# EXAMINING THE EFFECTS OF SEQUENTIAL POLYHEDRON VISIBILITY ON WAYFINDING AND EVACUATION

A Thesis

by

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Submitted to the

Graduate School of Sciences and Engineering
In Partial Fulfillment of the Requirements for
the Degree of

Master of Science

in the
Department of Architecture

Özyeğin University
May 2022

# EXAMINING THE EFFECTS OF SEQUENTIAL POLYHEDRON VISIBILITY ON WAYFINDING AND EVACUATION

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# ABSTRACT

This thesis presents the understanding that the basics of the human wayfinding process can be substantially illuminated by the correlations between space-syntactic variables and kinesthetic data of individuals roaming in a spatio-temporal environment. Although two-dimensional syntactic concepts offer a perception of place to some extent, they may neglect to capture the volumetric effects of space on human perception, especially during movement. Therefore, besides 2D syntactic variables, this master thesis essentially focuses on polyhedrons as 3D isovists to explore the impacts of the sequential volumetric visibility data on human behavior in terms of the spatial decision-making process in the wayfinding and evacuation issues. In this framework, the research discusses the results of a series of wayfinding and evacuation experiments implemented in a virtual building environment consisting of randomly arranged and dimensioned circulation areas. While the evacuation experiments contain legal egress signages at properly designated doors and spots, wayfinding experiments present no signboards.

On the other hand, the virtual building model is designed with a couple of architectural 3D modeling software and transferred into a simulation environment. The experiments are conducted with forty-four (44) respondents over an online meeting platform. Then, the respondents' routes and kinesthetic data are retrieved from the experiments, and the correlations between behavioral and syntactic data are investigated. The primary findings demonstrated that participants in the regular exit group tended to be around the zones with higher integration values. In contrast, the signages and volumetric visibility data are highly influential on the emergency exit group when evacuating the building.

# ÖZETÇE

Bu tez, insan yön bulma sürecinin temellerinin, sentaktik değişkenler ve makan-zamansal bir ortamda dolaşan bireylerin kinestetik verileri arasında ortaya çıkan bağıntılarla büyük ölçüde aydınlatılabileceği anlayışını sunmaktadır. İki boyutlu sentaktik kavramlar mekan ile ilgili insan algısını bir dereceye kadar sunabilse de, mekanın insan algısı üzerindeki hacimsel etkilerini özellile hareket sırasında yakalamayı ihmal edebilir. Bu nedenle, bu yüksek lisans tezi yol bulma ve tahliye sırasındaki mekansal karar verme konularında iki boyutlu sentaktik parametrelerin yanı sıra, ardışık hacimsel görünürlük verilerinin de isan davranışı üzerindeki etkilerini araştımak için esasen üç boyutlu 'isovist' olarak değerlendirebileceğimiz 'polyhedron' kavramına odaklanır. Bu çerçevede araştırma, rastgele düzenenmiş ve boyutlandırılmış sirkülasyon alanlarından oluşan sanal bir bina ortamında gerçekleştirilen bir dizi yön bulma ve tahliye deneylerinin sonuçlarını tartışmaktadır. Bu yön bulma deneylerinde herhangi bir acil çıkış işareti bulunmazken, bu işaretler tahliye deneylerinde sanal binanın uygun noktalarında ve acil çıkış kapılarının üstünde mevcuttur.

Bahsedilen üç boyutlu sanal bina modeli ise birkaç mimari modelleme yazılımı ile tasarlanmış ve simülasyon ortamına aktarılmıştır. Deneyler ise çevrimiçi bir toplantı platformu üzerinden kırk dört (44) katılımcı ile gerçekleştirilmiştir. Katılımcıların rotaları ve kinestetik verileri bu deneyler sayesinde elde edilmiş ve binanın sentaktik değerleri ile kişilerin mekansal davranışları arasındaki anlamlı ilişkiler araştırılmıştır. İlk bulgular, yön bulma gurubundaki katılımcıların yüksek 'entegrasyon' değerlerine sahip bölgeler etrafında olma eğiliminde olduklarını gösterirken, bina tahliyesinde acil çıkış grubu üzerinde tebalalar ve hacimsel görünürük verilerinin oldukça etkili olduğu söylenebilir.

# ACKNOWLEDGMENTS

I cannot express enough thanks to my thesis supervisor, Prof. Dr. Alper Ünlü, for his considerable support, meaningful counseling, and continued encouragement. I offer my sincere appreciation for sharing his profound expertise and valuable time with me while dealing with this master's thesis.

This study could not have been accomplished without the support of my family. Therefore, I would like to thank my mother, father, brother, and other collateral relatives for their kind respect and supportive dedication to my study.

Last but not least, I would like to thank my friends who gave moral support and people who provided important guidance on technical issues by sharing their illuminating knowledge for this research. Herein, I would also like to thank the volunteers of this experimental study since it would not have been conducted without you.

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# CHAPTER I

# INTRODUCTION

Human beings are highly sophisticated creatures. Accordingly, people's physical, mental, and social activities may have various and intricate reasons. In this regard, there is no single theory that could explain human nature within all its aspects. Still, we can clarify the complicated characteristics of humankind through a broad sense of interdisciplinary approaches. Therefore, every study field focusing on a particular subject about human and human nature is essential to reveal the facts about humanity.

At this point, we can define human beings as autonomous and mobile creatures who constantly experience reciprocal interrelations with the three-dimensional spatio-temporal world. Correspondingly, people facilitate most of their everyday activities due to the ability to move and navigate in space. In this way, individuals can explore their environment, socialize with others, and obtain their personal needs from their surroundings. Thus, we can argue that the concept of mobility plays a highly critical role in human life.

On the other hand, human mobility is a complicated concept, and the wayfinding issue is one of the fundamental parts of this subject. Therefore, it requires a holistic perspective to understand the wayfinding issue, its underlying factors, and how these factors affect spatial behavior. Some research fields, such as artificial intelligence, cognitive science, geography, human factors, psychophysics, and urban planning, focus on the wayfinding issues (Gluck, 1991) [1].

Architecture and architectural research fields, like most other disciplines, are also highly interrelated to the subjects of human movement and wayfinding issues. Moreover, within the scope of architecture, communities build structures, towns, and cities. Therefore, the ultimate goals of architecture cannot be concerned aside from humans and their sequential interactions with the physical world.

In this context, we can discuss that human perception plays a vital role in the wayfinding processes. Correspondingly, sight can be considered one of the most prevailing senses during human movement. Thus, people can perceive and get visual information, bear in mind, compare it with other sensory data, and relate this information with previously accumulated and obtained experiences. In this way, human beings can decide which direction to move in the three-dimensional physical environments.

From this point of view, it can be indicated that finding a way as quickly as possible might be life-saving at times, especially under emergency conditions in buildings. Thus, most countries have emergency regulations for the buildings, and it is compulsory to present emergency exit signages in these lay-outs. However, it is still controversial how these signages affect spatial decisions, how human beings perceive their environments, and how they navigate accordingly in the three-dimensional space.

Therefore, this master's thesis primarily investigates the effects of volumetric visibility on human wayfinding and evacuation behaviors in complex indoor environments. In this context, this study handles this issue within the scope of Space Syntax Theory and Environment-Behavior Studies in architecture. At this point, it can be argued that two-dimensional syntactic visibility measurements are highly effective in capturing human perception, providing information about space, and revealing human wayfinding and evacuation behaviors.

On the other hand, this study asserts that although these 2D measurement concepts, as the two-dimensional representations of space, substantially contribute to knowledge about human wayfinding and evacuation issues, they might neglect the volumetric features of the surrounding. In this context, Ünlü et al. (2019) [2] argue that although planar representations provide information about space and spatial perception, two-dimensional parameters are limited in explaining the volumetric space. Hence, as three-dimensional volumetric visibility representations of the space, the ‘polyhedron’ concept may more accurately represent the environmental perception in this sense, and it may further contribute to the existing literature on wayfinding and evacuation issues.

## *1.1 Purpose of the Study*

This study’s primary purpose is to contribute to the existing wayfinding and evacuation investigations by trying to answer these four (4) research questions:

- Can volumetric visibility properties capture and reveal spatial behaviors more accurately than 2D syntactic visibility properties?
- Besides, how are the wayfinding and evacuation processes affected by the volumetric visibility features of unfamiliar complex indoor environments?
- On the other hand, how do directional signages affect wayfinding and evacuation processes in unfamiliar and complex indoor environments?
- Consequently, how do people behave in unfamiliar and complex indoor environments during wayfinding and evacuation processes?

In this context, it can be stated that we have strict arguments about how different spatial features are perceived and interpreted by people and how these spatial properties affect decision-making processes in wayfinding. However, we can still express that the ongoing investigations on these issues do not fully explain these previously asked questions. Therefore, cognitive and perceptive investigations that can shed light on these subjects have critical importance, specifically for a discipline such as architecture, directly related to environment-behavior relations.

In this framework, Miller (1992) [3] argues that it is necessary to anticipate human orientation patterns in specific environments and create more elaborate built settings for human beings by understanding the wayfinding issues since modern urban environments and architectural megastructures require to be planned more intelligently and designed more efficiently. On the other hand, understanding the wayfinding behaviors might also be effective in improving the travel quality in complex environments and might be beneficial for "…system designs and interfaces for geographic information systems (GIS), and more general Hypertext/Hypermedia systems." (Glcuk, 1991) [1].

Furthermore, the human wayfinding performance might be highly critical and life-saving under emergency evacuation conditions. In this context, Zhu et al. (2020) [4] point out that improper environmental designs can entail drastic emergency consequences. On the other hand, Golledge (2004) [5] mentions the 'Smart Envrionenmt' concept in which wanderers can be informed about the hazardous situation and guided to the safer zones by verbal directions where the egress signages are not visible due to the fire smoke or dust. Nevertheless, we can discuss that these solutions might be more appropriately applied by examining and understanding the evacuation behaviors over concrete data obtained by the related case studies. Correspondingly, Hajibabai et al. (2007) [6] indicate that we need smart approaches instead of assumptions based on the evacuation operations.

## *1.2 Scope of the Study*

This study aims to answer the abovementioned questions within the scope of Space Syntax Theory and Environment-Behavior Studies. Space Syntax Theory is one of the prominent research fields that examine environment-behavior relations within the framework of the architectural discipline. The theory asserts that universally accepted quantitative and syntactic analysis methods may explain human perception.

In this framework, Hillier et al. (1976) [7] discuss the concepts of 'integration' and 'segregation' of spaces considering these places' position in a spatial order. On the other hand, Benedikt (1979) [8] puts forward substantial studies on the 'isovist' concept by describing it as the two-dimensional representation of the visible space from a vantage point and formulating some isovist properties such as the area, perimeter, variance, skewness, and circularity. Moreover, Dalton and Dalton (2001) [9] handle those previously mentioned variables in their study and focus on other syntactic variables such as drift, standard deviation, depth, and mean depth.

Besides volumetric visibility data, this study also covers these 2D syntactic parameters as isovist area, isovist perimeter, drift (the distance between vantage point and isovist's center of gravity), circularity (approximation of the isovist to the circular shape), standard deviation (variation of radial lengths in an isovist), variance (dispersion of the isovist), skewness (asymmetry of the isovist's dispersion), depth (the visual distance from a place to another), mean depth (the average depth level of one place to all others), and integration (integration rate of one place according to the whole spatial system). In this way, it aims to reveal the effects of the volumetric visibility properties on wayfinding and evacuation issues since these 2D syntactic variables may also be influential on human orientation and spatial-decision making processes. On the other hand, this study primarily focuses on the polyhedron volume, polyhedron surface area, optimized polyhedron volume, optimized polyhedron surface area, and spherical circularity parameters as the volumetric visibility data.

Accordingly, we considered polyhedron volume as the visible volume of the space from a vantage point, whereas the optimized polyhedron volume can be conceived as the instantly viewed part of the visible space. On the other hand, spherical circularity might be indicated as the three-dimensional version of the 2D circularity parameter, which is generated specifically for this study. Hence, we investigate these 2D and 3D syntactic properties based on experimental research created as two different online computer simulations. While we handle wayfinding issues in the first experiment without the guiding signages, the second experiment focuses on the evacuation issues and effects of the emergency exit signs on participants' spatial decision-making processes in a virtual building.

On the other hand, Lin et al. (2020) [10] mention that culture can be essential in determining the wayfinding or evacuation processes. Therefore, we invited only the Turkish citizens to these experiments to eliminate the effects of the cultural factor on our investigations. However, we covered the personal data of the respondents, such as their genders, ages, education levels, professions, and computer experiences, to see if the wayfinding or evacuation performances differ by these variables.

Moreover, it can also be argued that the color and illuminance level factors might influence spatial decisions in indoor environments (Bae et al., 2020) [11]. Thus, we intended to stabilize the density of the light and aimed to present grey or transparent surfaces in our virtual building model to reduce the effects of these variables on wayfinding and evacuation issues. In addition, Li et al. (2019) [12] point out that crowdedness or crowd flow might be another essential determinant in wayfinding and evacuation issues. Hence, we also aimed to omit the influence of these variables on spatial behaviors by not including any other avatars in our virtual experiments except the avatar representing the participants during simulations.

## *1.3 Hypothesis*

As the visible field from a specific vantage point, isovists can be conceived as the two-dimensional planar representations of the three-dimensional environment within the minimal loss of spatial information (Benedikt, 1979) [8]. Although many illuminating and isovist-related investigations examined human behavior within the physical surroundings, the issue of minimum spatial information loss can be considered a highly controversial argument. In this context, Gewirtzman et al. (2005) [13] express that “2D visual analysis cannot capture the whole 3D situation and get close to the human perception.”.

In addition, Yang et al. (2007) [14] review previous investigations on the 3D isovist approaches and conclude that these methods reflect the human perception of space better than the 2D approaches. Although the concept of 2D isovist may effectively analyze spatial properties in wayfinding issues, it remains quite abstract by missing the spatial information to a great extent by omitting the volumetric features, and these features may attract people’s attention during wayfinding processes (Bhatia et al., 2013) [15]. Varoudis and Psarra (2014) [16] also defend three-dimensional visibility in this sense. They emphasize its essential role in the architectural experience and assert that it effectively expresses how people observe and comprehend spatial and visual connections while physically interacting with the surroundings.

Ünlü et al. (2019) [2] mention that volumetric values and polyhedron structure of the sight concerning parameters such as width, height, and depth of an architectural space may also influence the wayfinding process. From this point of view, Turner et al. (2001) [17] mention that Benedikt has envisioned polyhedrons and taking a slice of this volume in the horizontal plane to define the concept of isovist as the simplified version of presented space. Recently, Ünlü et al. (2019) [2] have focused on the concept of the polyhedron and expressed the importance of these forms in visual affordance, especially for understanding the potential of the effects of three-dimensional volumes in wayfinding.

Thus, the polyhedron concept can be conceived as one of the primary syntactic measures to capture spatial perception through geometric and radial data values, just as Benedikt’s isovist concept. Therefore, this master’s thesis primarily defends the notion that polyhedrons may represent the three-dimensional visible space more accurately, and as the generators of volumetric visibility data, the polyhedrons might be essential for comprehending the spatial behaviors in wayfinding issues. However, besides these syntactic parameters, it is also highly crucial to consider the dimension of time when investigating the human perception issue.

