attachment, and urban sentiment; (2) by providing a comprehensive analysis of the resulting dataset, exploring time and space dimensions, to come to new insight regarding place dependence, place attachment, and urban sentiment over a relatively short time span. The resulting dataset

can also be used by the research community to further explore bonds, attachment and perception of non-native urban residents.

1.4 Research Methodology

To achieve the research objective and answer the research questions, a multi-disciplinary research methodology was set. We employed a survey reseach method combining social science, computer science and data analysis methods and techniques to develop a comprehensive framework for collecting, processing and analyzing in situ data on sense of place. Below, the undertaken research process is detailed, along with the research methods used.

1. Development of a conceptual framework to contextualize the focus of the thesis from existing literature and identified research gap, and define the dimensions of sense of place along with the variables from which a questionnaire for in situ data collection is delivered

2. Development of a context-aware mobile app that generates in situ the questionnaire designed in step 1 and alerts users about the availability of the questionnaire to be taken through push notifications

3. Conducting a user study over a period of one month in two different urban areas using the context-aware mobile app developed in step 2 to gather spatial-temporal data on the dimensions of sense of place identified in step 1 from participants in situ

4. Preprocessing the data acquired from the user study for normalization, aggregation, and further the extraction and integration ofcontextual data from either the in-situ dataset or third-party services

5. Generating visual representations of the results and conducting analyses to examine the spatial-temporal patterns and correlations

After a thorough implementation of the above process, we discuss the results referring to the research questions and the contribution of this study to the body of knowledge, and finally draw conclusions based on the findings and highlights potential areas for future research.

1.5 Thesis Outline

The remainder of this thesis is organized as follows:

- Chapter 2 describes background and key concepts on sense of place, in-situ data collection and spatio-temporal exploratory analysis.
- Chapter 3 highlights the methodology in general focusing on the research method

employed, case study area, and data collection, processing and analysis workflow used in implementing this research.

- Chapter 4 presents the analysis results from methodology implementation.
- Chapter 5 discusses the research findings, and highlights some of the limitations to this research
- Chapter 6 presents conclusion, and recommendation for future works.

2 Background

2.1 Sense of Place

Researchers in the field of sense of place have encountered the challenge of conceptualizing and clearly defining this concept. Terms such as community attachment, place attachment, sense of community, and many others, have been interchangeably used making it difficult to discern if all the terms are talking about the same concept with different names or they are different concepts [12]. The confusion in conceptualization and terminologies has blocked the rapid advancement mainly with the definition and methodological approach that best suits exploration in this field as pointed out by researchers [12, 26, 30]. More recently, the construct has begun to be harmonized in terminologies in different disciplines including environmental psychology [27, 30], human geography, social sciences [37, 38], urban studies [5, 20, 28], to name a few.

Among a multitude of concepts describing the relationship between people and spatial settings, Sense of Place (SOP) is the most general technical term employed to delineate the bond between individuals and their surroundings [14, 21]. In their scholarly article, Chapin and Knapp (2015) described sense of place as the collective interpretations, principles, and emotions that individuals or communities attribute to specific locations. Moreover, sense of place is characterized as an ongoing progression wherein individuals consistently identify, form attachments to, and rely upon places [4]. Consequently, within the realm of environmental psychology, sense of place generally pertains to our perceptual understanding of places, the connections forged between individuals and their environments, as well as the symbolic connotations ascribed to specific locations[16].

In the context of cities, sense of place is not simply an abstract concept, but rather a complex intersection of numerous factors, including culture, environment, history, economics, and the overall urban context [23], the reoccurence of experiences and activities of individuals or groups at a certain location strongly influence the perception and meaning attached to the mere three dimensional shapes (geometric space) [13]. Furthermore, one cannot overlook the profound influence that global mobility and migration have on shaping the sense of place within cities [30], rendering them as experiential constructs with a distinctiveness that is characterized by how people perceive their surroundings based on their own unique experiences [1, 24]. It is crucial to acknowledge that these perceptions are inherently subjective and context-dependent as argued by Resch. et al. (2015) in their paper on urban emotions [24], which inevitably leads to a considerable variation in the sense of place experienced by different individuals and communities [1, 30]. Therefore, it is imperative to further explore the multifaceted nature of sense of place as a way to

highlight sense of place specifically in urban contexts.

2.2 Dimensions of Sense of Place

The scholarship of sense of place has explored this construct conceptually and operationally as a multidimensional phenomenon. The pioneering study by Jorgensen and Stedman [14] introduced the three fundamental dimensions, namely place dependence, place attachment and place identity, each corresponding to the affective, behavioral, and cognitive aspects respectively[30]. These three dimensions have been extensively examined and in subsequent research further dissected into additional dimensions including place inherited, place discovered, urban sentiment, to mention a few. Each of these dimensions details how a specific functional aspect of sense of place unfolds with the introduction of variables to evaluate the contribution and significance of each aspect to the development of the whole construct[8, 26, 32, 30].

In their recent research, Westerholt et al. explored the relationship of urban facilities with place dependence, place attachment and place identity to identify how the presence of such facilities that reflect functional urban aspects influence the meaning people ascribe to places[36]. The choice of dimensions explored stems from the initial conceptualization established by Jorgensen and Stedman [14] to highlight the complex link between physical and social factors and interpret results more accurately. One of the interesting findings is the significant influence of perception on all the dimensions, with the strongest relationship with place attachment, whereas, familiarity is not significantly related to any of the sense of place dimensions [36].

In a mobility and migratory context, Bazrafshan et al. explored the same dimensions through virtual park visits. Among other aspects, the authors evaluated the impact of place attachment on individuals' affective and perceptual properties [2]. An experiment conducted using visits of bi-cultural migrants to two virtual parks disclosed that place attachment and familiarity with green spaces, such as parks, have a significant influence on the affective responses. This influence stems from a matured sense of place among the migrant participants in the new place of residence [2], hence confirming one of the facts illustrated in [36] by Westerholt et al. highlighting that the presence of green space generally promotes neighborhood attachment and sense of place [20].

Furthermore, still in the context of spatial mobility and migration, Trabka explored the three fundamental dimensions and expanded further to include place inherited and place discovered into the extended family to shed light on the complex, multidimensional construct of sense of place, and as well analyse the dynamic process involved in the development of these dimensions among first-generation migrants with a case study on

Poles living in London and Oslo [32]. Results of the study revealed that these dimensions can coexist, and grow gradually, with place dependence and place discovered emerging relatively faster [32].

Additionally, Tang et al. explored a slightly similar set of dimensions in their study [30] to understand how distinction on residence time can be a factor in the distinction of dimensions of sense of place among non-native residents. Place dependence, one of the four dimensions of focus defined as the functional attachment in this study was found to be stronger across the city mainly towards areas dominated by working, leisure, and academic activities representing places where non-native participants carried out most of their routine-based activities. The above fundamental dimensions introduced by Jorgensen and Stedman [14] including the reinterpreted dimensions [30, 32] appear mostly in the environmental psychology literature.

Moreover, in the lens of urban studies, another interesting dimension of sense of place referred to as urban sentiment has been explored as a collective feeling of individuals about a city as places rather than simple spaces by Gao et al. in their study on measuring urban sentiment from social media data [8]. People's perception of the city environment and events form the unique identity of a city. Therefore, platforms where individuals express their opinions immediately, such as social media with the option to geotag the spatial extent, were used as a way to measure and analyse diverse perceptions of places, following the construct of sense of place, urban sentiment is considered as an influencing factor or a dimension that is evaluated and revealed the spatial distribution and heterogeneity of urban sentiment [8]. Urban sentiment is the most dynamic dimension of sense of place due to the fact that it depends on contextual factors that change from time to time. In their study, Resch et al. explored aspects of urban sentiment to reveal how the subjective feelings and perceptions of citizens about the city can be used in the context of urban planning [24]. Thus, a combination of dimensions explored in environmental psychology and urban studies is a good fit to capture the physical/functional, the social/emotional and individual/perceptual aspects of sense of place relevant to this study.

2.3 SpatioTemporal variation of Sense of Place

In various studies to explore the transition from functional bonds to place identity of migrants, authors like Trabka (2019), Qingjiu and Maliki (2013) argued that relationships between people and place are seemingly complex and evolve both through space and time [21]. Consequently, the development of sense of place with a new place is described adequately as a dynamic process [32], and the dimensions of sense of place are considered dynamic both in space and time [30]. In different literature, the dynamic nature of sense of place has been revealed by a number of methodologies used to map the variation

across space and time [30, 8], thus proving that sense of place evolves through personal experiences, and further defines how people interpret and perceive the world around them [25]

To address the dynamic nature of sense of place, Chapin and Knapp in [4] emphasized the influence of increased mobility as a factor among others leading to variation in levels of dependence, and length of residence in shaping the heterogeneity in attachment [4]. Evidently, long-term residences are likely to have matured as many dimensions of sense of place, for instance, valuing a place for its capacity to provide a livelihood through affordance and opportunities and at the same time viewing a place as socially active and feel emotionally attached. On the other hand, newcomers or short-term residents might only be attracted to the aesthetic and symbolic appeal which are fostered prior to their experience [4, 30].

Variation of sense of place on different spatial ranges have been explored by Hidalgo and Hernandez in [12], the spatial ranges in this paper were categorized from house, to neighborhood, to city level on both the physical and social aspects. The results revealed variation in the levels of attachment, with neighborhood level exhibiting the weakest relation [12]. The spatial variation of the dimensions of sense of place is explored again in [30], where each of the dimensions of focus exhibited a different spatial pattern and distribution across the study area in this research [30]. Sense of place is thus perceived to be primarily spatially heterogeneous.

As mentioned previously, the heterogeneity in spatial coverage of sense of place is also correlated with the temporal influence. In literature, the length of residence has been considered as the temporal aspect in the development of dimensions [30, 4, 36]. Time within a city intensifies sense of place, since people gradually access places, interact and expand their social network [30]. Some dimensions such as place dependence are not highly correlated with time while others, such as place attachment, generally develop with more time spent in the city [32]. Temporal influence can also be considered on a low-level temporal scale. One of the findings in [36] revealed that temporal rhythm such as recurrent interaction with a place or daily exposure can be meaningful to the development of sense of place, therefore, this could be a potential take for exploring the temporal variation.

Both the spatial and temporal variation of sense of place are important patterns to dissect in the development of sense of place. Acedo et al. emphasized the need for longitudinal time-series studies and a dynamic collection of data to depict the dynamism, time dependency and scale variability of place-based concepts such as sense of place [1]. We must acknowledge that existing literature on sense of place to some extent considers

the spatial and temporal variation, however, a large timestamp that is usually recorded once lacks the visually continuous detailed aspect of the temporal variation despite the ability to delineate the spatial variation. It is thus paramount to couple the spatial and temporal variation to fill the research gap presented in [1].

2.4 Sense of Place in Situ

Sense of place can also be fostered through processes that are considered to be immediate (perception-action) [30]. Instant experiences, emotions and perception of individuals recorded in situ have been used to explore the dynamism of sense of place, though mostly on the dimension of urban sentiment [8]. Raymond et al. in their study on the so-called fast and slow sense of place argued that sense of place can form through both immediate and direct perception-action processes, in addition to the longer-term processes that are based on intellectual abstraction, representation, or computation [23].

Studies that carried out in situ exploration aimed at picturing to a good extent the unfiltered perception [8, 24, 33]. In [33] participants were asked to describe different landscapes in situ to depict the extent to which sense of place is expressed. Through the data collected, patterns in the frequency of visits to recreational settings were identified and revealed a difference in sense of place. Additionally, geotagged social media content written in situ has been used to explore the collective sense of place [13], urban emotion [24] and urban sentiment [8]. The use of such data reveals the perceptual aspect of sense of place.

Furthermore, given the subjective, dynamic, and context-dependent nature of sense of place, exploring sense of place in situ provides additional inputs for accurate analysis in different contexts and dimensions. Collecting data on sense of place in situ also requires the willingness to explore this construct across time. This includes considering place forms and changes in respect to the immediate perceptions and longer-term processes of social construction as argued by [23]. Individual experiences and perceptions in this sense are analysed on the most detailed level with the advantage of having different temporal inputs that can be used to add either external environmental inputs such as traffic data, weather data, noise, time of the day at which the records are taken, and so forth, or they can be used to track the changes in sense of place along an extended time frame.

Few studies collect data on sense of place in situ, therefore, the role of in situ perceptions and experiences in the development of sense of place is unclear [1]. Consequently, this leads to recall bias where individuals might not still be retaining a clear picture of the events, situations, sentiments and experiences endured in specific places [1]. The shortage of literature exploring sense of place in situ presents a need to conduct studies or provide tools

that facilitate capturing direct perceptions, contextual effects, and low-level timestamped and geo-referenced data on overall sense of place or its different dimensions.