Human beings live in a spatio-temporal world that is in constant motion. External environmental factors continuously change the mood even if people are not in motion. Every moment contains a wide variety of information for an individual. Every millisecond may considerably impact spatial behavior and human perception. Batty (2001) [18] expresses that spatial perception can change with variations in the isovist parameters while people are in motion. Moreover, Gewirtzman et al. (2003) [19] argue that people’s time experience is significant in the observer's perception and the evaluation of their environment. Accordingly, each moment in every specific location may lead to differentiation in human perception and even in the spatial decision-making process in wayfinding.

In this case, just as the two-dimensional representations of volumetric fields may not wholly reflect the volumetric features of the physical surroundings, steady syntactic analysis methods might also omit to capture and evaluate instantaneous spatial behaviors. Therefore, obtaining as much perceptual data as possible about these moments might be essential when conducting experimental studies on wayfinding and evacuation issues. Within the developments in computer technologies, the cognitive values related to human perception and spatial behaviors can be evaluated instantly and synchronously, especially by simulation experiments.

Therefore, this study also defends that we can more frequently capture space-related human perception by sequentially measuring the polyhedron features during the movement process, as also underlined the importance and suggested by Ünlü et al. (2019) [2]. In this way, we can investigate the uncovered human behaviors between previously defined distant vantage points by instantly handling and evaluating every necessary point of view on the route in terms of spatial decisions and orientation processes.

In this context, Gewirtzman et al. (2005) [13] also point out that human perception can be altered entirely by the observed view during the movement. Therefore, we also suggest that considering the viewed side of the polyhedron structure in the sequential syntactic calculations may also reveal crucial outcomes about the spatial behaviors during the movement. Theoretically, we can discuss that people cannot obtain visual knowledge from the spaces they do not observe yet. Thus, these people might not be attracted by the unviewed parts of their surroundings during the wayfinding or evacuation processes.

Hence, we can refer to the viewed part of the visible space as optimized polyhedron volume.

From another point of view, we can argue that the volumetric visual complexity may also influence people's decision-making processes and entail spatial hesitations in wayfinding issues. In this context, Benedikt (1979) [8] explains the spatial complexity by measuring how well an isovist form approximates a circular shape with the circularity parameter. Hence, we can convert this 2D syntactic variable to a 3D volumetric complexity measure, which might be called spherical circularity. In this way, we can also investigate the effect of three-dimensional spatial complexity on the wayfinding behaviors with the sequential calculation method.

Consequently, we can argue that it is worth investigating the effects of the polyhedron volume, optimized polyhedron volume, and spherical circularity on human wayfinding and evacuation issues. On the other hand, we can also measure the polyhedron surface area and optimized polyhedron surface area as the by-products of these previously discussed volumetric visibility parameters when focusing on the effects of these variables in spatial decisions.

## *1.4 Methodological Approach*

This research presents two different experimental studies, one for wayfinding and one for evacuation issues, to investigate the effects of volumetric visibility on human orientation primarily. Both experiments are designed as virtual reality simulations and conducted through online meetings. In this case, there are several reasons to conduct this study in a virtual environment over online meetings. First, the simulated environments provide more flexibility in designing spaces and manipulating spatial properties. Second, it is more feasible to conduct such an investigation in virtual settings when considering economic conditions. Third, it can be challenging to find and arrange such a complex building that is available, especially for this experimental study.

Furthermore, we can mention that experimental studies on wayfinding issues as computer simulations can be conducted in three different methods. The first is the applications in which certain moments in a virtual space are displayed on the computer screen as photographic frames, as applied by Wiener et al. (2007) [20]. The second is the experiments where participants can move freely in the simulation environment monitored by the computer screen, as demonstrated by Stamps (2009) [21]. The third is the simulations where the participants can freely navigate in the virtual environment exhibited by virtual glasses, as shown by Shushan et al. (2016) [22].

In this context, Cha et al. (2019) [23] mention that participants perceive and experience spatial features more intensely in simulation experiments conducted with virtual glasses. Nevertheless, this study focuses on the second method because of the pandemic lockdowns and social distance issues due to the Covid-19 conditions, which entailed difficulties in having face-to-face meetings to conduct the experiments with participants.

In this context, we designed a highly complex virtual building with different sizes of corridors and halls to present various syntactic features and aimed at capturing different spatial behaviors in this way. We should indicate that the 3D building model is explicitly designed for this study to ensure the proper experimental conditions. Moreover, we converted this building into a simulation environment so that participants could roam freely in this virtual building during the experiments.

On the other hand, two different experimental cases are created, one for wayfinding and one for evacuation issues. Forty-four (44) participants joined these studies remotely from different cities in Turkey and Italy, such as Istanbul, Ankara, Milano, and La Spezia. In the wayfinding experiments, one-half of the participants are requested to find the regular exit doors from a certain point in the building. Besides, the other half of the attendants are asked to evacuate the building from regular exits or emergency egress in the evacuation simulations. Accordingly, while the evacuation experiments contained emergency exit signages to reveal the effects of signages on spatial decisions, we eliminated these signages in wayfinding experiments to uncover the influence of the volumetric visibility features on the human wayfinding process.

Consequently, we revealed the routes of the participants and their collective tendencies in orientation through the experimental simulations. Furthermore, we obtained the kinesthetic data of the respondents during these experiments and compared these data with personal, 2D syntactic, and 3D syntactic data to ensure whether there are significant correlations between these variables. In this regard, we handled manually observed kinesthetic data and personal data under the subjective assessments. On the other hand, the correlations between manually observed kinesthetic data and 2D syntactic data are evaluated under objective assessments. Moreover, we sequentially computed the kinesthetic and 3D syntactic data revealed around the decision-making points. At this point, we focussed on the correlation between these parameters in the sequential objective assessments. Correspondingly, we should indicate that we handled these computations by computer-aided algorithmic calculations.

## *1.5 Results of the Chapter*

Wayfinding is considered a highly essential issue for architecture and architectural research fields. Architects can elaborately design more legible and comprehensible buildings for the sake of human beings through understanding the wayfinding behaviors.

On the other hand, the wayfinding performances can be vital under emergency conditions, especially in complex and unfamiliar indoor environments. Hence, perceiving the emergency exit signages and quickly finding a way out of the building can be life-saving under these critical circumstances. In this context, ongoing investigations related to these subjects have been intended to reveal how human beings perceive their environments and how people make their directional decisions under these conditions.

In this context, we can argue that human perception plays a vital role in orientation and navigation, and sight can be regarded as one of the prevailing senses in these processes. We can argue that the Space Syntax Theory and its syntactic measurement tools have aimed at capturing human perception in this sense. Thus, the theory asserts that perceptive features can be measured quantitatively, and we can reveal concrete knowledge about environment-behavior relations through these quantitative measurement methods. Accordingly, we can express that the isovist is one of the substantial concepts of this theory, and isovists can be defined as the two-dimensional representations of the visible areas from specific vantage points through which we can obtain information about both human perception and spatial features of the environment.

From this point of view, the theory reveals essential discussions related to wayfinding and evacuation issues about how people perceive their environment and how human beings orient themselves in these environments. Nevertheless, we can still argue that ongoing investigations could not totally uncover these issues. Some researchers discuss that the isovists might be insufficient in obtaining the volumetric features of the space, and 3D isovists might more accurately capture the human perception of the environment. Hence, this master’s thesis also defends this argument and asserts that polyhedrons, as the three-dimensional volumetric data generators, may prominently reveal the spatial behaviors regarding the wayfinding and evacuation issues, especially in complex and unfamiliar indoor environments.

Therefore, we created simulation experiments to investigate the effects of the volumetric visibility features on people’s wayfinding and evacuation behaviors. These experiments are realized in the virtual building environment specifically designed to target these issues. Thus, we obtained participants’ behavioral data and routes from these experiments and revealed the building's 2D and 3D syntactic features. Accordingly, we primarily investigated participants’ wayfinding and evacuation behaviors based on the polyhedron volume, polyhedron surface area, optimized polyhedron volume, optimized polyhedron surface area, and spherical circularity values under the sequential objective assessments. On the other hand, the correlations between kinesthetic data and personal and 2D syntactic data are also considered separately under subjective and objective assessments.

# CHAPTER II

# THEORETICAL DISCUSSION

This chapter primarily focuses on the theoric discussions about the wayfinding and evacuation issues. On the other hand, it reviews the Space Syntax Theory and considers 2D and 3D syntactic approaches regarded in this theory. Furthermore, it also discusses related experiments on environmental behavior studies covering the significant outcomes revealed in these investigations based on the wayfinding and evacuation behaviors.

## *2.1 Discussion on Wayfinding and Evacuation Issues*

Wayfinding issue can be defined as a creative problem-solving process based on a goal-oriented travel action. In this context, although navigation might be conceived as a wayfinding process, it can be argued that the wayfinding and navigation processes differ from each other. Golledge (2004) [5] mentions that wayfinding implies the ability to discover, learn, and memorize a path, whereas navigation refers to the travel controlled by technical assistance or provided by the modes of commercial transportation.

Accordingly, we can argue that wayfinding is mainly considered an exploratory process involving spontaneous spatial decisions. On the other hand, navigation can be conceived as a deliberate path tracking process with the aid of a 'priori knowledge' about space that is obtained by external guidance. Nevertheless, it can be indicated that a trip might encompass both wayfinding and navigation processes either interwoven with each other or in sequential order. On the other hand, we can also handle the evacuation issue as a wayfinding process. However, it differs from the wayfinding concept due to the specific emergency conditions when people's stress levels might dramatically increase, and thus, the ability to perceive and process the environmental information might decrease.

With the innovations in technology, material sciences, and the construction sector, architects started to design and build highly complex and massive buildings. In this context, Bae et al. (2020) [11] mention that the complexity of the building layout might entail difficulties in evacuation processes, where the "…escape time is a critical determinant of survival…". Therefore, finding a quick way out from these buildings has become challenging in emergency conditions. In this framework, although wayfinding and evacuation processes can be conceived as complicated issues, there are essential theoretical discussions aiming to explain these processes regarding human perception, cognition, and spatial behaviors.

### 2.1.1 Wayfinding Issue

We can argue that several sophisticated perceptual and cognitive skills involve the wayfinding process. Accordingly, Vandenberg (2016) [24] states that "…environmental information is encoded by a human body and brain, processed with different cognitive resources, stored or represented in the body and brain, and then retrieved, integrated, and applied for a particular purpose such as wayfinding.". In this sense, it can be expressed that restrictions in any of these processes may negatively impact the human wayfinding process.

On the other hand, Golledge (2004) [5] expresses that "Humans are generally effective, though frequently inefficient, wayfinders." and adds that "…human history is replete with examples of a search for assistive devices that help to turn wayfinding into navigating.”. In this framework, Raubal (2001) [25] mentions that human beings must regard the external information in unfamiliar surroundings, in which they have not experienced the environment, and thus, could not develop a space-related cognitive map yet. Hence, the wayfinding process can be considered a challenging and stressful experience at certain points, especially where the required environmental knowledge is insufficient for decision-making operations (Passini, 1996) [26]. Thus, Vandenberg (2016) [24] points out that human beings reveal many orientation errors during the wayfinding processes and tend to walk in circles when they cannot obtain significant visual cues and become lost in the surroundings.

Besides, Lin et al. (2020) [10] express that environmental uncertainty might remarkably increase people’s stress levels that can negatively impact the perceptual and cognitive skills during the wayfinding processes. Individuals might get confused, show hesitation, and move back during movement, especially when they have higher stress levels (Golledge, 2004) [5]. However, Vandenberg (2016) [24] indicates that the spatial anxiety might differ according to the culture and gender issues, and the age variable might also be effective in wayfinding performances. Hence, we can state that some people can be more successful in wayfinding performance than others if we regard wayfinding as an ability.

Hunter et al. (2016) [27] argue that although the wayfinding performance depends on the individuals’ competence in orientation, it is also substantially related to the characteristics of the environment, and they state that “Places support wayfinding to a greater or lesser degree by how information is organized and communicated to people as they travel.”. In this regard, Miller (1992) [3] mentions that these environmental characteristics might be evaluated under spatial characteristics and wayfinding support systems and highlights the importance of architectural differentiation, spatial layout, and visual access for wayfinding performances.

Consequently, people can obtain spatial knowledge by perceiving the environmental affordances such as signs, guidance systems, and architectural clues (Raubal, 2001) [25]. Moreover, it can be argued that people might pay more attention to architectural differentiation and consider the atypical places more legible than others. On the other hand, we can also express that the increased complexity in the spatial layout might entail wayfinding errors.

In this context, Gluck (1991) [1] indicates that people gradually comprehend their surroundings as the environmental familiarity increases, and human beings primarily tend to recognize landmarks in the spatial network, in which not all the places are equally important to them. Hajibabai et al. (2007) [6] explain the order of the commonly acknowledged spatial learning phases by stating that the primary step is the "…landmark knowledge, unique features or views that identify a place. Second is route knowledge, based on travel routines that connect ordered sequences of landmarks. Third stage is survey knowledge, knowledge of two-dimensional layouts that includes the simultaneous interrelations of locations.".

On the other hand, Miller (1992) [3] discusses that it is not precise whether people regard metric or topological cognitive imagery during wayfinding processes. In this framework, Gluck (1991) [1] implies that people might estimate distances in topological understanding and consider directional evaluations during their orientation processes according to the topological cognition. Nevertheless, Golledge (2004) [5] indicates the importance of cognitive maps and expresses that people mostly rely on the mental representations of space during their travels, in which they are satisfied with the routes that are relatively good enough instead of searching for optimal paths.

### 2.1.2 Evacuation Issue

Herein, we can indicate the ‘crowd panic’ as one of the essential considerations for the evacuation issues. Accordingly, Hajibabai et al. (2007) [6] express that evacuation processes might be disastrous and jeopardizing, especially when the crowd terrifies and rushes in different directions. Furthermore, Lin et al. (2020) [10] also point out that there might be a herding tendency to follow the crowd during the evacuation processes, and cultural factors can influence this crowd flow in certain ways.

On the other hand, Zhu et al. (2020) [4] imply that familiarity with the environment can be regarded as another essential factor in determining evacuation performances. On the other hand, Bae et al. (2020) [11] express that individuals might neglect the emergency egresses during the evacuation processes and tend to head forward to the entrances through which they entered the building. Passini (1996) [26] also supports this argument and indicates that people might not try new paths during emergencies. Besides, Natapov et al. (2022) [28] discuss that environmental visibility and legibility might play a key role while escaping the building under emergency conditions, and visually integrated spaces might attract people since these places offer multiple directional possibilities to move.

From another point of view, signages also play a crucial role during these crisis moments. Accordingly, Golledge (2004) [5] mentions that signs can be prominent for newcomers in finding their ways and states that “Signage is a way of minimizing the chances of becoming lost.”. Hence, Hajibabai et al. (2007) [6] also highlight the importance of signages and underline the notion that people might be stressed and frustrated due to the false information on these signs.

In this context, we can express that most countries have regulations for building emergency issues, and as part of these regulations, it is compulsory to present egress signages in complex buildings. Thus, people are expected to see the signages and orient themselves accordingly to the safer zones. However, Bae et al. (2020) [11] indicate that although the signage systems can support the wayfinding performances, the regulations do not consider the efficiency of these egress signs by evaluating them quantitatively. Besides, it can also be mentioned that the lighting and color of the signages might be influential on human beings' path choices during the evacuation processes (Bae et al., 2020) [11].

## *2.2 Space Syntax Theory and Discussion on Syntactic Measurements*

Space Syntax is a prominent research field that proposes several theories and aims to verify these theories by focusing on the quantitative analysis of spatial layouts and human behavior patterns. Accordingly, it asserts that perceptual qualities can be measured and represented quantitatively, and thus, spatial behaviors can be revealed and evaluated objectively.

Peponis (2016) [29], as one of the contributors to the theory, describes the Space Syntax as a "…descriptive theory of the perceptual and functional affordances of inhabited space that are relevant to its cognitive and social intelligibility, thus to its planning, design and use.". In this regard, Hunter et al. (2016) [27] mention that Hillier and his colleagues bridged the diverse scientific disciplines through an integrative approach and created a conceptual structure including analytical methods investigating the spatial configurations within the scope of culture and human experience that is also closely related to the human movement, route choices, and wayfinding issues.

Hillier and Hanson (1984) [30] express that mutually interrelated spatial and social hierarchical orders reflect each other, and these interconnections can be revealed with the 'justified graph maps' as graphical expressions. The concept of depth levels within the framework of graph data and calculated mean depth concepts are key concepts in these justified graphs. While the depth can be defined as the visual distance of a place from any other point on the justified map, the mean depth indicates the average of the depth levels from all other locations in the space.

Moreover, the concept of integration can be explained as a normalized version of the inverse of the mean depth. Normalizing the mean depth values enables researchers to compare various spatial layouts syntactically. In this context, the integration value of the space illustrates how the area is integrated or segregated compared to other zones in the surrounding. Peponis et al. (1990) [31] argue that the integration values of spaces might be closely related to the spatial patterns in wayfinding.

The concept of isovist might be described as the polygonal two-dimensional representation of all visible areas from a particular observation point (Dalton and Dalton, 2001) [9]. An isovist can be evaluated in two sub-categories: isovist and radial data. Isovist data is related to the measurements of the features based on the geometric form of the isovist polygon (Benedikt, 1979) [8]. On the other hand, radial data deals with the comparisons or changes in the lengths of the rays thrown from the observer's point to the surroundings (Batty, 2001) [18]. These rays as radials play a role in creating the concept of the isovist. In this context, Benedikt (1979) [8] asserts that numerical values may represent certain human perceptual and cognitive factors related to specific isovist properties.

On the other hand, isovist fields can be expressed as diagrams where the isovist values are calculated and demonstrated simultaneously for every possible observation point in the space (Benedikt, 1979) [8]. Similarly, Turner et al. (2001) [17] also posit the ‘visibility graph’ concept by looking at the area units and their neighborhood relations in each observation point within the other neighboring vantage points. These syntactic diagrams give a holistic idea about the spatial configuration regarding the isovist or radial data values in the building or urban scale. Eventually, Franz and Wiener (2005) [32] investigate the empirical studies about isovists regarding human behavior and suggest that isovist is an observer-centered model capable of capturing environmental features related to spatial behavior and experience.

On the other hand, there are various methods for creating the 3D isovist application forms, and some of these may be produced with the spherical projection method (Gewirtzman et al., 2003) [19] or 360º rotation of the two-dimensional isovist form (Yang et al., 2007) [14] or calculations based on voxel-based neighborhood relations (Morello and Ratti, 2009) [33] or the scatter of the rays through the three-dimensional surroundings (Bhatia et al., 2013) [15]. Each method for obtaining the 3D isovist may have competence in investigating specific syntactic values and might be a suitable calculation method for the targeted issues. For example, the concept of the ‘Spatial Openness Index’ (SOI), which is put forward by Gewirtzman et al. (2003) [19], describes the observer’s perception of spatial density, so SOI is calculated by dividing the visible volume by the surface area of the 3D isovist. Thus, it can be expressed that the spherical projection method has been used sufficiently in creating the 3D isovist, especially for this process.

## *2.3 Preliminary Wayfinding and Evacuation Experiments*

Herein, we can mention important experiments related to the wayfinding and evacuation issues within the scope of Space Syntax Theory and Environment-Behavior Studies. These experiments are conducted in physical and virtual environments, and researchers found significant outcomes relating to environmental perception, cognition, and related spatial behaviors. On the other hand, it can be mentioned that most of these researchers focused on 2D and 3D syntactic measures when investigating the wayfinding and evacuation issues in indoor and outdoor environments.

### 2.3.1 Wayfinding Experiments

Many substantial wayfinding experiments are conducted at the urban and the building scales. The experiments conducted by Peponis et al. (1990) [31] can be counted among one of the significant studies in this field. Their experiments examined the correlation between the participants' wayfinding success and integration values of circulation areas in a hospital building. As a result, these researchers revealed that the participants tended to be in places that presented higher integration values during the wayfinding processes. Accordingly, they explained this tendency by expressing that integrated spaces attract newcomers since they provide more probabilities of obtaining spatial information.

In this context, Peponis et al. (1990) [31] mentioned the wayfinding behavior that people tended to head forward to the integrated spaces when they felt spatial hesitations. However, these researchers also demonstrated that participants tended to have difficulties when finding their way around some of these highly integrated decision-making points. On the other hand, it is indicated that inadequacy in the number of signages might entail participants not noticing the destination locations and missing them walking by these points (Peponis et al., 1990) [31]. Consequently, these researchers remarked that a complex building should be designed concerning syntactic properties, and signages should support the circulation areas as the directional guidance.

O'Neill's (1991) [34] experiments in a university campus library building also have significant results in this discussion. These experiments investigated the effects of topological complexity on architectural legibility and thus the wayfinding performances. In this context, O'Neill (1991) [34] examined the topological complexity through InterConnection Density (ICD) measure by concerning the topological visual connections disregarding the metric distances. Accordingly, the study revealed that the increase in topological complexity in the environment, especially without signages, may cause difficulties in comprehending spatial organization. Hence, he argued that topological complexity might entail wayfinding problems, and reaching the destination can take a long time, especially in these complex environments.

In this framework, the experiments conducted by Haq and Zimring (2003) [35] investigated the effects of environmental familiarity on individuals' wayfinding performances in three different hospital buildings. Accordingly, they implied that the integration variable is essential in predicting spatial decision-making processes when considering the wayfinding issues. Furthermore, Haq and Zimring (2003) [35] expressed that participants, unfamiliar with the buildings, initially tended to pass by the nodes they had previously discovered; however, they slowly became attracted by the nodes presenting high global nodal integration values as they became familiar with the environment. These researchers also indicated that as participants became familiar with the spatial configuration, they tended to change their spatial behavior from environmental exploration to direct searches. As a result, Haq and Zimring (2003) [35] pointed out that spatial order directs human movement, lets people understand spatial characteristics, and entails better wayfinding performances.

On the other hand, Franz and Wiener (2005) [32] conducted prominent experiments in virtual environments. They examined the effects of variables such as perceived complexity and spaciousness on human behavior in a 3D model of exhibition areas. As a result, Franz and Wiener (2005) [32] suggested that isovist and visibility graph analysis can capture the spatial properties and thus the human experience of the space. On the other hand, they implied that people might be aware of the center of the environment since the respondents tended to move to the centers of the space, most probably to capture the best overview and obtain comprehensive environmental knowledge about the surrounding by maximizing the visible area.

Furthermore, we can mention another simulation experiment conducted by Stamps (2009) [21]. In this context, he also aimed to handle the spaciousness concept in a 3D model of an arbitrary street. According to the results of these experiments, Stamps (2009) [21] revealed that the main factor in the perceived spaciousness is the horizontal area of the space, and the participants recognized streets with shallow and large setbacks as more spacious than streets with deep and short setbacks. Herein, we can argue that the spaces with more horizontal widths might attract people during the wayfinding process since people might perceive these places as more spacious environments that might reduce the spatial anxiety of the people, as also implicated by Franz ad Wiener (2005) [32].

We can also mention some other experiments investigating the effects of three-dimensional visibility features on spatial cognition and behavior. In this context, we can mention the studies conducted by Gewirtzman et al. (2005) [13]. Accordingly, they intended to examine the urban density and the openness qualities as the 3D visibility data considering the building heights and urban morphologies. As a result, Gewirtzman et al. (2005) [13] indicated that visual connection might be increased or decreased according to the morphological features of the urban environments, and perceived density and openness can differ by the observation point from the lower floors to the upper floors of the buildings. Thus, we can express that visually connected spaces may be viewed and memorized by more people during the movement, and these places might be conceived as the attraction points of the city.

Mavridou et al. (2009) [36] also conducted simulation experiments at the urban scale, and they examined the effects of the integration and building heights under the 3D visibility considerations, especially on wayfinding behaviors. As a result, they mentioned that the main factor for people in their orientation is the integration parameter and that the building heights might be ineffective in spatial decisions. On the contrary, Stamps (2011) [37] conducted similar experiments, and these simulations revealed that people might perceive streets with shorter buildings as more spacious.

Moreover, Bhatia et al. (2013) [15] conducted another virtual experiment at the building scale, and they aimed to capture how spaces are perceived as salient by using 3D isovist measurements. Accordingly, these researchers revealed that the regions containing the staircase and ramp might be perceived as more salient places in the building. On the other hand, Bahtia et al. (2013) [15] also indicated that the virtual building's least salient space is the corridor, with no architectural differentiation compared to other zones.

On the other hand, Shushan et al. (2016) [22] conducted urban scale simulation experiments using virtual reality (VR) glasses. Accordingly, they intended to examine the imageability of the city by focusing on the homogeneity and heterogeneity of the urban structure. As a result, Shushan et al. (2016) [22] revealed that participants walked and covered most of the spaces in the homogenous environments, whereas participants in the heterogeneous environments tended to be around large built volumes. Moreover, these researchers also argued that heterogeneous environments might be conceived as more legible than homogeneous urban layouts.

Furthermore, we can discuss the prominent virtual experiments conducted by Natapov and Gewirtzman (2016) [38]. Accordingly, these researchers investigated the effects of three-dimensional visibility on urban activities and suggested that pedestrian movement is goal-oriented action influenced by the visual features of the environment. In this regard, Natapov and Gewirtzman (2016) [38] revealed that visible signages related to the targeted activity or location, especially on the predetermined routes, might reduce the effects of the integration and volumetric visibility parameters on wayfinding behaviors.

Ünlü et al. (2019) [2] also focused on the effects of spaciousness, as the volumetric feature of the environment, on human perception and behavior. They conducted a building simulation experiment by creating a 3D representation of a university campus building. As a result, Ünlü et al. (2019) [2] mentioned that large central voids in the building might be conceived as more legible than in other places in terms of volumetric considerations. On the other hand, these researchers also indicated that the isovist area parameter is crucial when evaluating the perceived spaciousness.

As other important contributors to the wayfinding issues, Li et al. (2019) [12] also conducted VR (Virtual Reality) experiments to investigate the effects of crowdedness on wayfinding behavior. Accordingly, they revealed that participants tended to avoid the population in the virtual shopping mall and moved along nearby the peripheries of the environment. On the other hand, these researchers also indicated that the crowd might increase the spatial anxiety of the people. Furthermore, Li et al. (2019) [12] implicated that as the participants became familiar with their surroundings, they tended to show clearer strategies in wayfinding processes also by stopping and rotating less after a while. In this context, these investigators asserted that participants tended to maximize the wayfinding efficiency by reducing the distance passed and minimizing the time allocated to spatial exploration.

Finally, we can mention the urban scale simulation experiments conducted by Gewirtzman (2019) [39]. Accordingly, the researcher investigated the participants' visibility patterns with Dynamic 3D Visibility Analysis (DVA). Consequently, Gewirtzman (2019) [39] indicated that differences in building heights might influence human perception. On the other hand, Gewirtzman (2019) [39] also expressed that although some spatial features such as vegetation, openness, and sky view may create positive feelings in participants, these respondents are not always attracted by these features, and they did not tend to head towards these places.

### 2.3.2 Evacuation Experiments

We can also mention important evacuation experiments present in the existing literature. However, it might be indicated that fewer studies are focusing on evacuation issues than the wayfinding processes. In this framework, we can argue about the simulation experiments conducted by Lin et al. (2020) [10]. Accordingly, they investigated the effects of crowd flow on human movement during the evacuation process in unfamiliar indoor environments.

As a result, Lin et al. (2020) [10] indicated that respondents tended to avoid fire by moving through the hallways instead of stairs when no signage guided these participants into specific zones. On the other hand, these researchers expressed that once participants started to join the crowd flow, they tended to sustain this behavior and keep following the crowd. Besides, they argued that participants might follow the majority of the people when several crowds are moving in different directions. Moreover, Lin et al. (2020) [10] also revealed that the culture might be an insignificant determinant in the evacuation processes.

Furthermore, we can also mention experiments conducted by Bae et al. (2020) [11]. In these experiments, these researchers examined the eye movement of the participants during the evacuation processes in unfamiliar environments. Accordingly, Bae et al. (2020) [11] revealed that most respondents tended to look between 1m-1,5m vertical heights during the movement. In this regard, Bae et al. (2020) [11] also underlined that the existing regulations regarding the emergency signage heights might be inappropriate for optimal evacuation guidance. Besides, they also discussed that participants tended to look in a particular direction during the movement when no alternative routes existed.

On the other hand, Zhu et al. (2020) [4] investigated the effects of visual access on the participants' evacuation performances. They conducted experimental research in the virtual metro station environment and revealed that respondents tended to head toward the more visible spaces during the evacuation processes. Besides, Zhu et al. (2020) [4] demonstrated that the participants tended to neglect the crowd flow when the environment presented a high level of visual access through the exit direction, and these participants tended to be more likely to decide to leave the building from these more visible paths. Thus, these researchers asserted that improvements in the visual access in the building might increase the evacuation performances and reduce the time spent and distance passed in these emergency processes.

Finally, we can consider the building scale simulation experiments conducted by Natapov et al. (2022) [28]. Accordingly, it might be indicated that these experiments focused on the effects of architectural features such as interior wall transparency, evacuation starting points, and architectural landmarks in the respondents' evacuation behaviors. As a result, Natapov et al. (2022) [28] revealed that the starting point of the evacuation is a highly crucial factor, and participants tended to show better evacuation performances where the nearby surrounding of the starting point presents more visual access with transparent walls rather than opaque surfaces. On the other hand, they also indicated that architectural landmarks such as external buildings, doors, windows, and atriums might be ineffective in wayfinding decisions, especially in the evacuation processes. However, Natapov et al. (2022) [28] expressed that only the staircases and ramps seem to be influencing factors in spatial decisions under emergency conditions.

## *2.4 Results of the Chapter*

Wayfinding and evacuation issues might be regarded as the goal-oriented movement to reach previously decided destination points or targeted functions. On the other hand, the evacuation process might differ from wayfinding due to the urgency of the escape action. We can argue that both processes require advanced mental and physical tasks. In this framework, a person needs to perceive the surroundings to acquire environmental knowledge, cognitive skills to make directional choices, and physical competence to take action.

Accordingly, people's familiarity with the environment can be considered an important factor in wayfinding and evacuation performances (Gluck, 1991[1]; Raubal, 2001 [25]; Zhu et al., 2020 [4]; Passini, 1996 [26]). Besides, the crowd flow might affect the evacuation behavior during emergency conditions (Hajibabai et al., 2007 [6]; Lin et al., 2020 [10]). Hence, cultural and personal factors can also be determinative in these processes (Vandenberg, 2016 [24]; Lin et al., 2020 [10]). On the other hand, we can argue that people slowly develop visual and topological cognition of their surroundings as they trace the spaces in their environments (Gluck, 1991 [1]; Miller, 1992 [3]; Raubal, 2001 [25]; Golledge, 2004 [5]; Hajibabai et al., 2007 [6]; Hunter et al., 2016 [27]; Vandenberg, 2016 [24]).