2.5 In-situ, location-based data collection tools

With the growing technology and availability of ubiqitous smart devices, the collection of in-situ, location-based data is consistently emerging in various research fields [1, 17]. This approach is enhanced by the use of location-based, context-aware data collection tools which are becoming prevalent in delivering the right information and triggering the right actions at the right place and time and thus facilitate the storage and retreival of the necessary data as well as the associated metadata of events in-situ[15]. These tools facilitate the acquisition of ground-based data offering advanced features such as real time readings, visuals, and easy data sharing in domains where constanst accumulation of data is crucial such as social sciences, platial research, urban planning, health, to mention a few examples [13, 3]

Mobile apps have been used as the easiest and convenient way for in-situ data collection for the advantageous capabilities of smartphones to detect and store objective sensor data from in-built GPS, accelerometer, gyroscope, and microphones [1] along with other information that the application is designed to capture. In literature, different mobile applications were developed to collect in-situ data coupled with sensor data. FotoQuest [17] is a mobile application developed to facilitate crowdsourcing of in-situ land cover and land use data in form of photographs and documentation coupled with their locations [17]. This data collection tool was used to validate the professional survey data against citizens' crowdsourced data, the results revealed a high level of agreement of the land use classifications acquired in the two different ways, and thus prove FotoQuest to be a useful data collection tool for urban planning [17].

Additionally, in-situ data collection tools are used in literature to investigate psychological and mental state and treat mental disorder. SYMPTOMS [9] is among the innovative solutions based on the use of geospatial and mobile technologies to improve mental health. It is generally an ecosystem of applications including the client-side applications (mobile and web application), and server-side services developed by the GeoSpatial Technologies Research Lab (GEOTEC) in collaboration with the Laboratory of Psychology and Technology (LABPSITEC) to help therapists provide remote treatment to patients with mental disorders through the patients' smart phone at any place (ecological) and time (momentarily) [9], and allow therapists to be able to identify, deploy, and follow-up location and sensor-based assessments and intervene accordingly to prevent relapse of the mental health disorders [9, 6].

In-situ data collection is facilitated by the SYMPTOMS android-based mobile application, which monitors the patients activities and delivers interventions according to the results of the collected data. The mobile application uses built-in and external sensors (GPS, accelerometer, heart-rate monitor,...) to collect the patients' passive data, and additionally collects active data from the patients through questionnaires and feedback [9]. Afterwards, the collected data are used to monitor the patient's progress or risk of relapse through the web application. The SYMPTOMS web application is used by therapists to register patients, configure the patients' mobile application in terms of the data to be collected in-situ by the mobile application (sensor data or patients feedback), the frequency of data collection, the intervention to be performed and the delivery condition (e.g. psycho-education, motivational messages via notification,...) and to visualize the patients progress on charts and map-based analysis of the data collected by the mobile application [9]. The collected data are first stored in a remote cloud database, which are further processed and analysed through the server-side services to extract meaningful information on the state of the patients. The analysis includes time spent inside or outside the patient's home, the mobility, the types of location and points of interest accessed by the patient along with the frequency of visits, to mention a few examples. The collected-processed data can then be used to inform the required intervention when the results reveal patterns that need attention such as the patients entering an area of interest for the treatment or when there are changes in the patient's behaviour [9]. Also, the mobile application can locally process the new collected data and determine whether there is a need for treatment intervention to be delivered, thus with the SYMPTOMS ecosytem functionalities and platforms, in-situ data collection is made easier, faster, and convinient for mental healht treatment [9, 6]

With the advanced capabilities of smart devices and in-situ, location-based data collection tools seen from the two examples from existing literature (FotoQuest [17], and SYMPTOMS [9]), this can be applied to other research areas where there is a need to collect longitudinal data, coupled with other details relevant to the study for more informed analyses [1], for instance in studies that seek to understand evolution of place attachments over space and time [20].

3 Methods and Data

This chapter describes in details the research methodology employed to carry out this study,the study area where the study is carried out, the conceptual framework to define the focus of this study and the methodological workflow and steps followed, and lastly, the implementation of the workflow along with the methods and tools used. Basically using a three-phase approach informed by an afore designed conceptual model, this study was implemented consecutively by collecting, processing, and analysing the data.

3.1 Research Methodology

The research methodology employed for this study is survey, which is widely considered as the most effective approach for its advantages, especially in social sciences, such as gathering a substantial amount of information including personal, social facts, beliefs as well as attitudes from a small sample that can be adopted over a larger population [18]. Hereby, the phases outlined in [18], which sequentially outlines a flow plan that starts with collecting data, performing descriptive studies based on the survey data, and the last part that involves the explanation of the data with statistics. We extended this generalised flow plan to include a conceptual framework so as to narrow down the extent of this study, and add specific parameters and steps suggested in [19] for survey methods on sense of place, including sampling, defining explanatory variables to the whole construct of sense of place, and applying quantitative approaches to assess the relevance of multiple layers that can be regarded as dimensions of sense of place on the development of sense of place.

By incorporating elements from both approaches above and founded in a literature-based conceptual models ([18], [19]), we developed a workflow aimed at achieving the objective and answer the research questions of this study. Employing an exploratory survey methodology, we conducted a comprehensive exploration of the spatial and temporal variation of sense of place in situ for the selected study areas (see section 3.2) through a sequential workflow (see section 3.3) detailing the data collection, data processing, analysis, and visualisation steps taken to answer the research questions that is informed by the conceptual model (see section 3.3.1) framing the extent of this study.

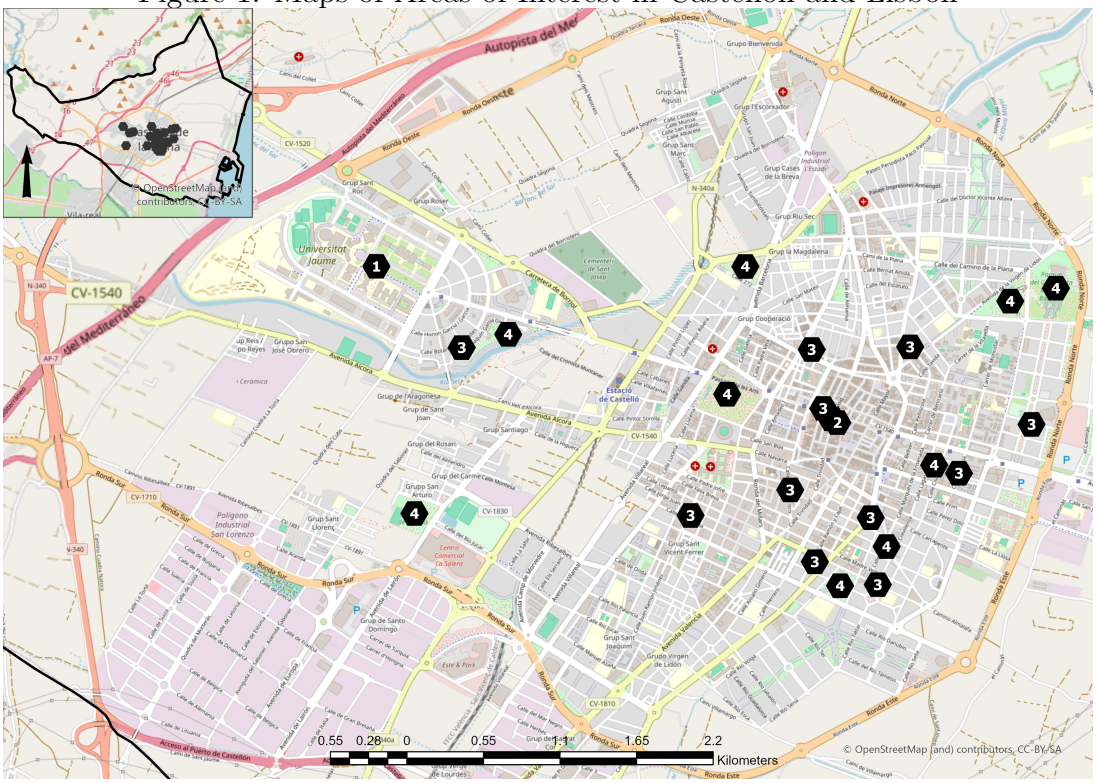
3.2 Study Area

This study was conducted in the cities of Lisbon in Portugal and Castellón de la Plana in Spain. Lisbon is a vibrant capital renowned for its historical significance and cultural dynamism, the increasing number of international students, and its fast-changing urban landscape [30], whereas Castellón de la Plana is comparatively a small city that has a

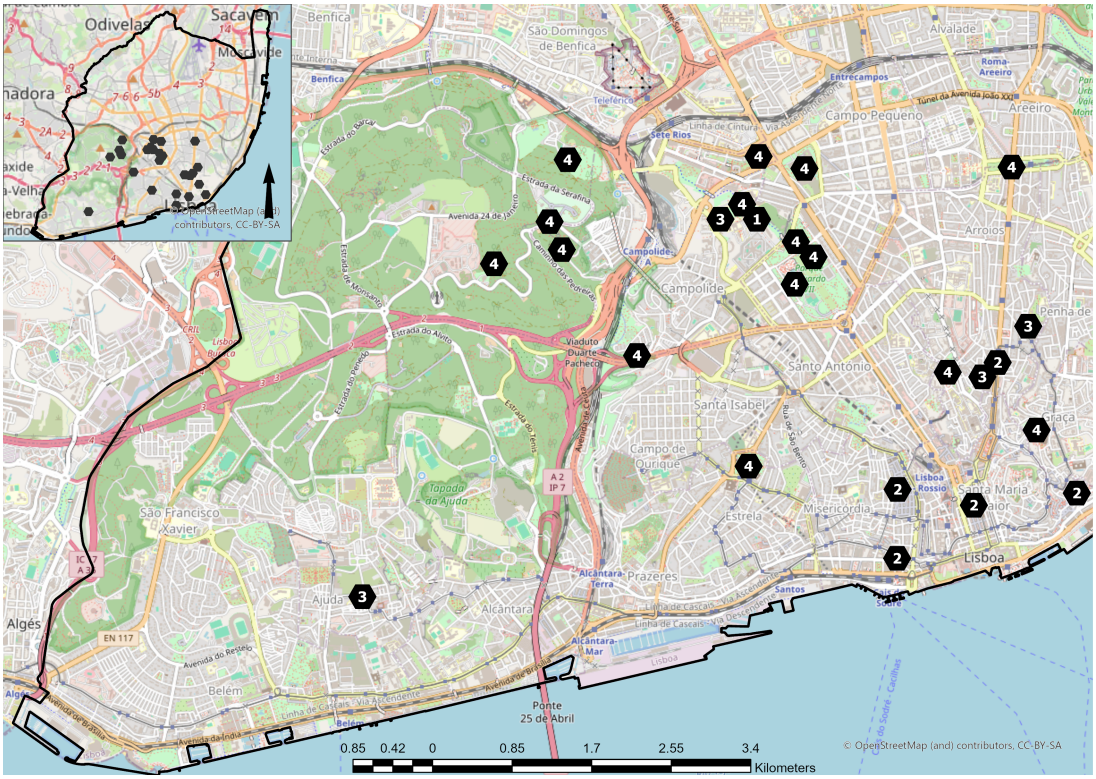
blend of modernity and tradition and a considerable number of international students in the Erasmus Mundus program. The contrasting urban settings in these two cities make them an interesting study area for this research, and in that sense, non-native students in the two cities are engaging in different activities, exploring the cities, thus making them the right fit to be recruited for data collection.

Given the nature of the study and the participants available, a few meaningful places were selected across the two cities as a precaution for randomly scattered and outlying data points. The locations that were chosen include those that students regularly visit for social, recreational, and entertainment purposes, as well as for daily tasks, chores, and routine-based activities. These locations can show which participant dimensions have already evolved and which are still emerging or show differences over time and space, allowing for a more thorough exploration of sense of place. The study area extent and the locations that were chosen for data collection are depicted on the figure 1 (map a and b, respectively, for Castellón de la Plana and Lisbon) below.

Figure 1: Maps of Areas of Interest in Castellón and Lisbon



(a) Castellón Map



(b) Lisbon Map

1 Campus 2 City center 3 Neighborhood 4 Parks

(c) Legend

3.3 Research Workflow

3.3.1 Conceptual framework

The inital step taken to carry out this study was designing a conceptual framework to narrow down and define the extent to which we explore sense of place. Drawing from the current state-of-the-art, this study treats sense of place as a multi-dimensional construct. The choice of dimensions of focus is supported by existing literature in environmental psychology [12, 30, 32, 36] and urban studies [24, 33, 8], and have been selected to better capture, represent and describe the spatial and temporal variation of sense of place. In addition, to conceptualize this study, it is only limited to a participant group of non-native students in urban areas.

Therefore, the dimensions explored in the above-mentioned studies that are relevant for this study are place dependence, place attachment and urban sentiment. Such a three-dimensional (place dependence, place attachment, urban sentiment) model better captures the spectrum of dimensions from functional, behavioral, and physical aspects of places towards more emotional and social aspects, then to individual/perceptual aspects of sense of place [23, 30]. This three-dimensional model applies the bottom-up theory of perception to attachment argued by Raymond et al. in [23], which considers the contribution of immediately perceived dimensions to the overall place meaning and can also reflect the intensity of place meaning, for instance, the amount of time spent in a place or the frequency of visits to a place can increase the attachment [23]. As such, sense of place can form through both an immediate and direct perception-action process in addition to longer-term processes [23].