Furthermore, besides individuals' competence in the wayfinding issue, we can also argue that environmental features play an essential role in orientation. In this regard, we can discuss that an unfamiliar or uncertain complex environment may entail spatial anxiety, and thus, it may reduce the wayfinding and evacuation performance (Golledge, 2004 [5]; Vandenberg, 2016 [24]; Bae et al., 2020 [11]; Lin et al., 2020 [10]; Passini, 1996 [26]). Moreover, the visibility and legibility of the spatial structure might also influence the spatial decision-making processes (Miller, 1992 [3]; Raubal, 2001 [25]; Vandenberg, 2016 [24]; Lin et al., 2020 [10]; Natapov et al., 2022 [28]).

Moreover, it can be indicated that signages might provide considerable guidance for novice visitors when they intend to find their way inside the built environments (Miller, 1992 [3]; Raubal, 2001 [25]; Golledge, 2004 [5]; Hajibabai et al., 2007 [6]; Hunter et al., 2016 [27]; Bae et al., 2020 [11]). We can also underline the importance of architectural differentiation and spatial features in wayfinding and evacuation processes, and architectural landmarks might also be crucial for developing cognitive maps (Gluck, 1991 [1]; Miller, 1992 [3]; Raubal, 2001 [25]; Hajibabai et al., 2007 [6]; Vandenberg, 2016 [24]).

On the other hand, Space Syntax is one of the salient research fields investigating the relationships between spatial layouts and human behaviors through specific quantitative measurement methods. Accordingly, as the two-dimensional representation of the space, the isovist concept is one of the notable approaches for capturing people's visual perception of the space. Hence, we can calculate the spatial parameters such as isovist area, isovist perimeter, circularity, and other isovist and radial data (Benedikt, 1979 [8]; Peponis et al., 1990 [31]; Batty, 2001 [18]; Dalton and Dalton, 2001 [9]).

On the other hand, we can also capture the topological features of the space with depth, mean depth, and integration parameters introduced by the Space Syntax Theory (Hillier and Hanson, 1984 [30]; Peponis et al., 1990 [31]; Dalton and Dalton, 2001 [9]). Besides these 2D syntactic features, researchers also aimed to captivate the three-dimensional visual perception through 3D isovists (Gewirtzman et al., 2003 [19]; Gewirtzman et al., 2005 [13]; Yang et al., 2007 [14]; Morello and Ratti, 2009 [33]; Bhatia et al., 2013 [15]; Varoudis and Psarra, 2014 [16]; Ünlü et al., 2019 [2]). Accordingly, ongoing investigations revealed different methods of volumetric isovist application regarding the measurement of the targeted perceptual variable, such as the 'spatial openness index' (SOI) introduced by Gewirtzman et al. (2003) [19].

On the other hand, there are prominent experimental studies based on the wayfinding and evacuation issues within the scope of Space Syntax Theory and Environment-Behavior Studies. In this context, we can express the significant outcomes revealed by these experiments at the urban and building scales in virtual and physical environments. Accordingly, it has been revealed that the integration parameter might be a highly effective determinant in spatial decisions during the orientation and wayfinding (Peponis et al., 1990 [31]; Haq and Zimring, 2003 [35]; Mavridou et al., 2009 [36]).

Moreover, we can also argue that high topological complexity may entail difficulties in wayfinding processes, and people might show better wayfinding performances as they familiarize themselves with the environment (Peponis et al., 1990 [31]; O'Neill, 1991 [34]; Haq and Zimring, 2003 [35]; Li et al., 2019 [12]). Besides, it can be expressed that the isovist area might be considered an essential 2D syntactic parameter when predicting spatial behaviors, and human beings might tend to maximize the visible area during movement (Franz and Wiener, 2005 [32]; Stamps, 2009 [21]; Ünlü et al., 2019 [2]; Zhu et al., 2020 [4]). On the other hand, researchers also revealed that three-dimensional visibility features of the space might be essential in spatial perception in wayfinding and evacuation issues (Getwirtzman et al., 2005 [13]; Stamps, 2011 [37]; Bhatia et al., 2013 [15]; Shushan et al., 2014 [22]; Natapov and Gewirtzman, 2016 [38]; Ünlü et al., 2019 [2]; Gewirtzman, 2019 [29]; Bae et al., 2020 [11]; Zhu et al., 2020 [4]; Natapov et al., 2022 [28]).

Moreover, we can argue that architectural differentiation and architectural landmarks such as stairs and ramps might be decisive parameters in the wayfinding and evacuation processes (Bhatia et al., 2013 [15]; Shushan et al., 2014 [22]; Lin et al., 2020 [10]; Natapov et al., 2022 [28]). Consequently, we can also argue that signages might be one of the significant determinants of the wayfinding and evacuation performances, especially in unfamiliar environments (Peponis et al., 1990 [31]; O'Neill, 1991 [34]; Natapov and Gewirtzman, 2016 [38]; Bae et al., 2020 [11]; Lin et al., 2020 [10]).

# CHAPTER III

# METHODOLOGY

This study primarily examines the correlations between volumetric visibility properties and the spatial behaviors during the wayfinding and evacuations processes in unfamiliar and complex indoor environments, either with or without guiding signages. At this point, it also investigates the effects of signages on human wayfinding and evacuation behavior during movement. On the other hand, it reviews the relationships between 2D syntactic data and spatial decision-making processes in wayfinding and orientation. Therefore, we adopted the experimental research method to reveal how these spatial parameters affect human behavior in usual indoor wayfinding and emergency evacuation processes.

Thus, we created two different experimental cases, one for wayfinding and one for evacuation issues. Forty-four (44) participants joined these studies remotely from different cities in Turkey and Italy, such as Istanbul, Ankara, Milano, and La Spezia. These experiments occurred in a one-story virtual building, and this 3D building model was designed specifically for this study to ensure the proper experimental conditions. In this case, we aimed to create a highly complex virtual building for the experiments since the spatio-temporal world provides infinite variety and size of volumetric spaces to the people.

This 3D virtual building model contains circulation areas with different spatial dimensions, and it aims to reflect various syntactic features to capture various spatial behaviors. Hence, these circulation areas consist of corridors, halls, and inner courtyards, and the building contains multiple exits and emergency egresses besides regular room doors. On the other hand, while participants could see the emergency exit signages in the evacuation experiments, we eliminated these signages in the wayfinding simulations.

Accordingly, we methodologically handled this experimental study in three (3) phases. First, we designed the experiment and created the wayfinding and evacuation simulations with Rhinoceros 3D [40], Grasshopper [41], Unity [42], and Microsoft Visual Studio [43] software. Second, we conducted these simulation experiments with participants online over Zoom [44]. Third, we revealed respondents' routes together with their kinesthetic data and obtained 2D and 3D syntactic data of the building in Grasshopper. On the other hand, we also obtained respondents' personal data during these simulations.

## *3.1 Designing the Experiment*

The design of this experiment consists of five (5) stages: creating the case study, designing the 3D virtual building model, converting this building model into a simulation environment, creating the preliminary simulation for drills, and conducting pilot studies.

### 3.1.1 Creating Case Studies

This research comprises two (2) case studies to investigate the wayfinding and evacuation behaviors in large-scale buildings. Both experiments occurred in the same virtual building environment. Accordingly, these experiments are created as computer simulation programs so that people can join from different locations online. Hence, participants could walk, run, make directional maneuvers, rotate their looking directions, and thus move freely in this simulated virtual building.

The large-scale complex virtual building design provides participants with various spatial volumetric properties through randomly dimensioned circulation areas. Thus, the building contains many decision-making points that allow participants to head toward different places and discover the entire building. On the other hand, we did not assign any material texture to the 3D building model. In this context, the surfaces are set as either grey or transparent so as not to distract participants with color or texture variables during their wayfinding or evacuation processes. Only the emergency exit signages are green, and these signs are adjusted according to the legal emergency egress standards of the National Fire Protection Association (NFPA) [45]. Thus, we aimed to reveal the spatial decisions based on the volumetric features or the guiding signages.

In the wayfinding experiments, participants are expected to find the regular exit doors from a previously decided node in the building. The starting point of the wayfinding experiment is determined as one of the deepest nodes according to the regular exit doors so that people can experience the building and reveal behavioral data as much as possible during their wayfinding processes. In these experiments, the signages are hidden not to guide people to the exits, and it is intended to obtain behavioral data only based on the spatial and volumetric features of the building. In the evacuation experiments, these signages are maintained as visible to examine the effects of signages on people while they are intended to find their way.

In these emergency experiments, people are asked to evacuate the building as quickly as possible, whether from emergency egresses or the regular exit doors. In this framework, the starting point of the evacuation experiment is decided as one of the deepest nodes according to the regular exits and emergency egress doors. In this way, participants could also experience the building and reveal behavioral data as much as possible during their evacuation processes.

After these experiments, all the revealed behavioral data are acquired and compared with the previously obtained personal and syntactic data to uncover the significant correlations among the variables such as visual polyhedron volume, isovist area, and participants' computer gaming experience. These parameters are described in detail under the 'Variables' part of this chapter.

### 3.1.2 Creating 3D Virtual Building Model

The design of the architectural building model is created by using Rhinoceros 3D and Grasshopper. On the other hand, the 3D building model is generated in two (2) stages. These stages can be described as creating the plan of the building and converting the 2D plan layout into a 3D structure.

The plan of the building is created with the aid of Grasshopper and its plug-in, Magnetizing Floor Plan Generator (Egor et al. 2020) [46]. What this plug-in does, in general, might be defined as fitting the desired number of rooms and halls into a particular area within a simple architectural understanding while considering the square meters specified for these spaces and the neighborhood relationship between these spaces.

However, it should be indicated that this plug-in is still in the development process, and it can be insufficient to create floor plans with a sophisticated architectural understanding. Therefore, we should also express that the 3D design is manipulated manually at certain points while creating the experimental building by using both Rhinoceros 3D and Grasshopper. In this framework, an initial schematic diagram of the building plan configuration is created in Grasshopper at first (Figure 1). Accordingly, this architectural program comprises one hundred forty-two (142) rooms and eight (8) halls. The sizes of all rooms are assigned as $60m^2$. On the other hand, the areas of the halls are designated in different sizes, from $60m^2$ to $300\ m^2$.

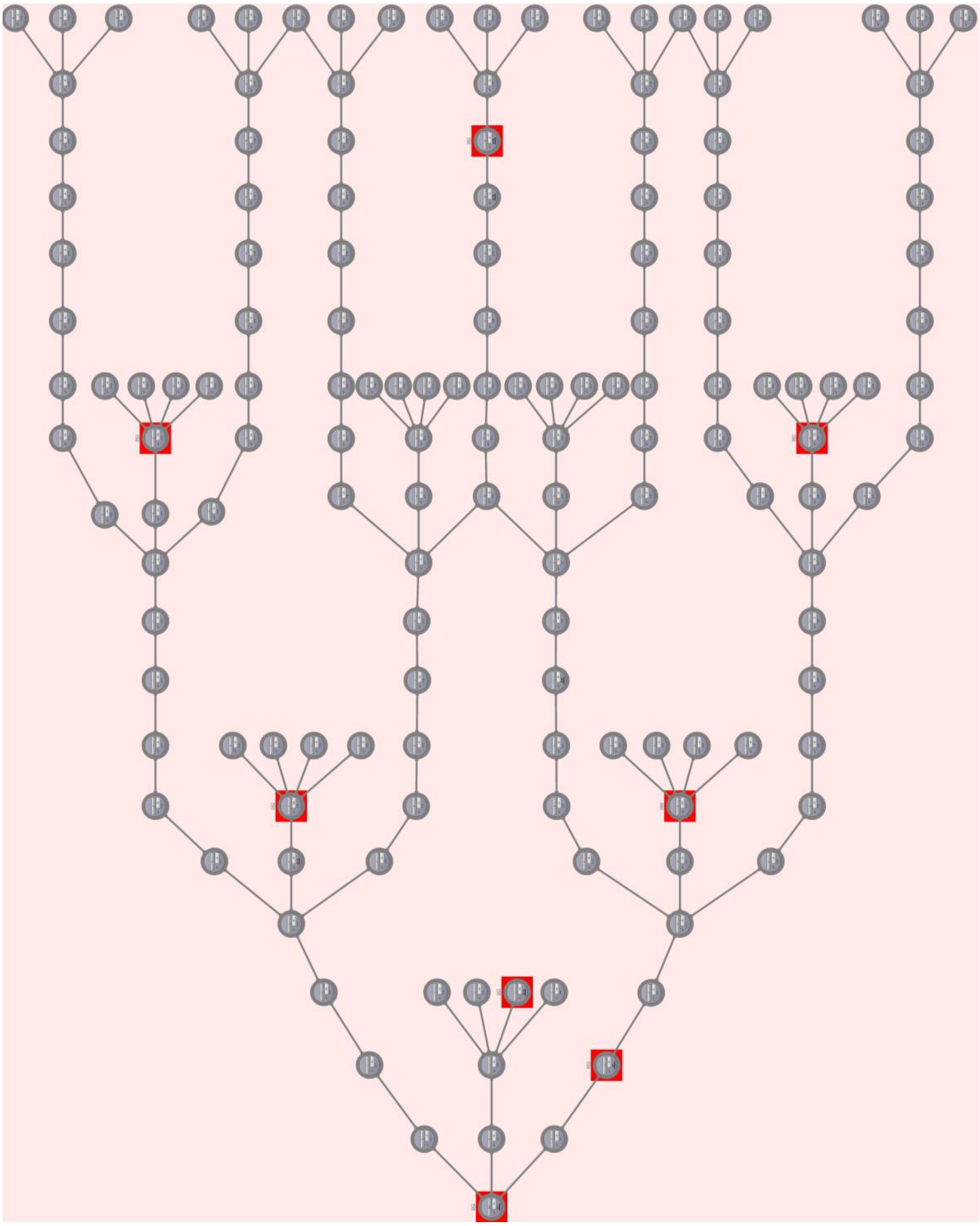


**Figure 1:** Initial schematic diagram of the floor plan configuration

Then, the Magnetizing Floor Plan Generator component is activated in the Grasshopper script (Figure 2). Accordingly, this plan generator component created a random floor plan configuration by considering and ensuring the spatial relations defined in the schematic diagram. The resulting building plan configuration is shown in Figure 3.

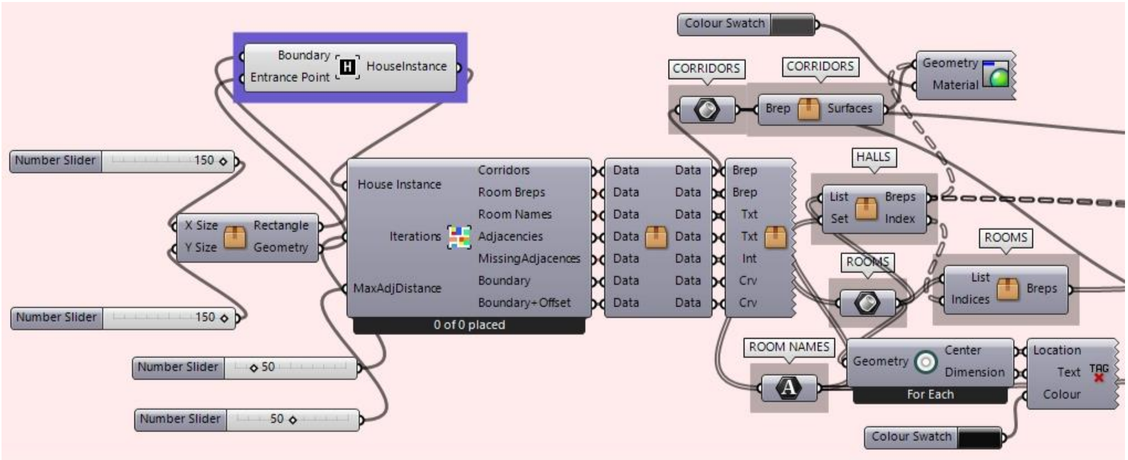



**Figure 2:** Grasshopper script that creates the initial floor plan of the building

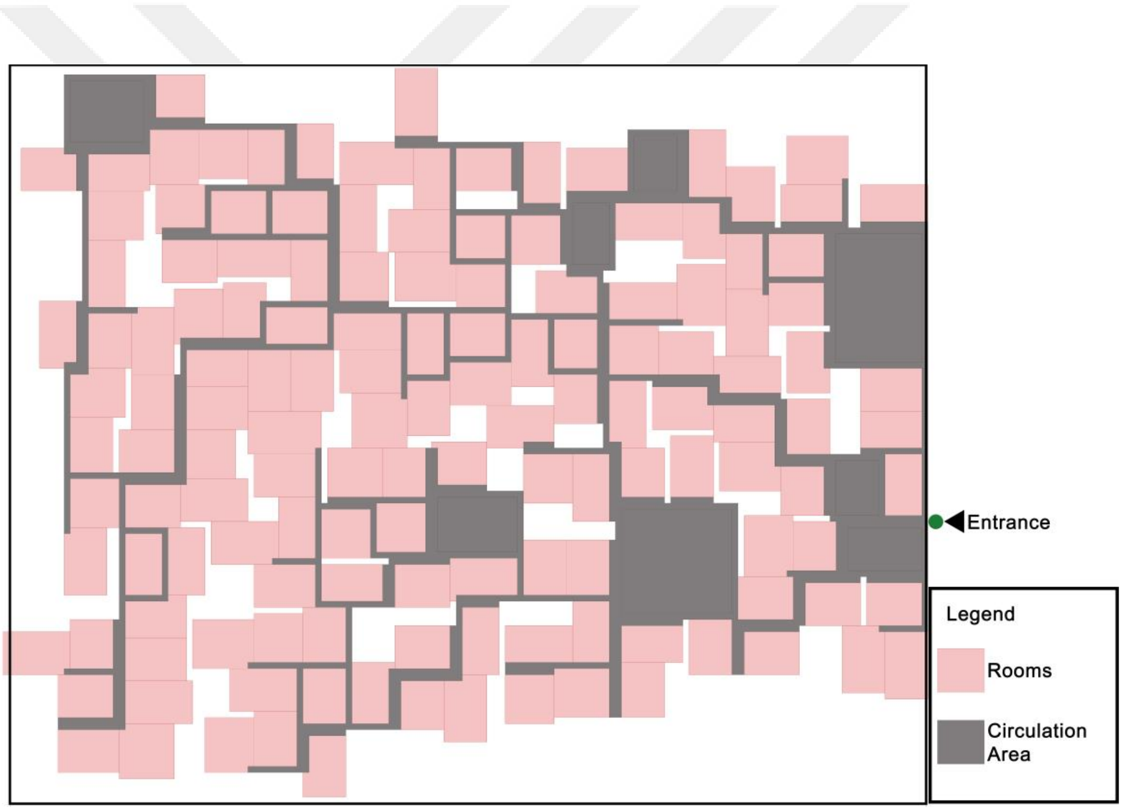



**Figure 3:** Initial floor plan configuration of the building

Accordingly, we can argue that the resulting floor plan is highly disordered, and its spatial organization logic is far from architectural understanding. Moreover, it can be stated that the outcome of this Grasshopper script is a labyrinth-like building plan, and it lacks axiality in circulation areas. Therefore, the design process of the building plan is continued with further Grasshopper algorithms to upgrade and transform the building plan configuration into a reasonable architectural layout. In this case, the existing axes are obtained and combined through an algorithm to rearrange and unify the axes that are in the same direction and 1m close to each other (Figure 4). However, it should be stated that the resulting circulation logic is still architecturally impractical. Therefore, the resulting axes are exported to the Rhinoceros 3D, and they are reconsidered and manipulated manually (Figure 5).

Subsequently, the manipulated and reorganized axes are imported to the Grasshopper, and an algorithm is added to the existing script to randomize the corridor widths (Figure 6). In this framework, each corridor is limited by random sizes between 1,5m and 4,5m. Then, the rooms are rearranged and reshaped around the corridors and halls in Rhinoceros 3D manually (Figure 7). These rooms are divided into multiple rooms, and some are defined as inner gardens. Besides, the locations of the room doors are designated in Rhinoceros 3D and exported to the Grasshopper in this stage.

After these processes, multiple algorithms are added to the existing Grasshopper script that transforms the 2D plan layout into a 3D building structure (Figure 8). In this framework, the corridor heights are designated with random altitudes between 3m and 6m. With these algorithms, we also produced door recesses and put the doors into these recessed zones. Each door recess has 160cm in length, 120cm in-depth, and 240 cm in height. On the other hand, each room door has 90cm in length and 210cm in height. Then, rooms are extruded to 6m. Subsequently, the hall heights are randomly arranged between 3m and 6m. Furthermore, the inner gardens are extruded to 8m, and glass curtain wall framings are created for these inner gardens. The resulting 3D building model is shown in Figure 9.