The dimensions are further tailored down to variables that guide the design of the questionnaire to be used to collect data. For each dimension, at least two variables are defined, supported in existing literature. For a place to be meaningful, it should be suitable for individuals' daily routines, provide a sense of ease, joy, safety, and enjoyable experiences[36, 24]. These variables are a good fit for the dimensional models used to explore sense of place for non-native residents in an urban context, for they capture the most important and basic aspects of concern for migrants settling in new cities, regardless of the length of residency. Furthermore, the variation of each of the variables provides insights for the spatial temporal variation of sense of place in a bottom-up approach. Table 1 defines the dimensions explored in this study along with the variables of interest for each dimension.

Table 1: Dimensions of sense of place and variables of each dimension explored in this study

Dimensions	**Definitions**	**Variables**
Place Dependence	Surplus of affordance, opportunities, amenities, and resources a place can provide for goal-oriented behavior. Aspects include daily tasks, physical activity, leisure, entertainment, working, and studying [30].	Accomplishment, Suitability
Place Attachment	Emotional bond formed between individuals and a place [14].	Joy, Attachment, Interaction
Urban Sentiment	The feelings, perceptions, and attitudes people have towards urban environments [8, 24].	Safety, Accessibility, City atmosphere

3.3.2 Workflow

The workflow is made up of three main parts: data collection, data processing, and analysis and visualisation. Each part is detailed into small steps including designing a questionnaire based on the variables of each dimension from the conceptual framework (see section 3.3.1), developing a data collection tool for in-situ use and conducting a user study to collect data on the dimensions of sense of place, followed by the processing and aggregation of the data, then lastly the analysis and visualization.

A set of methods and tools were put together for each part of the workflow to be implemented effectively;

1. For the data collection part, following the conceptual framework, a questionnaire was designed and integrated into a context-aware mobile application developed with NativeScript, Angular, and AwarNS framework (see section 3.4.1.2) to trigger the questionnaire in situ and used to conduct a four-weeks user study to collect data.

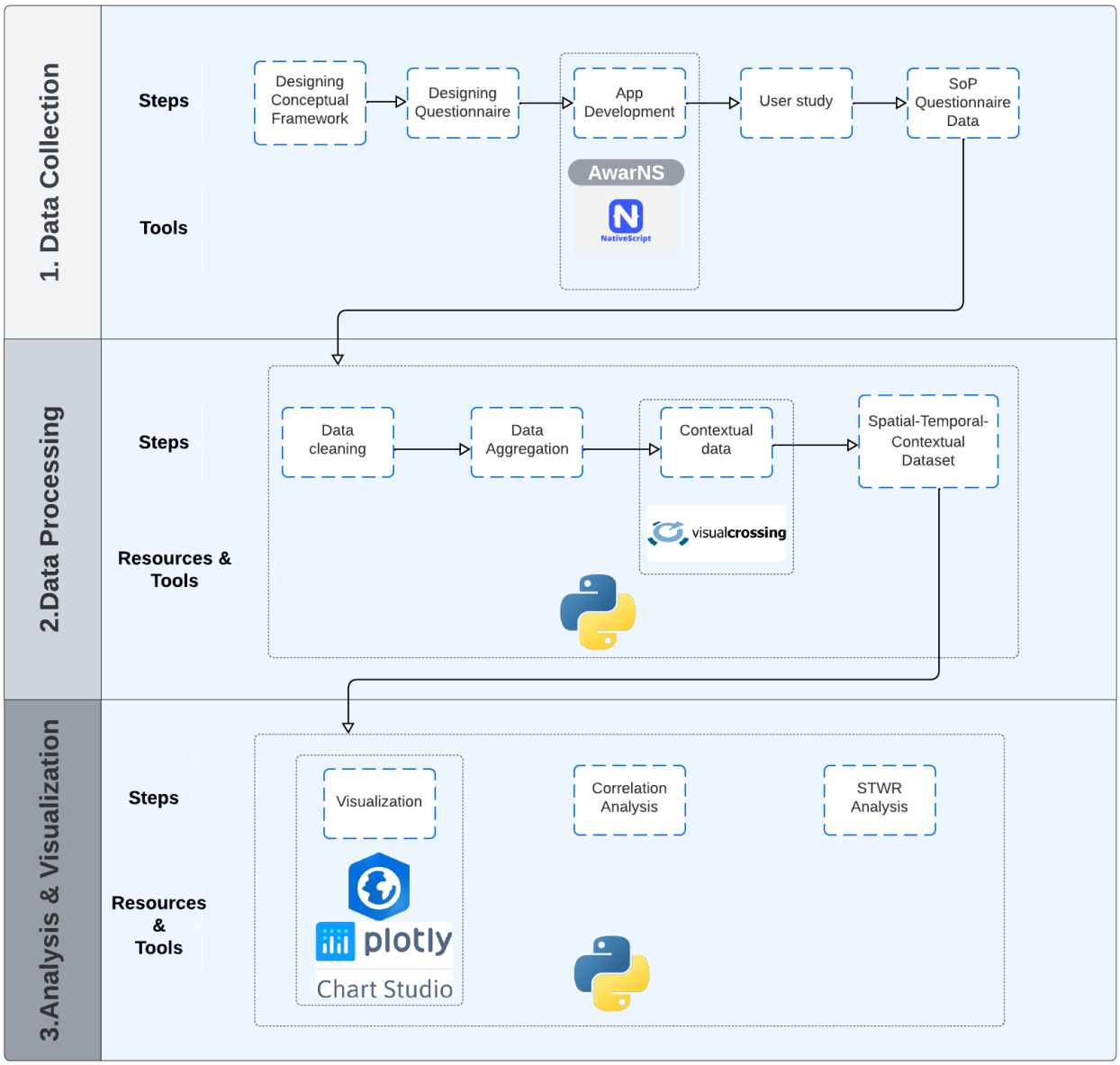
2. For the data processing part, data collected in the first step are processed and cleaned and aggregated using Python libraries and integrated with contextual data from third-party service to enrich the dataset for analysis.

3. The last part of the workflow, involved the creation of visualization and a set of

analysis including spatial-temporal weighted regression and correlation analyses using Python libraries and models.

Figure 2 details the sequence of steps involved in each part of the workflow, the corresponding tools and resources used to implement each step.

Figure 2: Research Workflow



3.4 Workflow Implementation

3.4.1 Data Collection and Tools

3.4.1.1 Questionnaire Design

After designing the conceptual framework, the next step involved the design of the questionnaire for data collection.. The questionnaire was designed to obtain data about each variable related to the dimensions outlined in Table 1 in the conceptual framework. The variables were used to define questions as statements that would rate the participant's relationship with and perception of the area they are currently in. A 5-point Likert scale was used to rate from strongly disagreeing (1 point - lowest rating) to strongly agreeing (5 points - highest rating). The questionnaire was designed to collect data starting with the questions related to participants' place dependence, followed by questions related to place attachment and finally, those related to urban sentiment. A total of 8 questions were defined from the nine variables to evaluate these dimensions of sense of place, and they were asked to the participants across all the places of interest to evaluate the development and variation of each of the dimensions of sense of place.

Table 2: Questions for the variables of each dimension

Dimension	**Variable**	**Question**
Place Dependence	Accomplishment	I am in this place to perform one of my daily tasks (work, school, chores).
	Suitability	I find this place suitable for accomplishing my tasks.
Place Attachment	Joy	I feel joy when I visit this place.
	Attachment	This is one of my favourite places.
	Interaction	My social interactions evolve the more I visit this place.
Urban Sentiment	Safety	I feel safe in this place.
	Accessibility	I was able to easily commute to this place
	City atmosphere	I feel at ease in this place.

3.4.1.2 App Development

The subsequent step in the data collection setup process was the development of a data collection tool. The approach used in this study was in situ, where participants were required to use a smartphone application to respond to the questionnaire while being physically present at one of the locations depicted on the maps of the study area in Figure 1. Collecting data in situ was fundamental for this study for two main reasons. Firstly, it allowed collecting the spatial and temporal data which could be supplemented later with contextual data during the preprocessing step. Secondly, it facilitated the collection of real-time in situ experiences and perceptions from participants, resulting in more accurate data for the evaluation of variables especially those related to urban sentiment dimension. This approach effectively addressed the recall bias issue highlighted in the study [1]. Therefore, to implement a different data collection approach that would enable gathering in situ perception and experience while capturing the spatial and temporal metadata, we developed a smartphone application.

A context-aware smartphone app was developed with the capabilities to track the device's current location, then, once found inside the radius of the area of interest (Figure 1), the app generates a questionnaire to the participants displaying the questions outlined in (Table 2) that are answered in situ. The application's main functionalities includes:

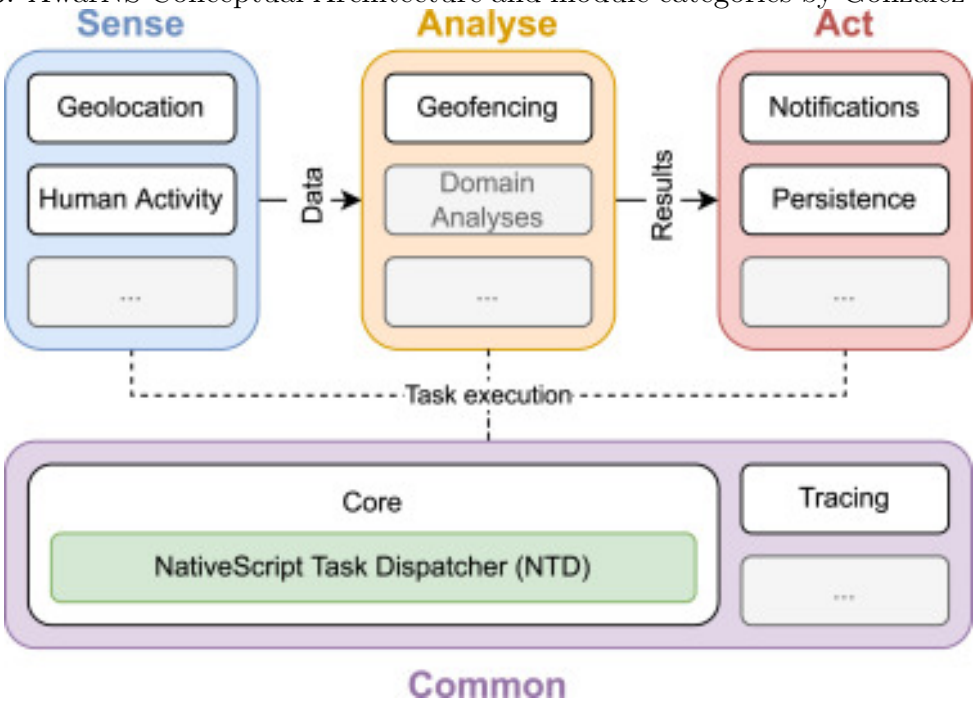
- Geolocation tracking: for obtaining the device's location updates, the tracking happens in the background at a regular time interval.
- Geofencing: to add a virtual fence around the areas of interest (Figure 1), a certain radius around the centroid coordinates of those areas was defined, so that the app notifies the user of the changes in the position relative to the area of interest and performs an activity given the current position.
- Push notifications: for triggering information that requires the participant's interaction, in this case notifying that they are inside the area of interest and that an in-situ questionnaire has been generated.
- Records storing: for storing the data collected by the app, such as questionnaire responses. This data is stored along with metadata like the timestamp and geofencing events.
- Application user interface: a home page with a button to share the app's records and a survey page that displays the questions one by one, ensuring that no question is skipped each time the questionnaire is taken.

Framework, Libraries and Modules

The native mobile app development framework used for this app is NativeScript, which specifically allows to build cross-platform mobile applications for both iOS and Android through accessing the native APIs to provide the native look and feel, and Angular, which provides a robust framework for building dynamic and responsive applications. Nativescript was coupled with Angular to create the two pages of a dynamic, user-friendly user interface for the app (the home page and questionnaire). These pages are related to the foreground activities where the user can interact with the app and be able to respond to the frequent questionnaire and later be able to share the compiled responses with other records stored in the app data.

Furthermore, the AwarNS framework [11] was used to implement all the background functionalities of the app. AwarNS is a NativeScript-based, context-aware modular development framework for Android smartphones created to simplify the development of mobile apps that listen to changes in the context and react even when the app is not visible or in use. This context-aware framework is based on the sense-analyse-act paradigm to facilitate data sampling in the background (sense), on-device or remote-server data analysis (analyse), and context-aware real-time offline or online intervention capabilities (act) [11] through different built-in modules including those that capture smartphones' data such as geolocation, physical activity, analysis modules for performing geofencing analysis, and act modules for persistence and delivering notifications. These modules are used together to listen for the change, then trigger a reaction in the form of a developer-defined task. This framework uses at its core the NativeScript Task Dispatcher (NTD) [10], which allows to define the mobile app's tasks and execution workflow, thus extending the NTD with primitives to ease the development of context-aware apps. However, only the Android platform is currently supported by AwarNS, thus by extension, our developed app currently only supports Android.