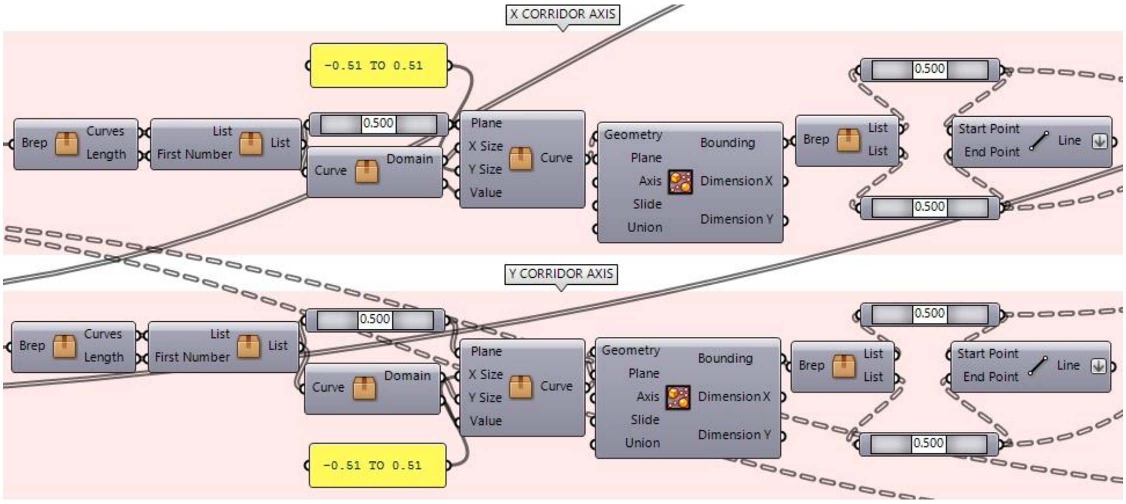



**Figure 4:** The Grasshopper script that rearranges the axes that are in the same direction and 1m close to each other

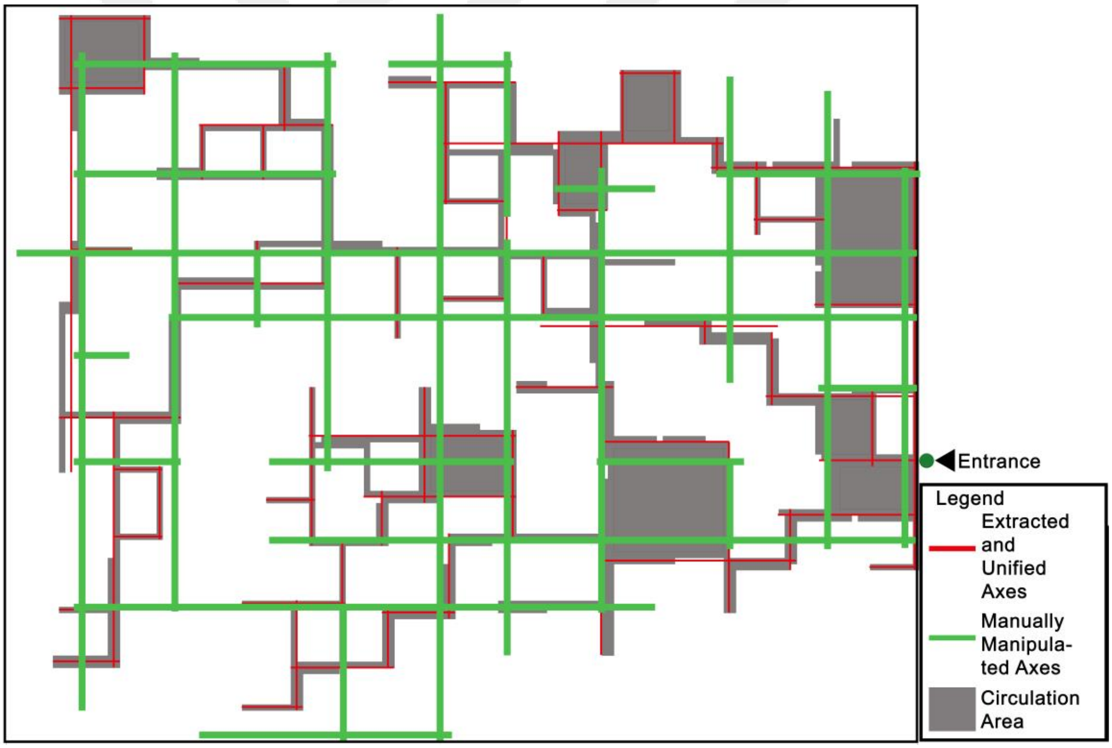



**Figure 5:** Rearrangement of the axes with the Grasshopper script and manual manipulations

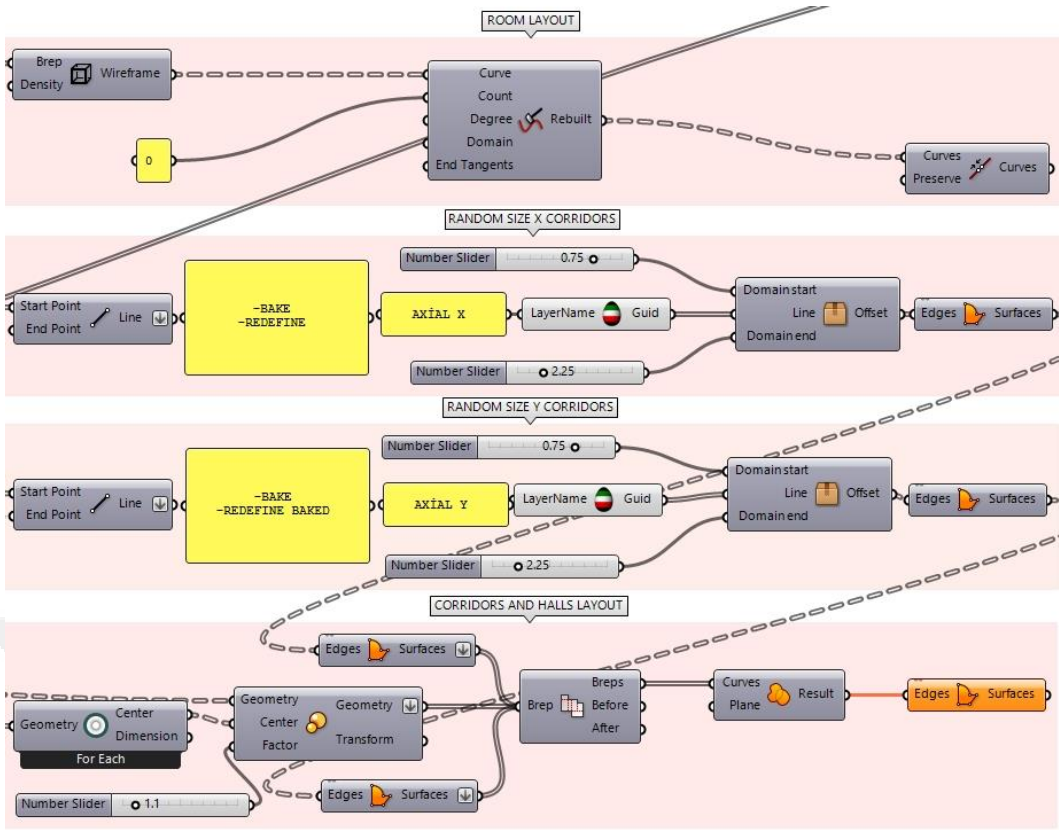



**Figure 6:** Grasshopper script that creates random corridor widths between 1,5m and 4,5m

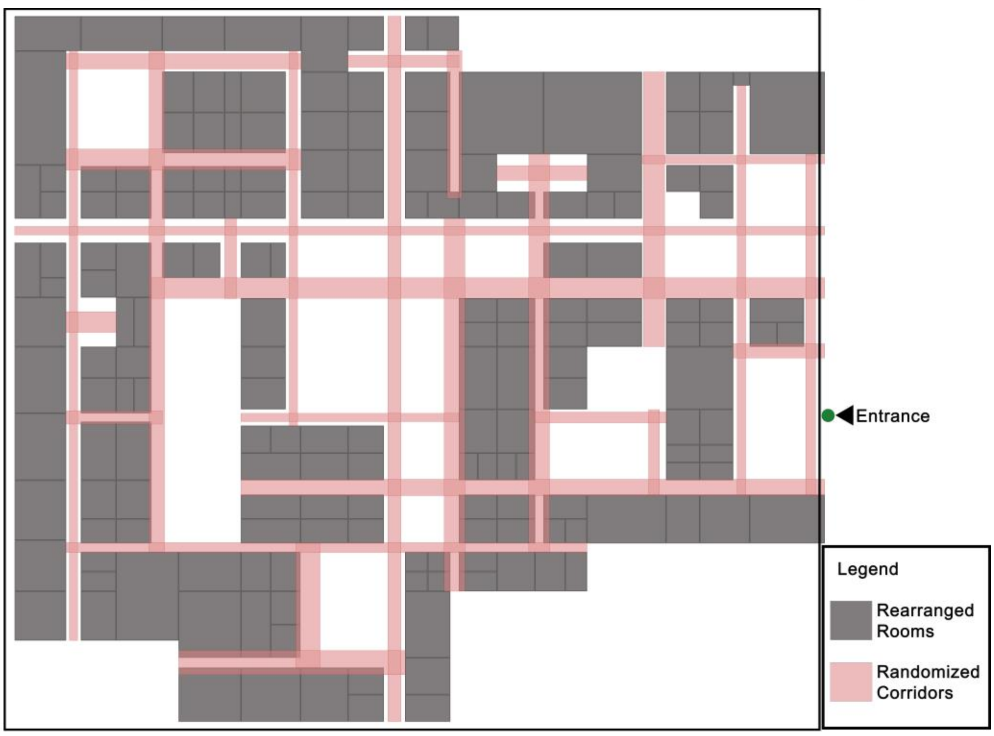



**Figure 7:** Rearrangement of the rooms around the corridors and halls

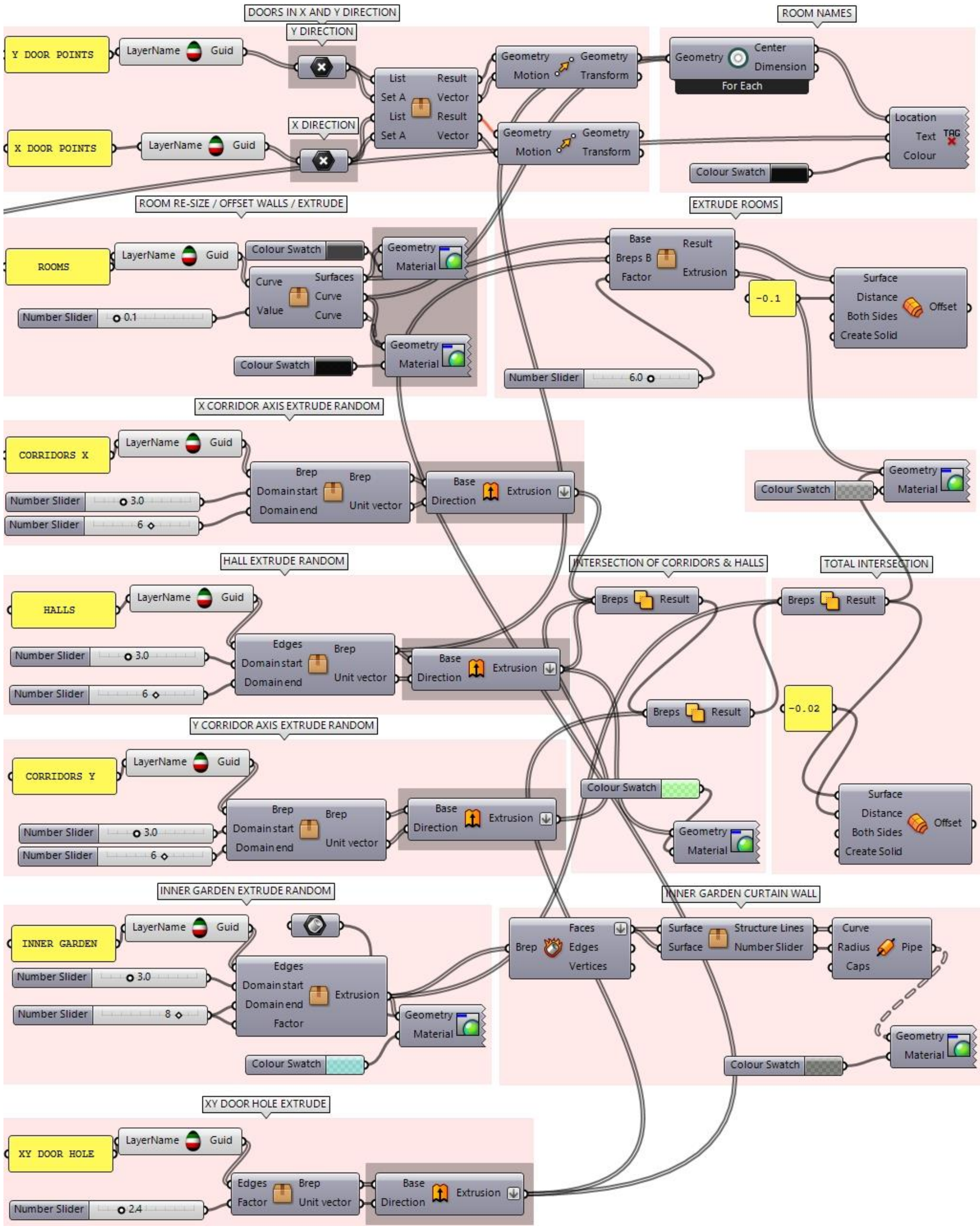



**Figure 8:** Grasshopper script that converts 2D plan layout into a 3D structure

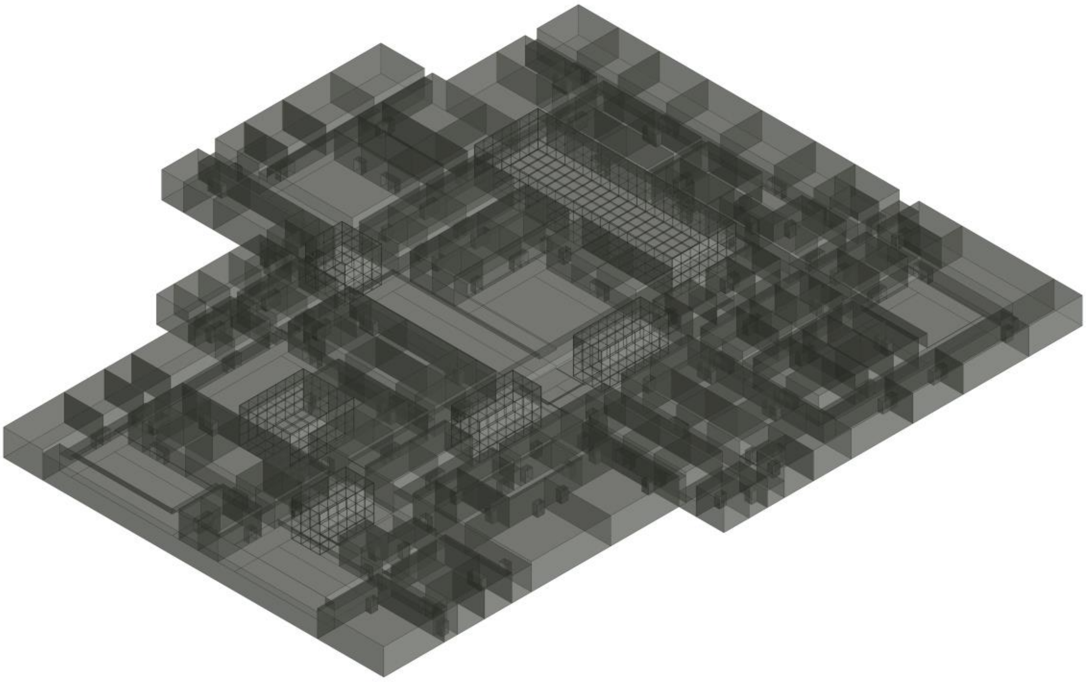


**Figure 9:** Resulting 3D building structure

Then, the Grasshopper model is exported to the Rhinoceros 3D, and some specific adjustments are made in this computer software. Firstly, all the surfaces and objects are layered to systematically work with the 3D model containing a vast number of surfaces. Then, four (4) entrance doors are added to the building entrance. All the entrance doors are designed as double swing glass doors that are different from the regular room doors to be realized by the participants as the exits of the building.

Accordingly, each building entrance door has 180cm in width and 210cm in height. Then, the facade of the building entrance is converted into a glass curtain wall with framings. Afterward, an urban plaza is added in front of the building's entrance, and terraces are attached to the other sides of the structure.

Subsequently, the locations of egress doors and signages in the building are designated, especially for the evacuation experiments. The National Fire Protection Association's (2014) [45] *Travel Distance to Exits* (2015 ed.; NFPA 101 Life Safety

Code) describes that there must be a maximum 60m travel distance from a specific location to any emergency egress door in a building.

In this context, the location of egress doors is manually determined, and a Grasshopper algorithm is created to test whether the area covered by each egress door is around a maximum of 60 meters (Figure 10). After a series of tests, the regulation is satisfied with nine (9) egress doors (Figure 11). At this point, it should be noted that the regular exits are also counted as emergency egresses for the evacuation experiments.

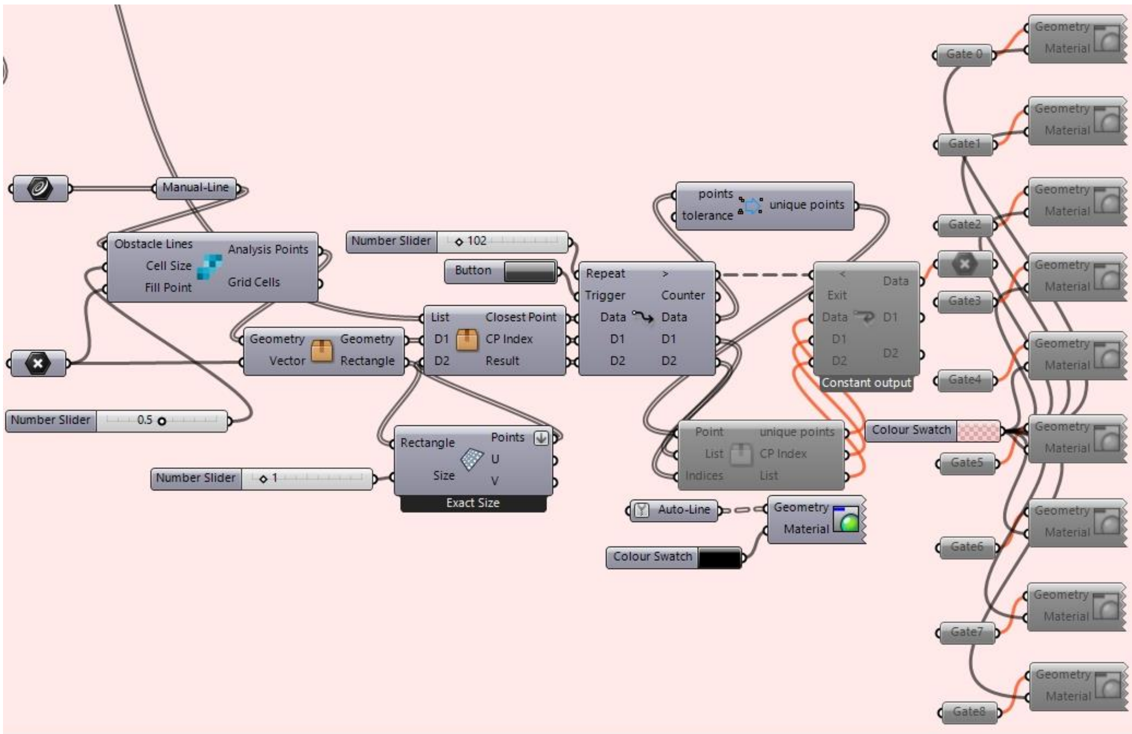



**Figure 10:** Grasshopper script that defines the area covering 60 meters from each egress


**Figure 11:** Locations of exits and areas covered up to a distance of 60m from emergency exits and regular exits.

In addition, emergency exit signboards are also added to the building in this phase. Hence, the distance between two egress signboards must not exceed 30 meters, as defined in the *Location of Exit Signs* (2015 ed.; NFPA 101 Life Safety Code; National Fire Protection Association, 2014) [45]. Therefore, we put these emergency exit signboards on every node and between some decision-making points exceeding the required distance. Besides, the egress signboards are also placed on the emergency exit doors.

The dimensions of all emergency exit boards are sized to be 18x45cm, which can be well perceived from a 30m distance according to NFPA-101 standards, as indicated by TheExitStore (2020) [47]. While the emergency exit signs in the circulation areas are positioned at 240cm height, the signages above the egress doors are located at 210cm height. These heights are designated according to the Turkish Fire Protection Regulations (2007) [48].

Subsequently, the starting point locations of the wayfinding and evacuation experiment are decided. In this context, a Grasshopper script is created to produce the justified map of the building for finding the deepest points on average from only regular exits and both emergency egresses and regular exits (Figure 12). Accordingly, node 53 is defined to be the starting point of the wayfinding experiments, and node 39 is designated as the evacuation experiment's starting location. The justified maps based on node 53 and node 39 are shown in Figure 13.

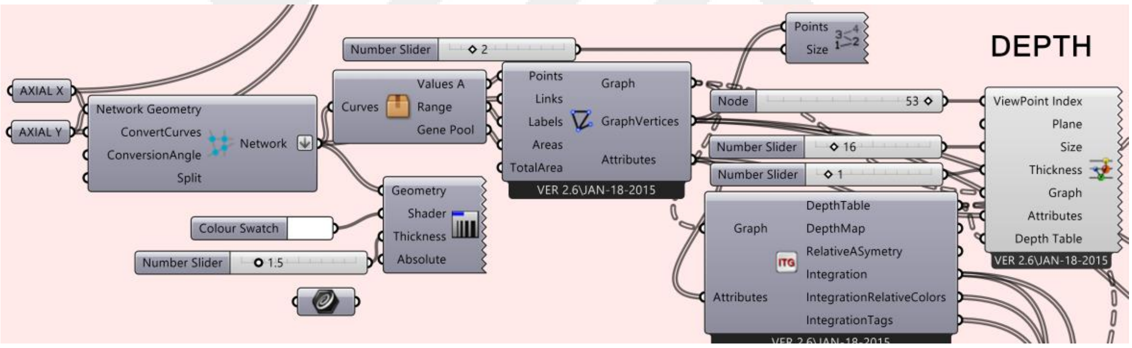



**Figure 12:** Grasshopper script that creates justified maps according to the selected node of the building

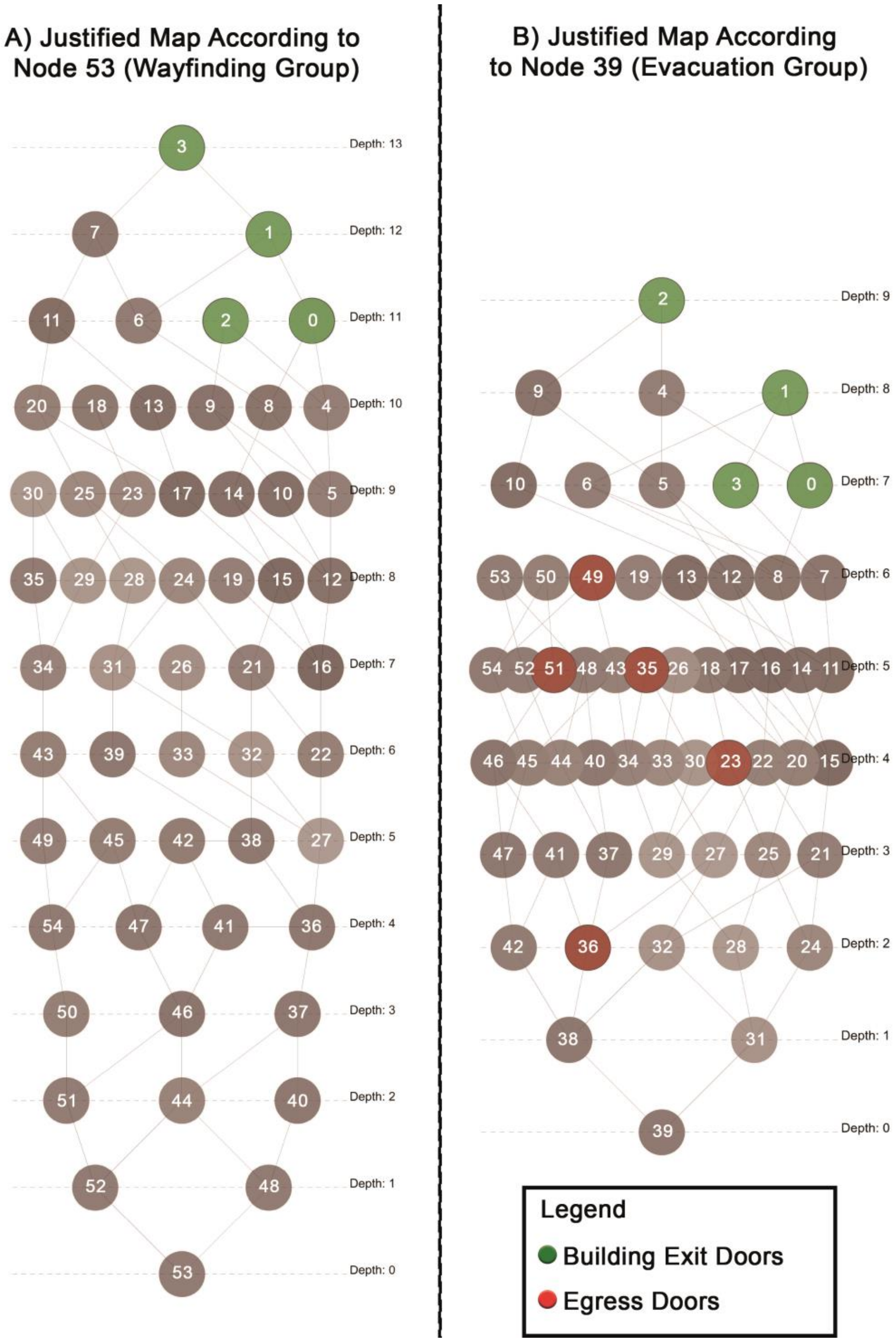



**Figure 13:** Justified maps according to node 53 and node 39

Finally, the building model contains nine (9) halls, six (6) inner courtyards, and one hundred seventy-four (174) rooms. On the other hand, the building has a $16230m^2$ total area and a circulation area of $6335m^2$ with 55 nodes. The final plan layout of the building is shown in Figure 14, and the 3D building model is shown in Figure 15.

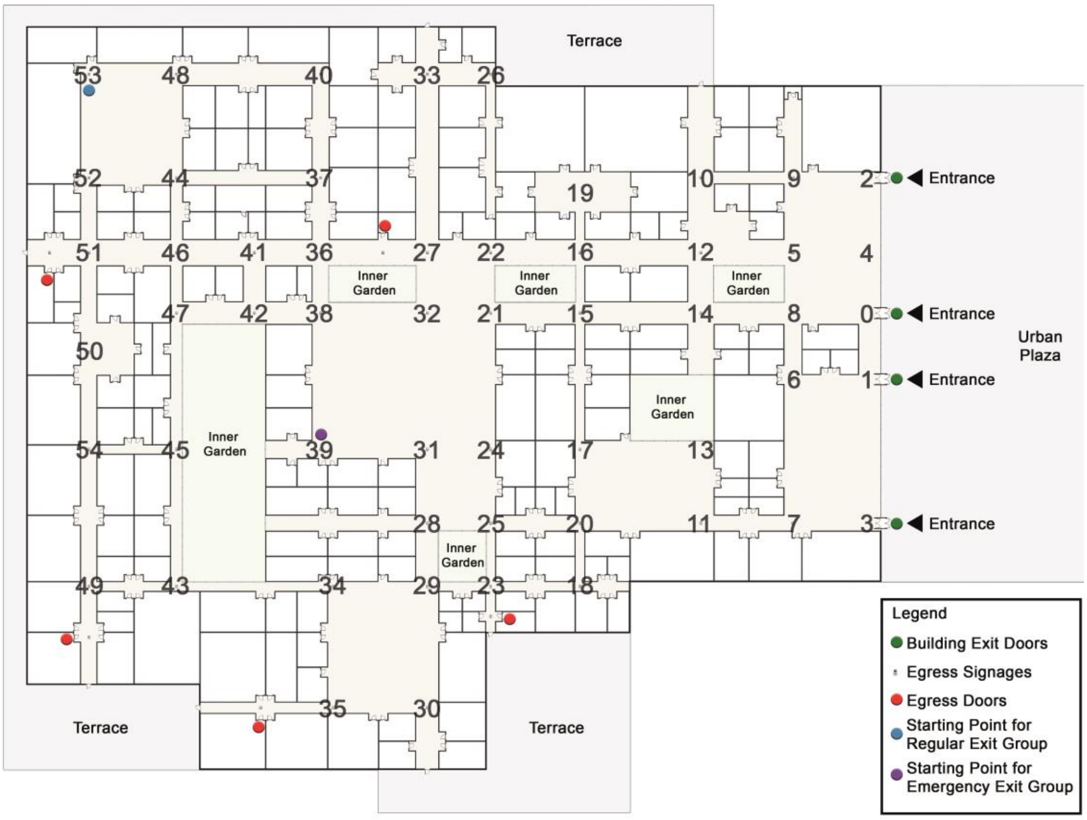



**Figure 14:** Nodes, location of exits, and starting points for wayfinding and evacuation groups

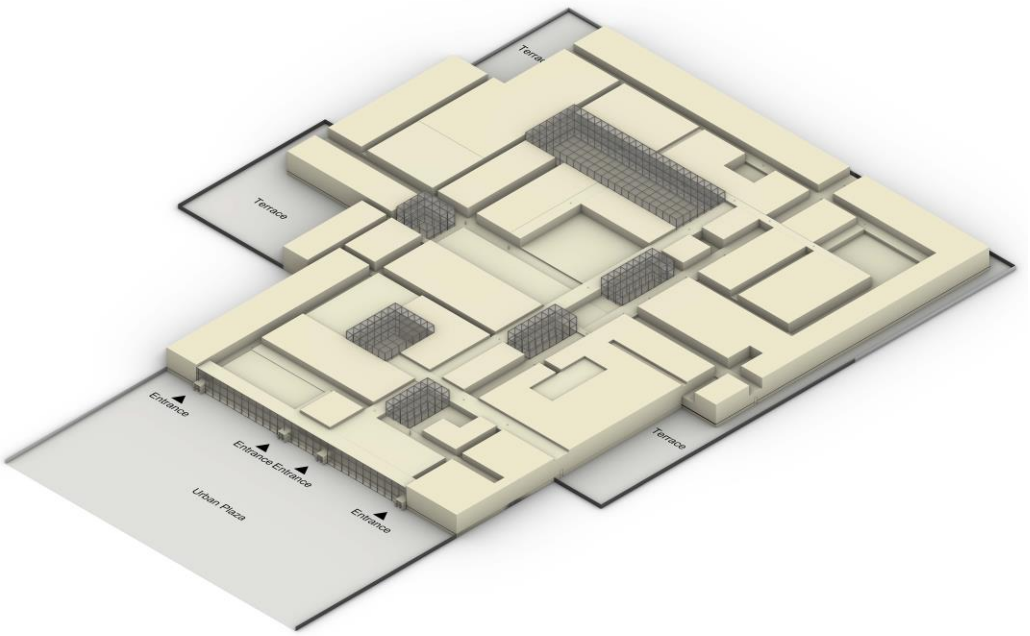



**Figure 15:** The 3D virtual building model

### 3.1.3 Creating the Simulation Environment

After creating the 3D building model, computer simulation programs are created with Unity and Microsoft Visual Studio software. Accordingly, two (2) computer simulation programs are created based on the previously designed building model: one for wayfinding experiments and one for the evacuation experiments.

First, the 3D building model is exported from Rhinoceros 3D and imported into Unity. In this case, the origin of the imported building model is adjusted according to the origin point of the 3D building in Rhinoceros 3D to match the coordinate systems for obtaining the kinesthetic data without any location error. Furthermore, the opacity of the glass materials is adjusted, and legal emergency exit signage pictures, including emergency exit notations and directional signs, are assigned to the appropriate sides of the egress boards. These egress signages are aligned to show the closest exit point of the building. Herein, we used four (4) emergency signages that show the directions of up, right, down, and left. On the other hand, the notations that are written on these signs are in Turkish.

After these processes, two (2) avatars are created. These avatars are produced using the template preset in Unity by default. Accordingly, the first avatar is located in node 53, which is the starting point for the wayfinding experiments. On the other hand, the second avatar is positioned in node 39 for the evacuation experiments. Besides, the avatars' initial looking directions are positioned diagonally so that participants could observe all the possible directions and make directional choices accordingly at the beginning of the experiments.

These avatars allowed participants to roam freely and observe the simulation environment at 170cm height during the experiments. In addition, the walking speed of these avatars is assigned as 1,5m/s, whereas the running speed is defined as 5m/s. Besides, the horizontal field of view of the avatars is designated as 105º, while the vertical is 60º. These processes are carried out in the interface of the Unity software. Besides, a footstep sound is assigned to the avatars' movement to make the simulations more realistic for the participants, especially when they are walking or running in wayfinding or evacuation experiments. Besides, the avatars' looking direction can be rotated by computer mouse gestures, and these avatars can be moved through the keyboard keys.

Subsequently, we gave operational directives to the simulation software through coding in Microsoft Visual Studio. These codes are written in the C# programming language. In this case, we created a code that saves the instant coordinates of the avatars into a previously created CSV (comma-separated values) file during the experiments. Furthermore, another code is written to obtain the avatars' head direction axis of X and the head direction axis of Z to obtain participants' instant looking directions during movement. Thus, we obtained the participants' instant vectorial looking directions, and these directional kinesthetic data are also saved into other previously created CSV files. On the other hand, we assigned the frequency of these saves as every 0,5 seconds.

Furthermore, we created two other scripts, and the first one automatically ends the simulation software when the people in the wayfinding group find and touch any of the regular exit doors. On the other hand, the second script closes the simulation software when the people in the evacuation group touch one of the regular exits or emergency egresses. Finally, we scripted one more code that manually ends the experiments if participants do not want to continue the simulations during the wayfinding or evacuation processes.

Finally, these simulation projects are exported as two different computer software, one for the wayfinding and the other for the evacuation experiments. In this framework, the first simulation contains no emergency exit signages. However, these signages are visible in the second software. On the other hand, the video aspect ratio of these simulations is assigned as 16:7 to stabilize the visible field of view that is displayed by the participants' computers since each respondent can have various sizes of computer monitors, and this situation would cause a difference or deformation in the participants' perception. In addition, these computer simulation programs are exported for the 64-bit version of Windows operating systems. These exported computer applications, including their own operating systems and target folders for saving the kinesthetic data, are zipped and named differently.

### 3.1.4 Creating the Preliminary Simulation for Drills

A preliminary simulation is designed after generating the experimental simulation environments. This preliminary simulation aims to allow participants to familiarize themselves with the simulation environment conditions and get accustomed to the avatars' movement controls. Therefore, we adopted a two-story and small-scale building to create a simulation environment where each participant could move freely for a while just before the wayfinding and evacuation experiments. This simulation is created by the same method as the actual experiments. However, we did not obtain the kinesthetic data of the participants from these simulations. Accordingly, the 3D model of the building that is used in this preliminary simulation is shown in Figure 16.

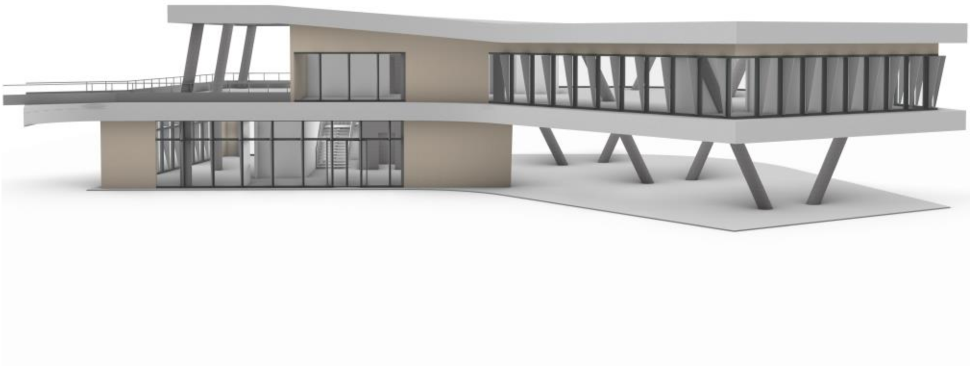


**Figure 16:** 3D building model used in the preliminary simulation for drills

### 3.1.5 Conducting Pilot Studies

The computer simulation programs are tested twice before proceeding to the actual experiments to reveal the bugs or possible errors that may occur during the actual experiments. Hence, we invited eight (8) people and conducted these tests that proceeded similar to the actual experiments. Accordingly, it should be indicated that the previously mentioned technical details about the computer simulation programs are the updated and final versions of these adjustments that are done after these tests.

Hence, these adjustments can be expressed as decreasing the avatar's walking and running speed and turning down the sound volume of its footsteps. These rearrangements are determined according to the participants' comments who joined these tests. On the other hand, these participants expressed that they found the avatars' visible field of view fine and appropriate. Therefore, we kept the vertical and horizontal field of view angles as they are since we could not fully imitate the field of view of the human eye. Besides, people who attended the emergency exit tests also stated that they could clearly see and perceive the emergency exit signages.

On the other hand, some technical issues occurred during these tests, such as not saving the kinesthetic data to the previously defined folder, sudden shutdowns, and freezes of the screen displays. It is revealed that some antivirus software may disable the operation of saving the behavioral data to previously defined folders. On the other hand, changing the zip folders' names containing the simulation software may also cause path file finding problems when saving the participant' kinesthetic data. Besides, it is recognized that screen freezes might be related to participants' computer performances. After updating and adjusting the computer simulation programs based on these errors, we proceeded to actual experiments.

## *3.2 Conducting the Experiments*

The experimental process can be explained in five (5) sections, and they can be listed as recruiting participants, conducting online meetings, the procedure of the experiments, preliminary simulation for drills, and the actual simulation experiment. In this context, all the online sessions are completed in a month.

### 3.2.1 Recruiting Participants

The experimental study is carried out with forty-four (44) people in total. All participants attended the experiments voluntarily. In this case, it should be stated that twenty-three (23) of these participants are women, and twenty-one (21) of them are men. On the other hand, the average age of the women participants is 30,04, and the average age of the men participants is 30,09. Moreover, all the participants are Turkish citizens, and these people joined the online experiments from different cities in Turkey and Italy. All the dates and meeting hours are arranged according to the availability of these respondents.

Before each experiment, each participant is randomly assigned to one of the two sampling groups based on age and gender considerations. The distribution of the participants to the sampling groups is done with coin flips. On the other hand, the behavioral data of the eight (8) people could not be obtained from the experiments due to technical issues. As a result, the total number of people in the sampling groups became thirty-six (36).

Consequently, we can indicate that each group has equal numbers of male and female participants. On the other hand, the average age of the wayfinding group is 29,94, and the average age of the evacuation group is 29,55. The sample size and participants' demographic information, including their locations, ages, and genders in each of the experimental groups, are shown in Table 1.

**Table 1:** Experimental groups, sample sizes, and demographics

| *Sampling Groups* | *Wayfinding Group* | *Evacuation Group* |
|---|---|---|
| Sample Size | 18 | 18 |
| Gender | Male:9 Female:9 | Male:9 Female:9 |
| Average Age | Male:30,88 Female:29 | Male:30,44 Female:29,22 |
| Location | Alanya:1<br>Ankara:3<br>Çorum:1<br>La Spezia:1<br>Milano:1<br>İstanbul:11<br>Uşak:0 | Alanya:4<br>Ankara:1<br>Çorum:1<br>La Spezia:0<br>Milano:1<br>İstanbul:10<br>Uşak:1 |

### 3.2.2 Conducting Online Meetings

The simulation experiments are conducted over online meetings via Zoom software. Participants attended these online sessions through invitation links sent via WhatsApp Web [49] or E-mail. All sessions are recorded, and the related zip files of the computer simulation software are sent to the participants via WhatsApp Web, E-Mail, or Zoom during the meetings. At the beginning of each experiment, an informative presentation is made to the participants. In this phase, these respondents' data are collected as gender, age, education level, profession, and computer gaming experience.

### 3.2.3 The procedure of the Experiments

All the experiments are conducted one by one. Each participant is assigned randomly to one of the two sampling groups considering his or her age and gender. At the beginning of each online experiment, an informative presentation is made to the participants via Microsoft PowerPoint [50]. First, it is explained what the experiments are related to in general, and then, the participants are informed that the whole session is recorded. At this point, we asked permission for these recordings from respondents.