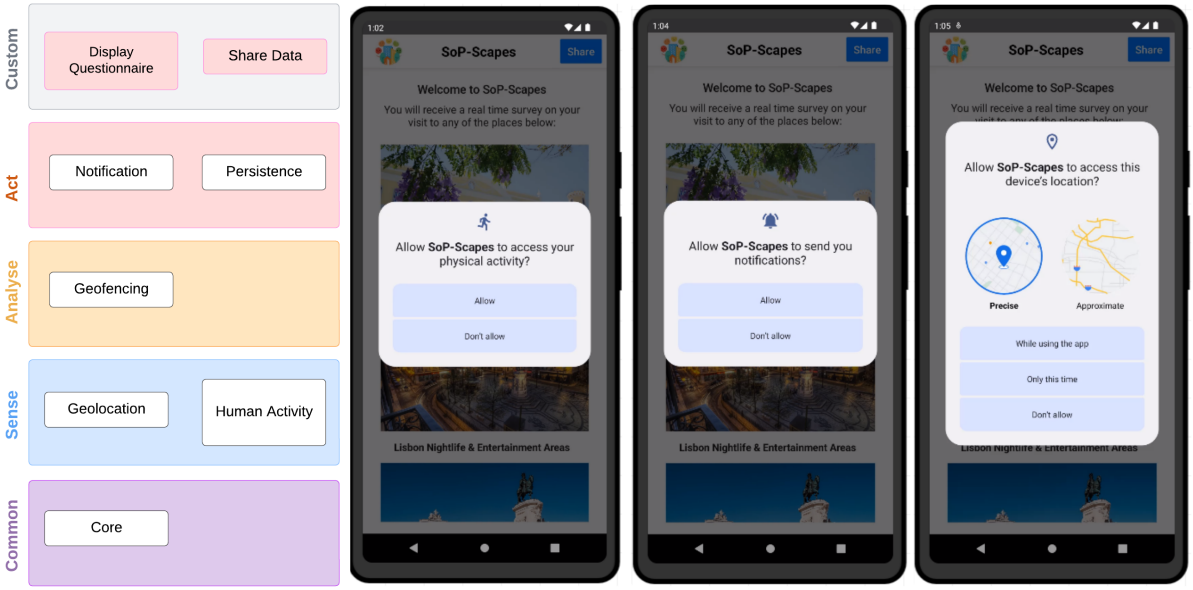
Figure 3: AwarNS Conceptual Architecture and module categories by Gonzalez et al. [11]



App Configuration

To configure our app for collecting data in situ, we put 5 different modules to work together from the AwarNS framework, namely: (1) the human-activity module to detect whether the phone is stationary or in movement, so as to start or stop the detection of the phone location; (2) the geolocation module, to access the location of the phone upon request after every one minute; (3) the geofencing module, for creating virtual boundaries with varying radius according to the area and inspect each of the collected locations to report if the proximity is found to be inside the area of interest; (4) the notifications module, to notify the users that the questionnaire has been generated, we specifically used the 'deliver_questions' type which supports user's tap actions to open and display the questionnaire page; finally, (5) the persistence module to store all the records. Figure 4 shows the architectual design of the app including the modules used and the paradigm they belong to [11].

Figure 4: SoP-Scapes App Conceptual Architecture



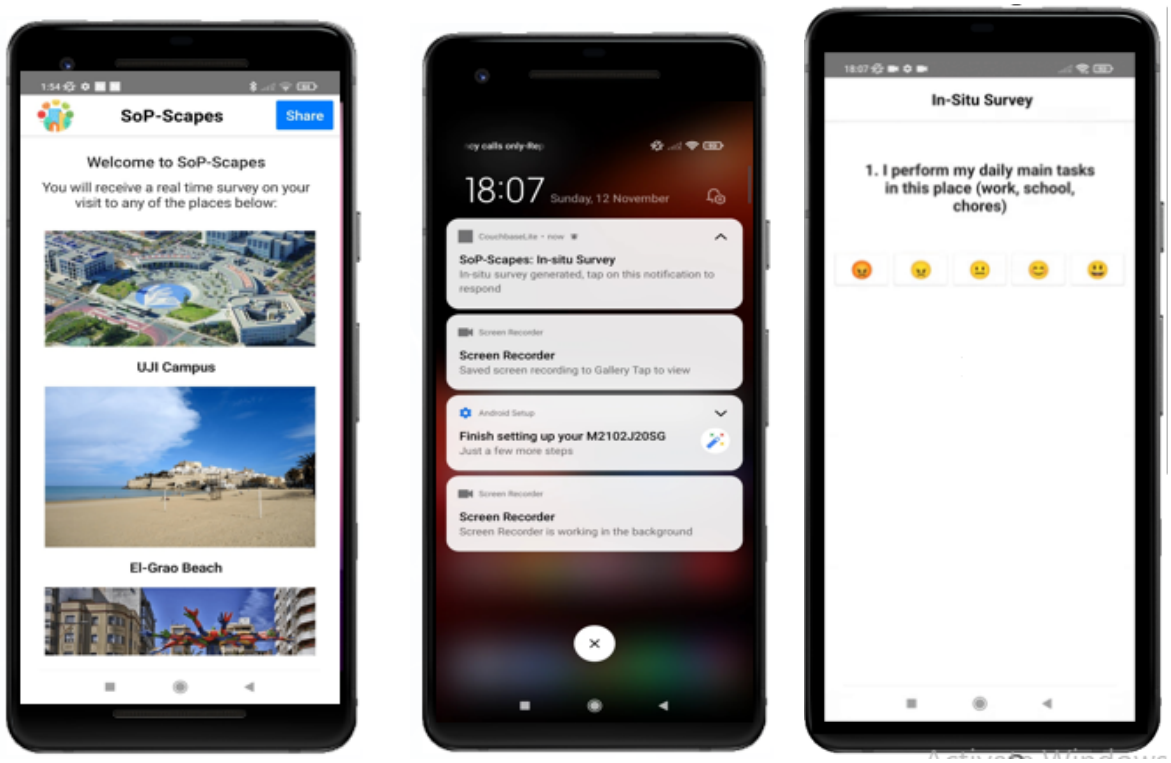
These features were defined as tasks following the NTD setup so that the app can run properly in the background, afterwards, we define how the sequence of the tasks will run once the app is installed on the smartphone using an NTD task graph. The sequence starts with detecting if the device is stationary or not. Once a non-stationary action is detected, the location of the phone is collected every minute. The collection of the phone location stops once the phone becomes still again. Each time a geolocation is acquired, the next task is to check how close it is to the geofenced areas, once found inside the geofence, a push notification is delivered in the phone's notification tray informing the user that an in-situ questionnaire has been generated and they are required to tap on the notification to access and respond.

The notification tap action brings the app into the foreground and opens the questionnaire page. The first display shows question 1 with options to answer with smileys that range from strongly disagree (1) to strongly agree (5). Once the participant clicks on one of the smileys, the next question displays continuously through the last question. The configuration of the questionnaire UI was done with Angular. For each performed survey, the responses are stored in an array together with the device UUID so that later we can differentiate the responses taken by each device, and group them to analyse the spatial and temporal variation in the responses. In addition, with the persistence module, other records written include the timestamp at which the questionnaire was answered along with the geofence coordinates. For privacy reasons, the participant's exact location is not stored, and the tracking is limited to confirming the presence within the defined geofence. All the stored records are written in the same JSON file and kept in the app's data on the

user's phone. To share these data, a NativeScript Zip plugin is used to compress the file, and then a share button on the home page is implemented to open the default email app of the smartphone and attach the zipped file with a preconfigured send-To email. The participant is thus only required to send the email through the designated button in the app. which is configured with the NativeScript Email plugin.

The functionalities of the app and the configuration allowed us to collect in situ perceptions and experiences of the participants on sense of place, and we were able to capture important information to analyse the spatial and temporal variation of the dimensions of sense of place. Below are the screenshots (Figure 5) showing the UI and the custom features (Figure 4) of the app developed and nicknamed SoP-Scapes [1] along with in-situ push notifications and the questionnaire page.

Figure 5: SoP-Scapes User Interface



(a) SoP-Scapes UI (b) In-situ Survey Delivered (c) Questionnaire Page

3.4.1.3 User Study and Participants

Lastly, to have actual data, a number of participants was invited to take part in the user study for a period of four weeks. We first conducted presentations and sent emails introducing the study to GEOTEC Master's students at the UJI campus in Castellón de

[1] https://github.com/Grace-Tumusanganire/SoP-Scapes.git

la Plana and the NOVA campus in Lisbon. We then shared a consent form [2] to recruit non-native students. In the consent, aside from the confirmation to participate in the user study, we also collected the length of residency, the basic demographic information, and the zip code or home address of the confirmed participants.

We then did the final configuration of the app by adding geofences to the zip codes or home addresses so that sense of place could also be explored in the participants' neighbourhoods in addition to the pre-configuration done before (see section 3.4.1.2) that includes geofences around the other 3 areas of interests namely campus, parks, and city centers (Figure 1), in-situ questionnaire generation once the current location is found within the geofences, and record storing and sharing via the app's UI. The questionnaire delivery was set to trigger everytime the user enters the area of interest to optimize the probability of having as many records as possible at different times of the day and different days of the week which is crucial for the temporal exploration in this study.

After the final configuration, we shared the fully configured app as APK files with instructions about the installation to each of the participants and continuously reached out to check for any bugs with the app. After 4 weeks, participants shared the data of the questionnaires they had answered across the locations they had been to at different times. The places chosen for collecting data were ideal given the complexity of data collection that was almost like an experiment, the number of participants, and the sample of places where the spectrum of people-place relationships experienced by non-natives likely exhibits variation across time on their quest to integrate into the new cities.

3.4.2 Data Processing

The next step of the workflow was processing the collected data for subsequent analysis. This step involved cleaning, aggregating, and normalising the collected data. The first step was to read the JSON files shared by the participants in the user study and consolidate them into a geodataframe. After that, we cleaned the geodataframe by removing unnecessary attribute columns for the study at hand (notificationId, timestamp.offset, aoi.id, aoi.radius) and performing datatype conversion to make future statistical analyses easier. Additionally, the JSON stored the location separately as latitude and longitude variables, thus, in the geodataframe, a geometry column was created to facilitate mapping the resulting geodataframe. Also, given the plugin used to collect the timestamp and the time difference between Castellón de la Plana and Lisbon, the time for Castellón data had an offset of 60 minutes, which was normalized in this step.

Furthermore, as part of the research questions, there is a need to explore the influence

[2] https://arcg.is/0T8rD0

of contextual factors on experiences, perceptions, and effects on the construct of sense of place. Thus, we extracted and added historical weather data for each record to the geodataframe. To do so, we used a third-party weather service [3], using the date and time variable from the geodataframe together with the name of the city where every record was taken, which are the required parameters to retrieve historical weather data. We retrieved the temperature, humidity, wind speed, and general weather conditions of the specific day and time at which all the questionnaires were completed. These retrieved variables were then merged into the dataframe. Additionally, we added the time of the day as a contextual variable by splitting the time from the date and then convert it to seconds. The resulting geodataframe was exported in a geopackage format [4] to be used in subsequent analysis and visualization.

The consolidated participants' collected data on the variables of the dimensions of sense of place, along with location and temporal data coupled with contextual historical weather data, and time of the day packed together into a single dataset produced a spatial, temporal, and contextual dataset on sense of place that was used for further analysis and visualization of sense of place across the two cities from which the results framed our discussions and contribution to the body of knowledge on the subjective concept of sense of place. The data processing part of the workflow was entirely implemented in the Python programming language, taking advantage of various libraries tailored for data manipulation.

3.4.3 Analysis and Visualisation

3.4.3.1 Visualization

We first created visualizations of distribution and patterns using ArcGIS Pro software to create 2D maps and disperse overlapping points in the radius of the area of interest to reveal the patterns. Afterwards, Plotly Chart Studio was used to create 3D visualizations of the aggregated sense of place across all the locations where questionnaires were answered by participants. The 3D visualization plots the location on the x and y axes, then plots the time on the z axis which is normalised as days. The variation and pattern of sense of place and its dimensions in space (x,y) and time (z) is shown by the varying sizes and colors of points on the corresponding x, y, and z values (see section 4.2.1).

[3] https://www.visualcrossing.com/resources/documentation/weather-api/timeline-weather-api/

[4] https://github.com/Grace-Tumusanganire/Spatial-Temporal-Contextual-Dataset-on-Sense-of-Place.git

3.4.3.2 Spatio-Temporal Analysis

To further analyse the spatial and temporal variation of the dimensions of sense of place with contextual factors, we performed a spatio-temporal weighted regression (STWR). With the advantage of incorporating the three essential characteristics of geographic entities (space, time and sense of place attributes), the evolution of the dimensions of sense of place is reflected. STWR has been used in literature to depict from big data the human and environmental dynamics through different perspectives including but not limited to patterns of human behavior [34], environmental risk assessment [29], disease outbreaks [31], to name a few examples. By modeling the changes in space and time of the attributes of such phenomena, this analysis complies with Tobler's first law of geography that "Everything is related to everything else, but near things are more related than distant things" [22].

In this study we used a model developed by Que et al. [22] to get statistical values significant enough to depict the variation of sense of place. This algorithm models the relationship between a dependent variable and one or more independent variables so as to identify the strength and significance of the association or relationship between the variables by considering that the velocity of value change in the variables is highly related if they are close in space and time [22]. Thus, STWR can borrow data from both nearer locations and nearby value variation in time. This model also uses the concept of time distance to refer to the rate of value variation through time, which is a value change reflecting the temporal effect of nearby points thus taking advantage of the variation in data to identify temporal non-stationarity [7].

This STWR model stems from the Geographic Weighted Regression (GWR), which extends the traditional global regression given by the formula (1) below. In Equation 1, y_i is a dependent variable of regression point i at a location with the coordinates $(u_i v_i)$ whereas x_{ik} is the k^{th} independent variable, and ϵ_i denotes the error term for the i_{th} point. Moreover, GWR in equation 2 allows the coefficient $\beta_k(uivi)$ to vary spatially to identify spatial heterogeneity shown in equation 2. $W_{(uivi)}$ is a diagonal weighting matrix specific to location i, which is calibrated by a specified kernel function with a given bandwidth. Every element w_i in the matrix reflects the impact from another observed point, whereby the higher weight the higher the impact [22].

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i) x_{ik} + \epsilon_i \tag{1}$$

$$\hat{\beta}^k(u_i, v_i) = (\mathbf{X}^T \mathbf{W}(u_i, v_i) \mathbf{X})^{-1} \mathbf{X}^T \mathbf{W}(u_i, v_i) \mathbf{y} \tag{2}$$

In STWR model, equation 1 and 2 are extended to deliver a spatiotemporal kernel, based on bi-square and Gaussian Kernel. Below, two equations are presented, respectively for the STWR spatiotemporal kernel

Figure 6: STWR - SpatioTemporal Kernel

$$w^t_{ijST} = \begin{cases} \left[(1-\alpha) \times \left[1 - \left(\frac{d_{sij}}{b_{St} - \tan\theta \times \Delta t}\right)^2\right]^2 + \alpha \right. \\ \left. \times \left(2/\left(1 + \exp\left(-\frac{|(y_{i(t)} - y_{j(t-q)})/y_{j(t-q)}|}{\Delta t / b_T}\right)\right) - 1\right)\right] \\ \text{if } \Delta t < b_T, \text{ and } d_{sij} < (b_{St} - \tan\theta \times \Delta t) \\ 0 \text{ otherwise} \end{cases}$$

$$w^t_{ijST} = \begin{cases} \left[(1-\alpha) \times \exp\left[-\frac{1}{2}\left(\frac{d_{sij}}{b_{St} - \tan\theta \times \Delta t}\right)^2\right] + \alpha \right. \\ \left. \times \left(2/\left(1 + \exp\left(-\frac{|(y_{i(t)} - y_{j(t-q)})/y_{j(t-q)}|}{\Delta t / b_T}\right)\right) - 1\right)\right] \\ \text{if } \Delta t < b_T, \text{ and } d_{sij} < (b_{St} - \tan\theta \times \Delta t) \\ 0 \text{ otherwise} \end{cases}$$

We used this model to calculate the spatial-temporal weighted regression. The model requires a time tolerance. We therefore set its value to be less than the smallest timestamp recorded in the dataset, which is the time when the first questionnaire was taken. By doing so, we ensure that every record in the dataset is considered while running the STWR. We also aggregated the Likert values of each dimension's variables outlined in Table 1 to find the mean value, and then applied the STWR model to each of the dimensions (place dependence, place attachment, and urban sentiment) as a dependent variable along with contextual variables (temperature and time of day) as independent or explanatory variables to evaluate the influence of the contextual factors on each of the dimensions. Finally, we calculated sense of place as the mean of all 8 variables, then applied the STWR model to each record, using timestamps as the temporal bandwidth and latitude and longitude as the spatial variables. The model revealed the statistical significance of the contextual variables on each dimension of sense of place and on the overall sense of place, as well as the coefficients considering the spatial and temporal non-stationarity of the observations.

3.4.3.3 Correlation Analysis

Next to the spatio-temporal analysis, we also performed a correlation analysis of the variables in Table 1 to explore how all the variables together relate to each other for both cities and separately for each city. The correlation is used to measure the strength and direction of the relationship between and among the variables by determining how the change in one variable is associated with changes in another variable. Afterwards, the relationships are visualized on a heatmap.

4 Results

4.1 User study and the Spatial-Temporal-Contextual dataset on Sense of Place

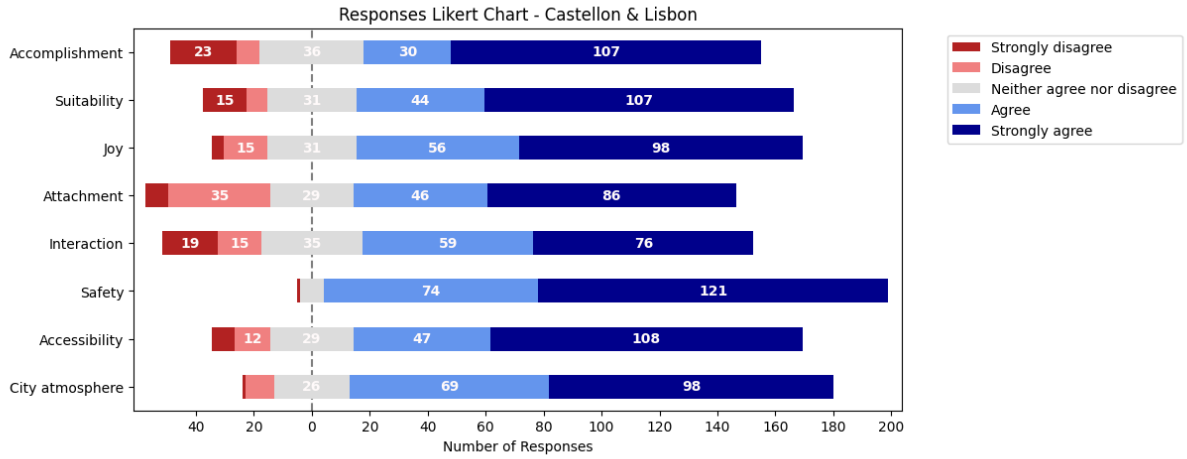
The user study kicked off with 24 participants across the two cities. However, there was a 33% dropout, due to which a total of 16 were able to participate till the end and share their data. Not all participants started on the same day; thus, to normalize the temporal attribute, four weeks for each participant were counted starting on the day they installed the app on their smartphones. Questionnaire notifications were not responded to every time they were generated, nor on consecutive days, however, there were multiple records of the same place on the same day. Table 3 summarizes the total records obtained across the two cities, all these records have spatial, temporal, and contextual information and comprise all the variables for each dimension explored in this study, given that participants could not skip any question each time a questionnaire was responded to.

Table 3: User Study Data Summary

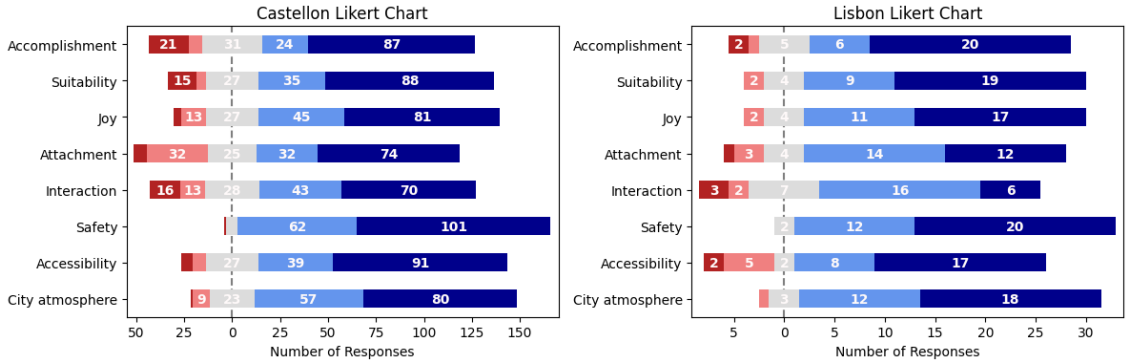
	Total Records	Castellón	Lisbon
Number of Participants	16	11	5
Places in total	204	170	34
Campus	48	36	12
City center	89	82	7
Neighborhoods	59	46	13
Parks	8	6	2

Exploring further the raw responses, as questions were asked according to the variables outlined in Table 1, and participants answered using a Likert scale, an overall summary (Figure 7) of the rating across all the places was created to explore the distribution of the ratings per variable and for each city. The variable of safety in urban sentiment has consistently got a high rating across the two cities, whereas in Castellón the variable of attachment has consistently rated poorly, same as the variable of interaction for Lisbon, both being the variable in the place attachment dimension.

Figure 7: Likert Charts



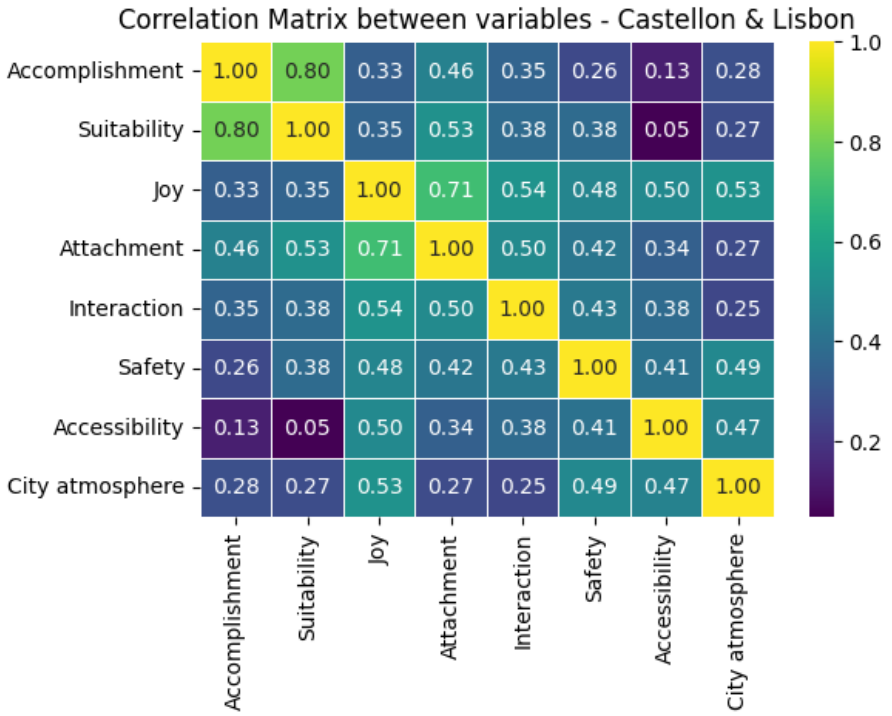
(a) Likert chart combining responses from the two Cities

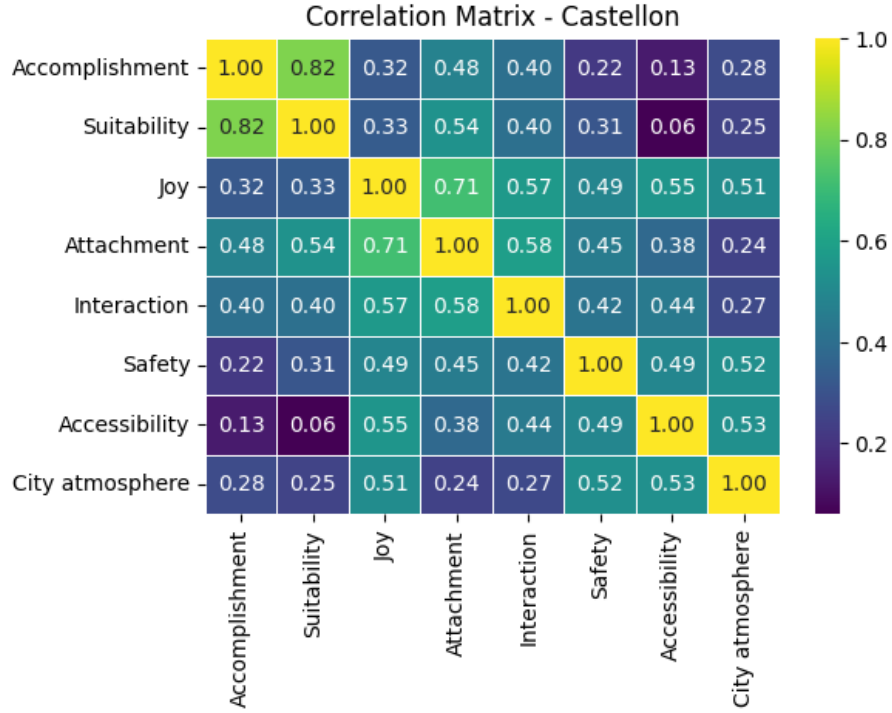


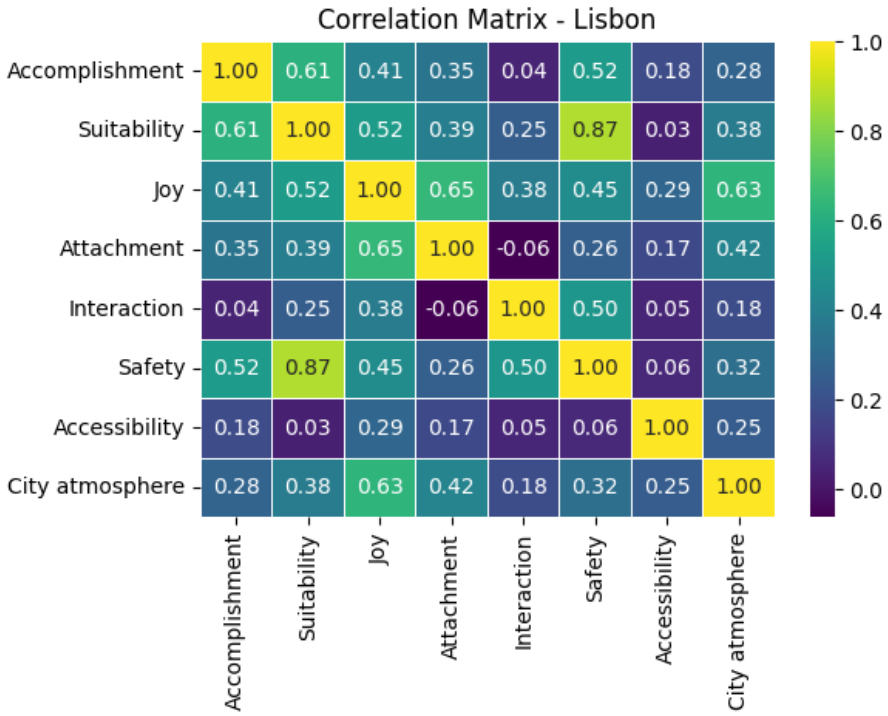
(b) Likert chart for each city

In addition, the correlation among these variables was explored to see the effects and relationships they have on each other. Figure 8 shows the resulting correlation matrices for all places (top) and for each city (bottom).

Figure 8: Correlation Matrices of the variables





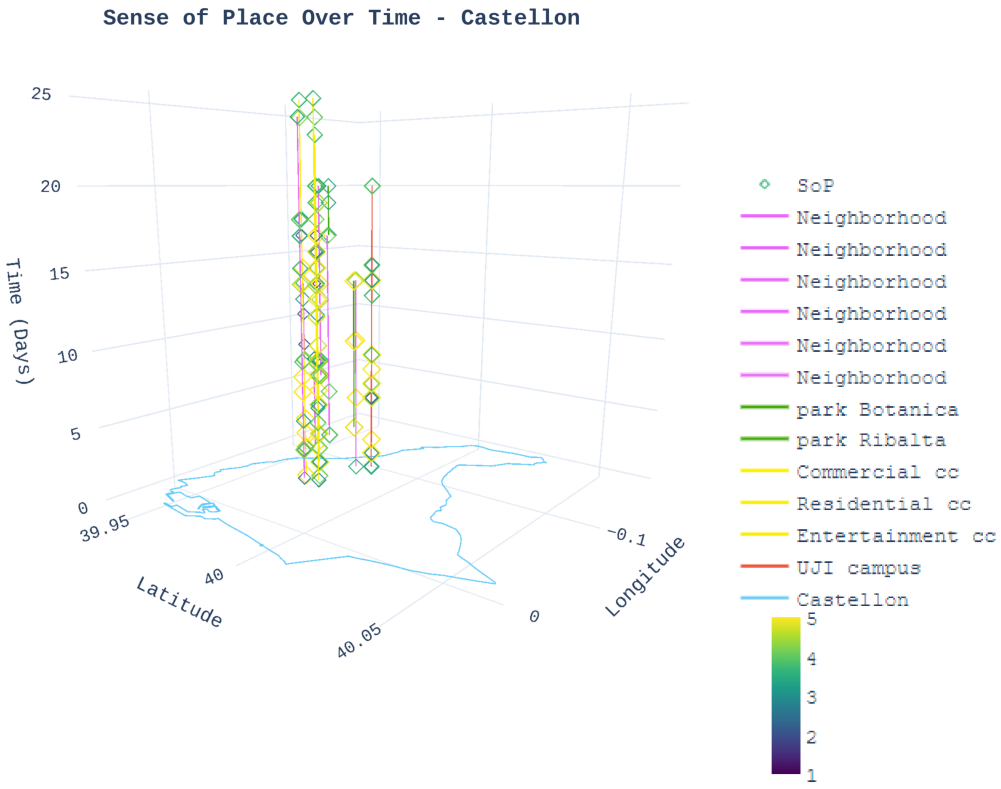


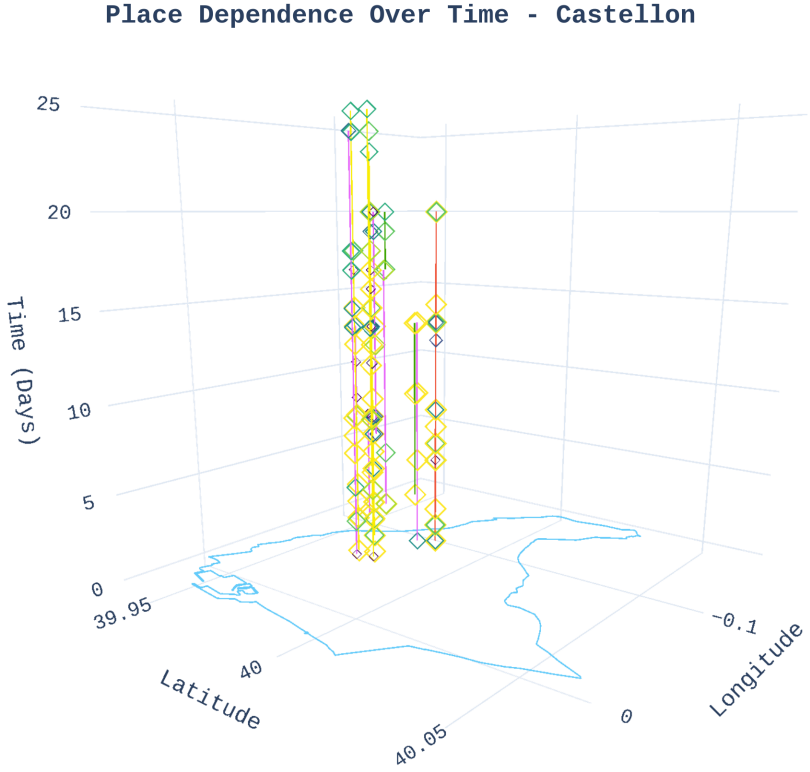
4.2 Spatial-Temporal Variation of Sense of place & Dimensions

4.2.1 3D Visualization of Variations

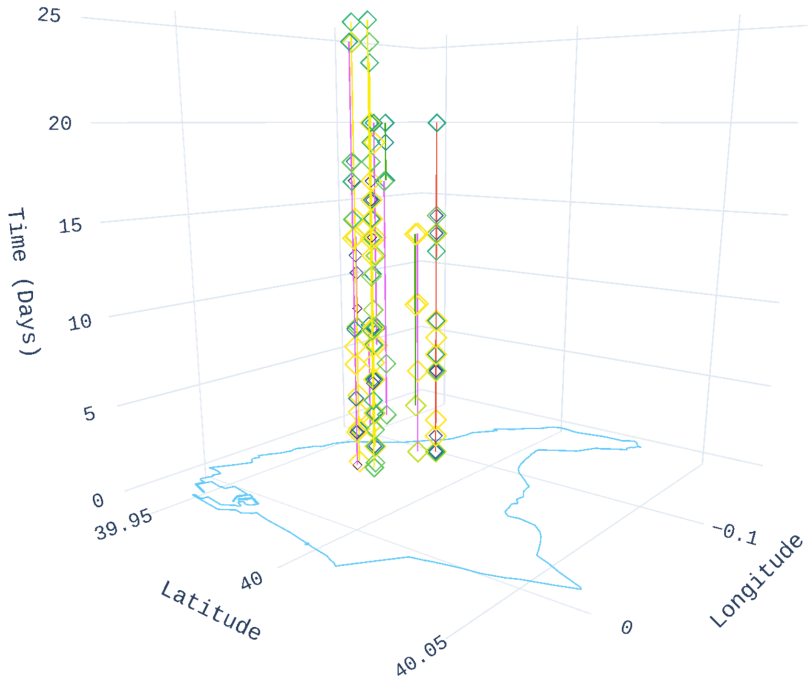
Figures 9 and 10 displays the 3D visualization of the variation of sense of place for Castellón and Lisbon respectively across the Areas of Interest. These charts were created from the aggregation of the variables for each dimension and from the aggregation of the dimensions for the construct of sense of place.

Figure 9: Sense of Place and Dimensions - Castellón





Place Attachment Over Time - Castellon



Urban Sentiment Over Time - Castellon

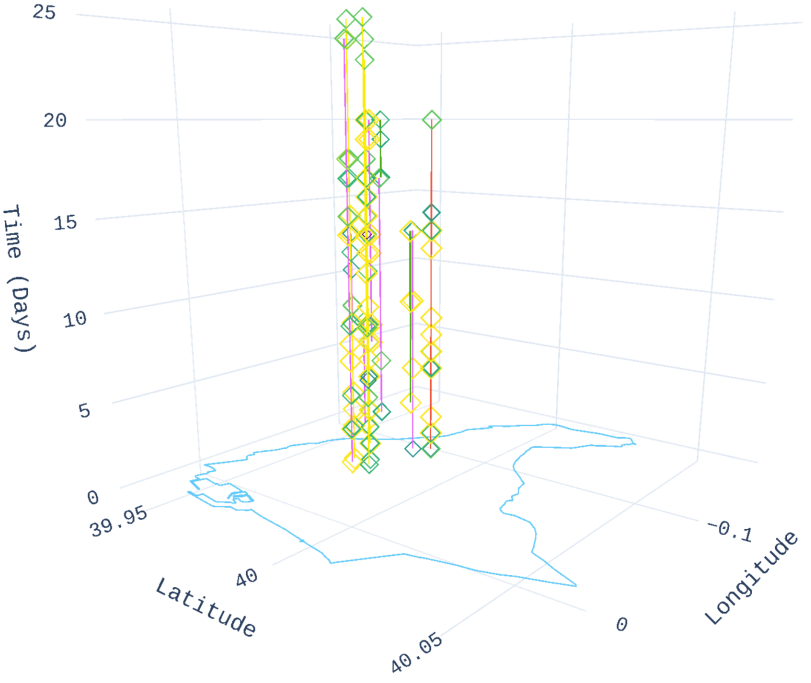
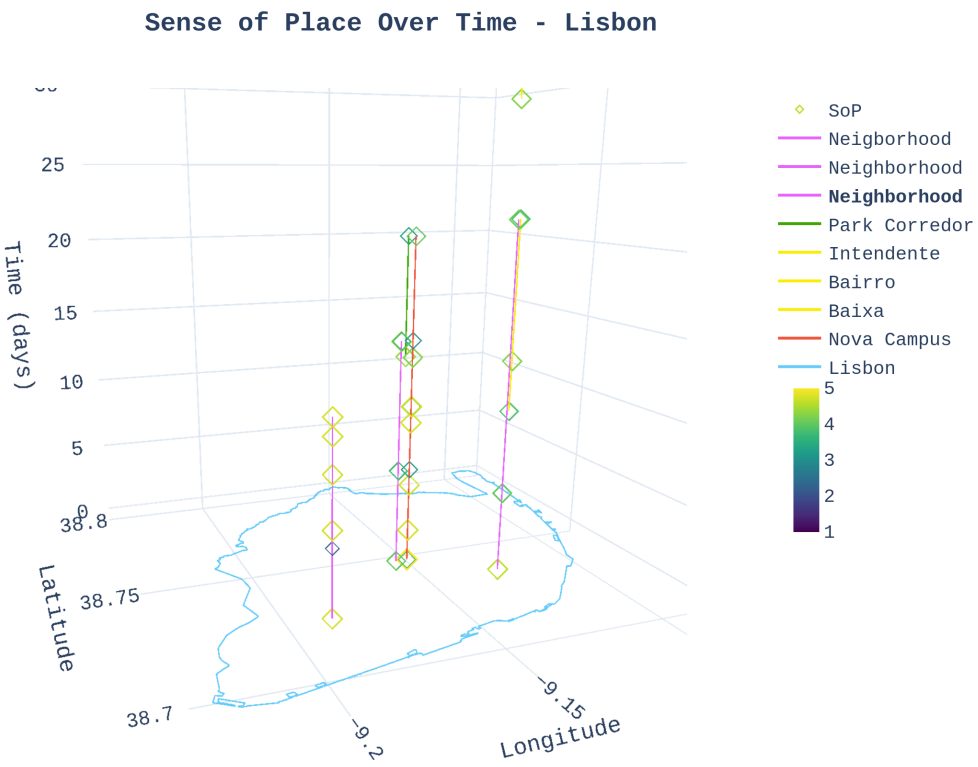
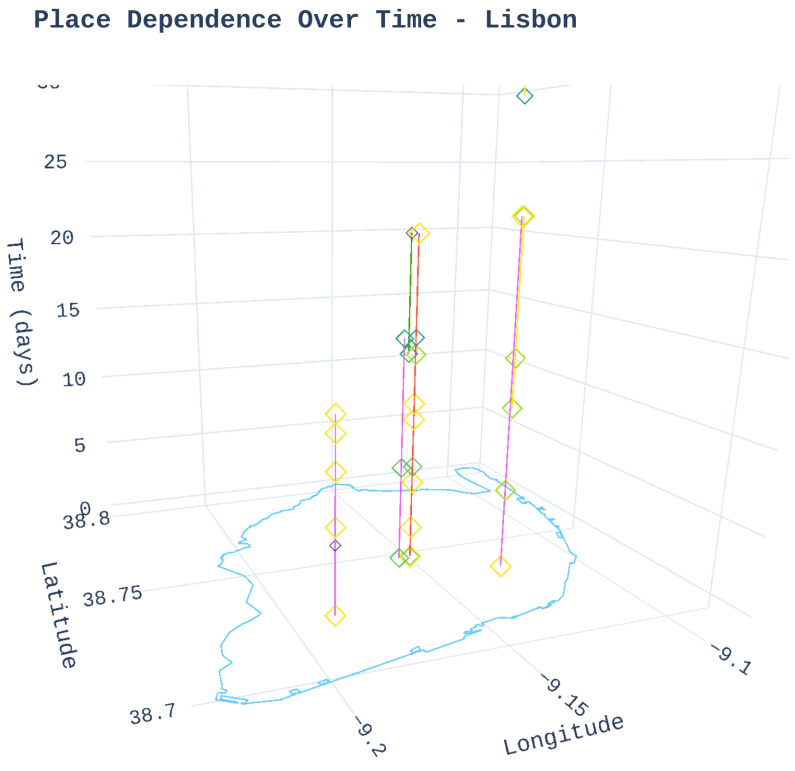
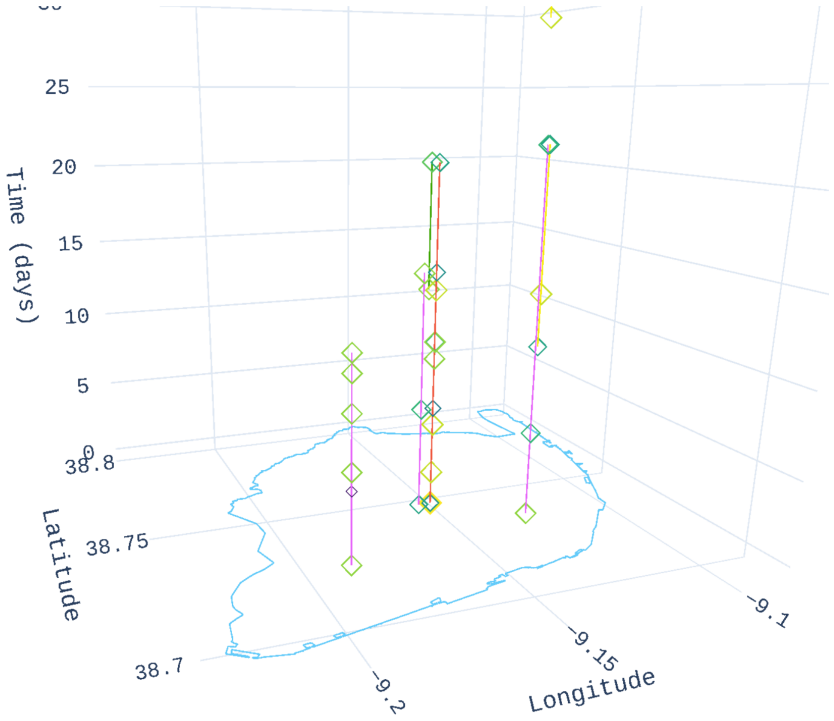


Figure 10: Sense of Place and Dimensions - Lisbon

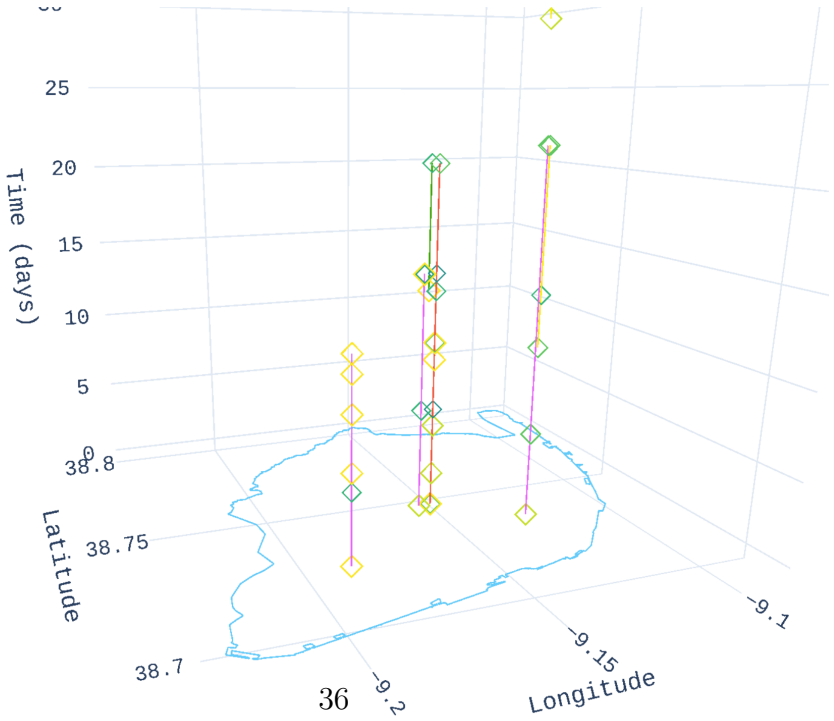




Place Attachment Over Time - Lisbon



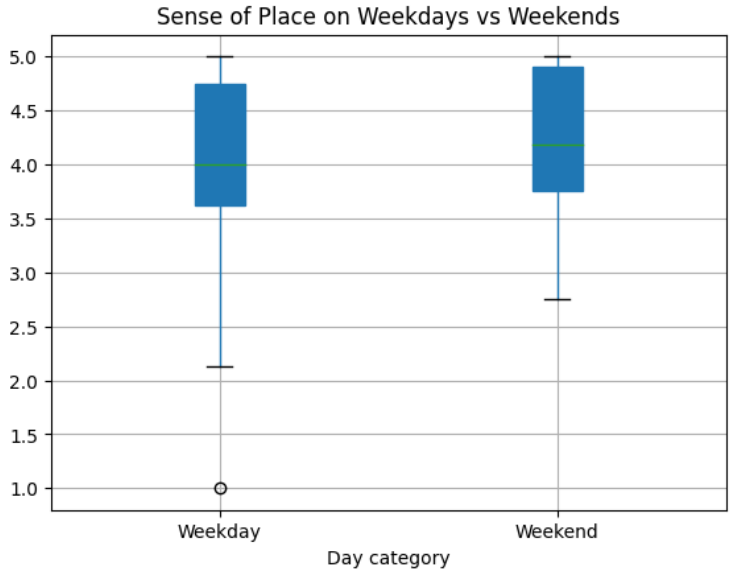
Urban Sentiment Over Time - Lisbon



4.2.2 Temporal Variation

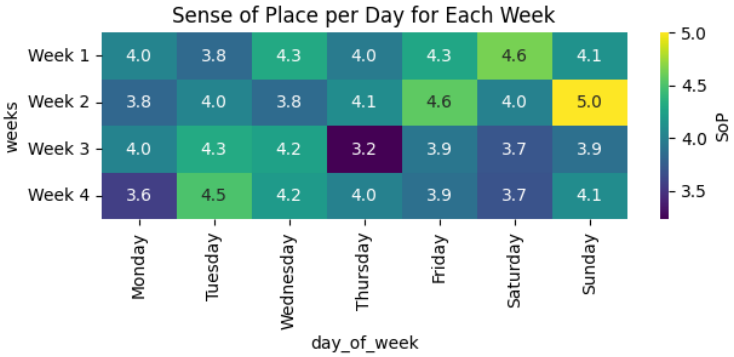
Looking into the temporal variation and pattern of sense of place, we used a boxplot to visualise and reveal the contrast in sense of place on weekdays (typically, working days) versus on weekends (typically, leisure days). On both weekdays and weekends, variation extends from the lowest rating to the highest, with the lowest outlying value observed during the weekdays. From the boxplot, on weekends, variation is more concentrated on positive values than it is during the weekdays, as shown in Figure 11.

Figure 11: Weekdays vs Weekends Sense of Place



Also, aggregating the daily sense of place for all four weeks, we created a chart to visualize any consistency from daily to weekly to the end of the user study shown in Figure 12.

Figure 12: Temporal Variation of Sense of Place



4.3 Spatiotemporal Analysis

Furthermore, we explored the spatial-temporal variation of sense of place and the dimensions of sense of place and how they relate to the contextual factors using a STWR model (see section 3.4.3.2). The results of the spatial-temporal weighted regression are summarized in Figure 13. To interpret the results, we first look at how the model fits the dataset. R2 is the statistical measure that determines the proportion of variance in the dependent variable that can be explained by the independent variable. The higher the value (0 being the worst, 1 being the best, and can also be represented as a percentage), the better the data fits the model. Each of the dependent variables (sense of place, place dependence, place attachment, and urban sentiment) used to run the model on the independent variables (temperature and time of day) has a different R2, with place dependence having the best fit (92.8%).

We also check the significance of the contextual factors (independent variables in the model) to the dependent variables through the p-values produced and summarized in the STWR results table (Figure 13). A p-value that is less than or equal to 0.05 is considered statistically significant in a regression, which means that there is strong evidence that the relationship between the independent variable and dependent variable is not due to random chance, in other words there is low probability (5%) that the observed relationship occured by random sampling variation alone, thus the smaller the p-value the better. From the summarized output, the contextual variables (x1: Weather represented by temperature, x2: time of the day) are less significant, however with weather being statistically significant to place dependence.

Figure 13: STWR results summary

Dependent Variables	Independent Variables	p-values	R^2
SoP	X1 : Weather	0.111	78.6%
	X2: Time of the day	0.410	
Place Dependence	X1 : Weather	0.050	92.8%
	X2: Time of the day	0.478	
Place Attachment	X1 : Weather	0.446	63.4%
	X2: Time of the day	0.357	
Urban Sentiment	X1 : Weather	0.847	73.9%
	X2: Time of the day	0.982	

A more detailed report of the model is found in Figure 14 for the model run on overall sense of place as the dependent variable and Figure 15 for the dimensions of sense of place (place dependence, place attachment, and urban sentiment) as the dependent variable to the contextual variables (weather and time of the day).

Figure 14: SoP STWR results summary

Variable	Est.	SE	t(Est/SE)	p-value
X0	4.586	1.165	3.937	0.000
X1	-0.088	0.055	-1.596	0.111
X2	0.000	0.000	0.824	0.410

Spatiotemporal Weighted Regression (STWR) Results

Spatial kernel:	Adaptive spt_bisquare
Model sita used:	0.000
Model alpha used:	0.070
Init Bandwidth used:	11.000
Model Ticktimes used:	1.000
Model Ticktimes Intervels:	2624950.000

Diagnostic information

Residual sum of squares:	0.508
Effective number of parameters (trace(S)):	6.000
Degree of freedom (n - trace(S)):	5.000
Sigma estimate:	0.319
Log-likelihood:	1.307
AIC:	11.385
AICc:	48.718
BIC:	14.171
R2:	0.786
Adj. alpha (95%):	0.025
Adj. critical t value (95%):	2.634

Summary Statistics For STWR Parameter Estimates

Variable	Mean	STD	Min	Median	Max
X0	5.772	0.892	4.795	6.586	6.586
X1	-0.141	0.071	-0.205	-0.205	-0.063
X2	0.000	0.000	-0.000	0.000	0.000

Figure 15: Dimensions STWR results summary

Variable	Est.	SE	t(Est/SE)	p-value
X0	5.465	2.187	2.498	0.012
X1	-0.204	0.104	-1.961	0.050
X2	0.000	0.000	0.710	0.478

Spatiotemporal Weighted Regression (STWR) Results

Spatial kernel:	Adaptive spt_bisquare
Model sita used:	0.000
Model alpha used:	0.000
Init Bandwidth used:	11.000
Model Ticktimes used:	1.000
Model Ticktimes Intervels:	2624950.000

Diagnostic information

Residual sum of squares:	0.668
Effective number of parameters (trace(S)):	6.000
Degree of freedom (n - trace(S)):	5.000
Sigma estimate:	0.366
Log-likelihood:	-0.205
AIC:	14.409
AICc:	51.743
BIC:	17.195
R2:	0.928
Adj. alpha (95%):	0.025
Adj. critical t value (95%):	2.634

Summary Statistics For STWR Parameter Estimates

Variable	Mean	STD	Min	Median	Max
X0	5.385	0.636	4.804	4.804	6.081
X1	-0.176	0.165	-0.327	-0.327	0.005
X2	0.000	0.000	-0.000	0.000	0.000

(a) Place Dependence

Variable	Est.	SE	t(Est/SE)	p-value
X0	3.783	1.851	2.044	0.041
X1	-0.067	0.088	-0.762	0.446
X2	0.000	0.000	0.921	0.357

Spatiotemporal Weighted Regression (STWR) Results

Spatial kernel:	Adaptive spt_bisquare
Model sita used:	0.000
Model alpha used:	0.070
Init Bandwidth used:	9.000
Model Ticktimes used:	1.000
Model Ticktimes Intervels:	2624950.000

Diagnostic information

Residual sum of squares:	1.799
Effective number of parameters (trace(S)):	6.000
Degree of freedom (n - trace(S)):	5.000
Sigma estimate:	0.600
Log-likelihood:	-5.649
AIC:	25.298
AICc:	62.631
BIC:	28.083
R2:	0.634
Adj. alpha (95%):	0.025
Adj. critical t value (95%):	2.634

Summary Statistics For STWR Parameter Estimates

Variable	Mean	STD	Min	Median	Max
X0	5.863	1.032	4.733	6.806	6.806
X1	-0.169	0.002	-0.172	-0.167	-0.167
X2	0.000	0.000	-0.000	-0.000	0.000

(a) Place Attachment

Variable	Est.	SE	t(Est/SE)	p-value
X0	4.477	1.780	2.515	0.012
X1	-0.017	0.086	-0.193	0.847
X2	0.000	0.000	0.022	0.982

Spatiotemporal Weighted Regression (STWR) Results

Spatial kernel:	Adaptive spt_bisquare
Model sita used:	0.000
Model alpha used:	0.070
Init Bandwidth used:	10.000
Model Ticktimes used:	1.000
Model Ticktimes Intervels:	2633924.000

Diagnostic information

Residual sum of squares:	0.549
Effective number of parameters (trace(S)):	6.000
Degree of freedom (n - trace(S)):	4.000
Sigma estimate:	0.370
Log-likelihood:	0.321
AIC:	13.358
AICc:	69.357
BIC:	15.476
R2:	0.739
Adj. alpha (95%):	0.025
Adj. critical t value (95%):	2.685

Summary Statistics For STWR Parameter Estimates

Variable	Mean	STD	Min	Median	Max
X0	5.921	1.921	4.000	5.921	7.843
X1	-0.088	0.088	-0.176	-0.088	0.000
X2	-0.000	0.000	-0.000	-0.000	0.000

(b) Urban Sentiment

5 Discussion and Limitation

5.1 Results Interpretation

In this chapter we first discuss the findings of the study with respect to the three main research questions posed before, and further discuss the contribution of the methodological framework to answer the research questions and achieve the objectives of this study, and lastly highlight the limitations encountered during the different implementation phases and how they affected to some extents the results.

Reflecting on the first research question, the findings from 3D visualization of variation (section 4.2.1) show that despite the fact that the two campuses have a considerable amount of records (Table 3), place dependence on campus shows few variation (Figure 9 and 10). For Castellón, the city center is the second place that exhibits a consistent positive sense of place in general and more positive place dependence. The city center in Castellón is classified into categories, including the area dominated by commercial activities, the one dominated by residential occupancy, and the part that is dominated by entertainment and social activities. All areas show consistent positive place dependence. Also, most of the participants' neighborhoods and home addresses are in the vicinity of the city center, which may explain the positive place dependence.

In contrast to Castellón, there aren't as many data points for Lisbon; in particular, there aren't many data points for the area of the city center where a vibrant nightlife predominates. Compared with the participants' neighborhoods, place dependence and urban sentiment are more intense in the neighborhoods than in the rest of the places where there are records. Similarly to Castellón, there is not much variation for Lisbon in the temporal aspect of sense of place

Parks were the least explored places, and the few records taken there are likely from participants living close to parks and randomly responding to the questionnaire because it was generated on their way home, not by voluntarily having visited the park.

Place attachment has been constant throughout the study, with its variable exhibiting a medium to negative correlation with the variables of place dependence. This shows that the three dimensions develop differently, and the feeling of belonging usually takes time to develop among non-natives adjusting to new urban settings [32]

Furthermore, reflecting on the influence of contextual factors on sense of place, and particularly in the variation of the three dimensions of sense of place considered in this study, the results of the spatio-temporal weighted regression (STWR) show the least statistical significance of the two contextual variables (section 4.3). Even though for a

busy city like Lisbon, where accessibility has a higher negative rating (Figure 7), the influence of contextual factors such as time of day still has little impact on the sense of place in general. This could be due to the shortage of data records. Thus, more exploration is needed of other contextual factors. When we applied the STWR to each dimension, weather exhibited statistical significance for place dependence, whereas for the rest of the dimensions, there was no statistical significance for the two contextual variables, and consequently, given their p-values, the observed differences were random.

Lastly, reflecting on the similarities and differences in the development of sense of place across the two cities, due to the shortage of participants, splitting them into groups according to the length of residence was not a viable option to discuss the spatio-temporal similarities, since some groups would end up being misrepresented. However, looking at the correlation among the variables (Figure 8), there are differences in the correlation across the two cities. For Castellón (Figure 4.1) , accomplishment is highly correlated with suitability, showing that place dependence influences a greater sense of place, while for Lisbon (Figure 4.1), suitability and safety are highly correlated, showing that place dependence and urban sentiment affect each other, additionally, for both cities the variable of joy is highly correlated with attachment and thus these two variables are crucial for place attachment. Another interesting relationship is the high correlation between city atmosphere and joy for Lisbon showing that for in this city is likely influenced by the feel and overall perception of the people and vice versa, whereas for Castellón, joy is also highly correlated with interaction, thus for Castellón the three variables of place attachment (joy, interaction, attachment) are all highly correlated. Interestingly looking at these three variables for Lisbon, attachment and interaction are negatively correlated, this can be an interesting observation that needs further exploration with more data. Nevertheless, these relationships generally have a great impact on the development of sense of place.

Reflecting on our improved methodological framework developed to conduct this study allowed us to implement suggestions from literature and contribute to the identified research gaps (see section 1.2). The conceptual framework (section 3.3.1) developed to narrow down and define the focus of this study is a contribution to the exploration of a set of dimensions that capture the functional/physical, the emotional, and the perceptual aspects of sense of place. With this conceptual framework we were able to explore variables of place dependence, place attachement, and urban sentiment relevant to a bottom-up theory of sense of place that can be explored in the context of their spatial and temporal variation among non-native residents regardless of the length of residency [23, 36].

Furthermore, with the design of the data collection phase in our methodological frame-

work, we were able to implement suggestions in literature [1, 23] related to in-situ data collection method as the best approach to tackle the recall bias which is related to the retaining of a clear picture of the events, situations, sentiments and experiences endured in specific places [1], as well as the spatial-temporal variation of sense of place which requires multiple timestamped records to explore the variation not only in space but also over time. We therefore developed an in-situ data collection tool (see section 3.4.1.2) to collect timestamped records in situ to acquire an spatial-temporal dataset.

Additionally, we enriched our spatial-temporal dataset with contextual data from third-part services to include weather data, we also extracted time of the day when questionnaires are answered to add more contextual variable during the preprocessing phase (see section 3.4.2). This dataset was used to explore the dimensions of sense of place, how they vary across different places and across a relatively short time span, the spatial-temporal relationship of dimensions of sense of place and contextual factors, and similaties and differences in the development of sense of place given the correlation of the variables. The spatial-temporal-contextual dataset and statistical analyses are an asset from the methodological framework developed in this study and can be used by other researches aspiring to explore bonds, attachment and perception of non-native urban residents.

5.2 Limitations

Among the limitations encountered while conducting this study was, firstly, the limitation of the framework used for developing the data collection mobile application (i.e., Android only; iPhone users were not supported), which consequently led to a limitation in the number of participants who could participate. The limited amount of participants became a notable challenge, and might have affected the study outcomes and conclusion. In addition, this led to a limitation of places to explore in our study area as a precaution to avoid outliers in the data. Further large-scale studies are needed to confirm the outcomes of this preliminary evaluation.

The time allocated for data collection was another major challenge for this study. This is due to the fact that there are locations that have either very few or no data, and these locations may have been visited by the participants at least once if the data were collected over a considerably longer period of time. Consequently, only places very close to each other have records, thus complicating the visualization of the spatial variation. Additionally, for the analysis of spatiotemporal weighted regression, the dataset could not be split by city due to that, there should be as many unique locations as possible to avoid errors in the model such as not finding calibration results or singular matrix during calibration whereby the model fails to find a spatial bandwidth (variation in space) despite the availability of temporal bandwidth. We run the model on the whole dataset to have

a considerable amount of unique locations (campuses, parks, city centers, neighborhoods across the two cities). This could also be a major limitation in case there are many independent variables to be run at once on a dataset with few data point or few unique location (which is the case for our study). These major limitations impacted the outcome of the study, even though we tried to find a workaround to successfully obtain the results.

6 Conclusion and Future Work

In a nutshell, this study explored the spatiotemporal variation of sense of place in situ with the aim of mining into the multidimensionality of this construct across two different urban settings namely Castellón and Lisbon , focusing on non-native residents. Following our improved methodological framework designed to address some of the research gaps identified in the sense of place scholarship (section 1.2), we developed a contex-aware mobile application and collected individuals' perceptions and experiences in situ. Afterwards, we retreived third-party weather data and time of the day at which in-situ questionnaires are answered and integrated the two contextual variable to create a rich dataset of spatial-temporal-contextual variables on sense of place and its three dimensions of focus in this study which are place dependence, place attachment and urban sentiment. We then explore the dataset to analyse and visualize the spatial and temporal variation of sense of place across our study areas.

Results of our study reveal consistent positive place dependence in areas representing routine based activies such as campuses, city centers, and neighborhoods. for place attachment, the results shows a comparatively neutral to positive values in city centers and neighborhoods for Castellón, whereas for Lisbon, place attachment is constistently neutral across the explored locations in the city. For both cities, urban sentiment revealed consistency in neighborhoods for Lisbon and Castellón with positive urban sentiment in city centers for Castellón. Exploring spatial-temporal regression of sense of place and the influence of contextual factors (weather and time of the day) on the variation of dimensions of sense of place, the results revealed that the variation is random except for weather which is statistically significant on place dependence thus increasing the probability that the percieved variation could be explained by weather conditions. We also used different variables (3.3.1) to explore their correlation (Figure 8) and discuss their dependence and influence in the development of sense of place across the two cities. These results add to the body knowledge despite a few limitations including that the mobile app for data collection only supported on Android devices hence limiting the number of participants during the data collection phase, and the extent of place to be explored around the study areas.

Our contribution includes a new methodological framework that could be applied to other social, psychological, and environmental phenomena that require exploration across space and time. This research also add to the body of knowledge by exploring a different set of dimensions of sense of place that is least explored in existing literature [8, 1, 23], and also by incorporating a low-level timestamp and contextual factors to depict the spatial and temporal variation of sense of place. The spatial-temporal-contextual dataset

on place dependence, place attachment and urban sentiment resulting from the employed methodological framework can also be used for further exploration and integration of other contextual factors to come to new insights on sense of place.

Future research should focus on getting a wider range of people to participate in an extended user study for in-situ data collection. Secondly, it could be interesting to use qualitative methods to record the variety of people's experiences and extract semantic meaning people ascribe to places while leaving the experiences in situ which could lead to more profound understanding. Also adding other contextual data such as noise and traffic could add lens to the understanding of immediately perceived sense of place dimensions such as urban sentiment.

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Masters Program in Geospatial Technologies

Exploring the Spatio-Temporal Variation of Sense of Place in Situ

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Dissertation submitted in partial fulfilment of the requirements for the Degree of *Master of Science in Geospatial Technologies*

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