On the other hand, we explained that they are free to close their computer's camera during the sessions. However, we requested to share their computer screens so that we could record and observe their movements to be able to intervene in the simulation process if an undesirable situation occurs during the wayfinding and evacuation processes. Subsequently, we collected the participants' personal data.

After these processes, we informed the participants that the experimental research is a two-folded process, and the study consists of preliminary simulation for drills and the actual simulation experiment. Accordingly, we explained that they could freely move around in the preliminary simulation and get used to controlling keys for ninety (90) seconds. Besides, we asked participants to turn off their computer's camera during the experimental process in order to record the whole scene.

Then, we gave the experimental instructions to the participants based on their sampling groups. In this context, we asked the wayfinding group to find one of the regular exit doors of the building and touch it when he or she comes to the end of the simulation. On the other hand, participants in the evacuation group are expected to leave the building as quickly as possible through one of the regular exits or emergency egresses. In this case, we did not mention emergency exit signs to the participants in the emergency egress group and expected them to realize these signs themselves during the experiments.

Moreover, it is indicated that we cannot answer any questions during the wayfinding or evacuation experiments. In this phase, we also sent the related simulation experiment software to the participants and demonstrated how the avatars could be moved and controlled with the mouse and keyboard buttons. Consequently, we also showed participants how to open the simulation software on their computers.

### 3.2.4 Preliminary Simulation for Drills

After these processes, we proceeded to the preliminary simulation for drills. First, we asked participants to unzip the preliminary simulation folder and open the EXE (Directly Executable Program) application in this folder. After participants opened the application, they started to move around, and we answered their questions about the following experiment and repeated the general instructions about the simulations to ensure that they understood the requirements well (Figure 17). After ninety (90) seconds, we requested them to quit the preliminary simulation to proceed to the actual experiment.

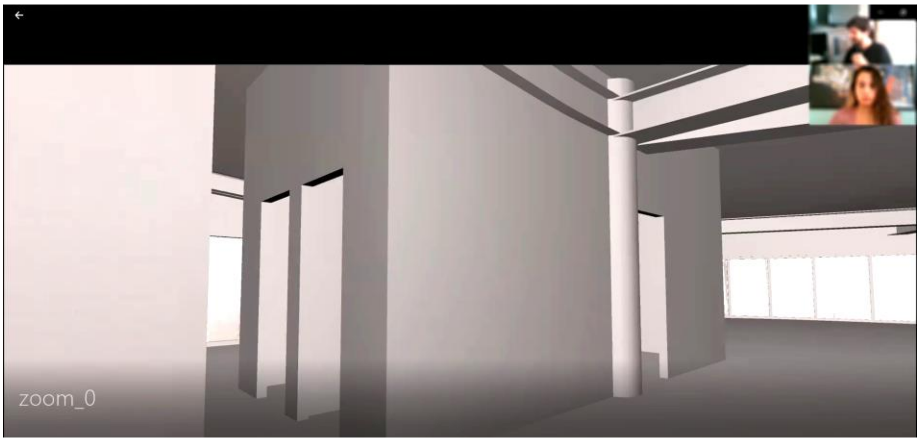



**Figure 17:** A scene from the preliminary simulation for drills

### 3.2.5 The Simulation Experiment

After preliminary simulations for drills, we continued with the actual experiment. Subsequently, we asked participants to unzip the previously sent actual simulation folder and open the EXE file to proceed with the actual experiments. Hence, the wayfinding and evacuation processes are started after participants run the simulation application (Figure 18). Then, we also made off recorded conversations about the experiments when participants completed the simulations. In this phase, we also asked them to zip the software folders and send them to us to obtain the kinesthetic data saved in these folders. Finally, we ended the sessions.

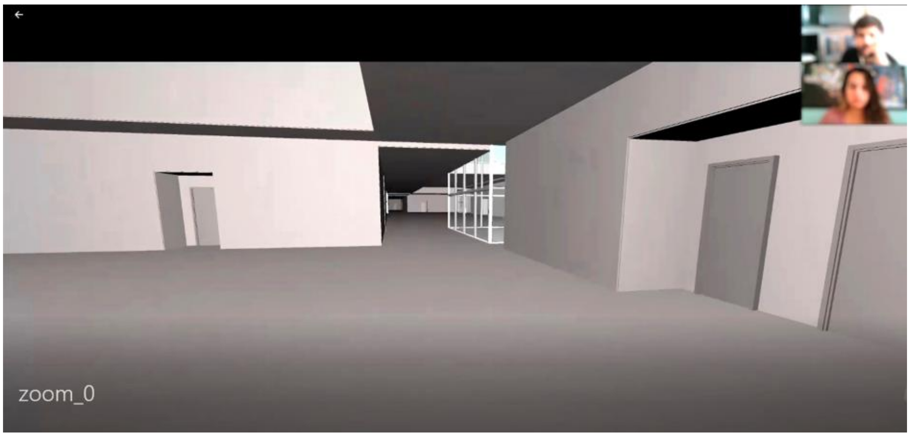



**Figure 18:** A scene from the actual simulation experiments

## 3.3 *Processing and Producing the Data*

In this study, the data processing and producing phase consists of three (3) parts: processing the raw kinesthetic data and creating the sequential measurement method, measuring the 3D syntactic data sequentially, and computing the 2D syntactic data. Moreover, we also explain how we considered these variables in this part of the chapter. Besides, it should be expressed that respondents' personal data are already obtained during the experiments, and these data are ready for analysis. On the other hand, the kinesthetic data of eight (8) respondents could not be obtained due to unknown technical errors during the experiments. Therefore, we handled behavioral data and 2D and 3D syntactic data regarding the remaining thirty-six (36) participants during this phase of the study, as mentioned before.

The sequential computation model can be seen as a highly functional method to obtain instantaneous perceptual and behavioral data in human wayfinding. In this case, we can argue that the issue of data management might be problematic since capturing and recording every perceptual moment reveals an enormous amount of data. Accordingly, Bhatia et al. (2013) [15] mention that adding a third dimension to the 2D models requires a high computer processing capacity. Grouping, analyzing, and systematically interpreting these data may also be challenging for researchers. However, algorithmic computational methods may greatly facilitate data grouping and analysis in these kinds of research.

In this study, to make sequential calculations, each decision-making point is taken with their surrounding as a square shape covering approximately $50m^2$. Thus, participants' volumetric visibility data and kinesthetic data values are taken into account for consecutive measurements when respondents are inside these borders. A series of specific algorithms in Grasshopper is created to handle this process. In other words, it should be expressed that this process does not include all points on the route, but it contains only the points inside these areas in the calculations that reduce the computer's processing time and avoid exceeding the central processing unit (CPU) capacity.

### 3.3.1 Variables

The study focuses on these 3D syntactic data: polyhedron volume, polyhedron surface area, optimized polyhedron volume, optimized polyhedron surface area, and spherical circularity. Besides, the research also examines isovist area, isovist perimeter, drift, circularity, standard deviation, variance, skewness, depth, mean depth, and integration parameters regarded as the 2D syntactic data. In addition, we also considered participants' personal data by investigating their genders, ages, education levels, professions, and computer gaming experiences. Hence, we regarded these 3D syntactic data, 2D syntactic data, and personal data as independent variables.

On the other hand, the kinesthetic data is investigated as the frequency of interpasses, frequency of stepbacks or stops, frequency of turns, average spent time, the average duration of stops, average frequency of head rotations, the average frequency of unmatched movement and looking directions, distance passed, duration, average speed, number of stepbacks or stops, and number of turns. In this context, we considered these behavioral data as dependent variables.

All dependent and independent variables are evaluated under the categories of objective assessments, subjective assessments, and sequential objective assessments in Chapter IV. We focused on the correlations between 2D syntactic data and manually observed node-based kinesthetic data for wayfinding and evacuation groups in the objective assessments. On the other hand, we concentrated on the correlations between personal data and route-based kinesthetic data in subjective assessments. Furthermore, in the sequential objective assessment, we covered the correlations between 3D syntactic data and sequentially calculated node-based kinesthetic data that are measured through algorithms. All the variables are listed in Table 2.

**Table 2:** Variables

| *2D Syntactic Data (I.V.)* | | *3D Syntactic Data (I.V)* | | *Personal Data (I.V)* | | *Kinesthetic Data (D.V.)* | |
|---|---|---|---|---|---|---|---|
| Isovist Data | Isovist Area | Polyhedron Data | Polyhedron Volume | Demographic Data | Gender | Node-Based Data (Manual | Frequency of Interpasses |
| | Isovist Perimeter | | Polyhedron Surface Area | | Age | | Frequency of Stepbacks or Stops |
| | Drift | | Optimized Polyhedron Volume | | Education | | Frequency of Turns |
| Radial Data | Circularity | | Optimized Polyhedron Surface Area | | Profession | Node-Based Data (Sequential Algorithmic Measurement) | Average Spent Time |
| | Standard Deviation | Polyhedron Radial Data | Spherical Circularity | Competence Data | Computer Gaming Experience | | Average Duration of Stops |
| | Variance | | | | | | Average Frequency of Head Rotations |
| | Skewness | | | | | | Average Frequency of Unmatched Movement and Looking Directions |
| Graph Data | Depth | | | | | Route-Based Data | Distance Passed |
| | Mean Depth | | | | | | Duration |
| | Integration | | | | | | Average Speed |
| | | | | | | | Number of Stepbacks or Stops |
| | | | | | | | Number of Turns |

#### 3.3.1.1 *2D Syntactic Data*

Two-dimensional syntactic data can be described in three (3) subcategories: isovist data, radial data, and graph data. In this context, isovist area, isovist perimeter, and drift variables can be evaluated under the isovist data. On the other hand, circularity, standard deviation, variance, and skewness parameters can be counted as radial data. Furthermore, we regarded depth, mean depth, and integration parameters as graph data.

As an isovist data, the isovist area is the visible area that is observed from a particular vantage point, and the isovist perimeter is the border length of this visible zone (Benedikt, 1979) [8]. In this case, the isovist polygon is the two-dimensional representation of the visible space that is observed from the vantage point, and this area is measured in square meters, whereas the perimeter of this area is calculated in meters. On the other hand, Dalton and Dalton (2001) [9] describe the drift as the metric distance between the vantage point and the center of gravity of the isovist polygon. In this case, it is stated that the observation point with minimum drift values may indicate that the spectator is close to the center of the space (Dalton & Dalton, 2001) [9].

On the other hand, the circularity value also gives an idea of how close the observation point is to the center of the visible space and provides information about the approximation of the isovist form to a circular shape (Dalton & Dalton, 2001) [9]. Moreover, Benedikt (1979) [8] states that the circularity parameter is also related to the ratio between compactness and complexity. In this context, it may be expressed that the visual experience is persistently stable in compact spaces. Although Benedikt (1979) [8] defines circularity as an isovist data, it may also be regarded as radial data according to the formula expressed by Dalton and Dalton (2001) [9].

Batty (2001) [18] mentions that Benedikt made the circularity calculation as the square of the isovist perimeter divided by the isovist area (1). According to Benedikt's (1979) [8] formulation, if the resulting value is 1, there is perfect circularity, while if it is greater than 1, it means that circularity is low. On the other hand, Dalton and Dalton (2001) [9] measure circularity value by multiplying the 'π' with the square of the average radial length and dividing the result by the isovist area (2). Hence, the results range from 0 to 1, and numbers close to the value of 1 indicate high circularity. In this study, we measure the circularity values according to Dalton and Dalton's (2001) [9] formulation and, therefore, we accepted the circularity parameter as radial data.

$$Benedikt's\ Circularity = \frac{(perimeter)^2}{area} \tag{1}$$

$$Dalton\ \&\ Dalton's\ Circularity = \frac{\pi.\,(\text{average radial length})^2}{area} \tag{2}$$

As another radial data, standard deviation measures the amount of variation of radial lengths in an isovist polygon, as expressed by Dalton and Dalton (2001) [9]. They measure the standard deviation by the addition of the differences between each radial length and mean radial length and by dividing the result by the number of the radials (3). On the other hand, variance (4) is the second moment of the isovist and measures how dispersed the isovist perimeter is, whereas the skewness (5) is the third moment of the isovist and indicates the asymmetry of this dispersion (Benedikt, 1979) [8]. In this context, the variance may indicate both the complexity and eccentricity of the isovist, whereas skewness may give an idea about whether the isovist polygon consists of more long radials or short radials. In this context, a positive skewness value may imply that there are more short radials in the isovist polygon, and a negative skewness value may be conceived as there are more long radials in the isovist.

$$S.D. = \frac{1}{m} \sum_{n=1}^{n=m} radial\ length - average\ radial\ length \tag{3}$$

$$Variance = \sqrt{\frac{1}{m} \sum_{n=1}^{n=m} (radial\ length - average\ radial\ length)^2} \tag{4}$$

$$Skewness = \sqrt[3]{\frac{1}{m} \sum_{n=1}^{n=m} (radial\ length - average\ radial\ length)^3} \tag{5}$$

If we continue with the graph data, Hillier and Hanson (1984) [30] express that going from one place to third place through passing a second place requires a conception of depth. In this framework, Hillier and Hanson (1984) [30] explain how to organize and align the spaces according to their depth levels in justified maps. Therefore, the depth parameter may be defined as the visual distance of a place from any other point in these graph maps. On the other hand, mean depth may be explained as the average depth level of one place according to all other places in the spatial configuration (Hillier & Hanson, 1984) [30]. In this context, we can mention that mean depth (6) can take values from 0 to infinity.

$$Mean\ Depth = \frac{1}{m} \sum_{n=i}^{n=m} depth\ level \tag{6}$$

On the other hand, the integration parameter may be conceived as the inversed and normalized version of the mean depth. Moreover, the integration value of the space illustrates how the area is integrated or segregated compared to other zones in the surrounding. Hillier and Hanson (1984) [30] demonstrate that the integration parameter can be used when comparing different environments that have different sizes. On the other hand, Peponis et al. (1990) [31] state that "… integration is a measure of the relative position of a space or axial line vis-à-vis the general pattern of the building configuration.". In this framework, the integration parameter can have values between 0 and 1.

#### *3.3.1.2 3D Syntactic Data*

Volumetric visibility data as 3D syntactic data can be explained under two (2) subcategories in this study: polyhedron data and polyhedron radial data. Hence, polyhedron volume, polyhedron surface area, optimized polyhedron volume, and optimized polyhedron surface area can be counted as polyhedron data. On the other hand, spherical circularity can be evaluated as polyhedron radial data that is implemented specifically in this master's thesis.

Polyhedrons can be conceived as the three-dimensional representation of the visible space. Polyhedron volume is the volumetric measure of the visible space from a specific vantage point, and this volume is measured in cubic meters. In addition, polyhedron surface area is the surface area of this polyhedron, calculated in square meters. On the other hand, optimized polyhedron volume can be explained as the polyhedron volume that remains in the field of view of the observer's looking direction from a particular vantage point. In this case, optimized polyhedron surface area can be defined as the surface area of the optimized polyhedron form. Hence, optimized polyhedron volume and optimized polyhedron surface area might be significant in deciphering spatial decisions since people can perceive and process the spatial information that remains in their field of view.

The discussed value as spherical circularity is the alteration of Dalton and Dalton's (2001) [9] circularity formula regarding the sphere volume formula in this study. On the other hand, the spherical circularity value can give an idea of how close the observation point is to the center of the three-dimensional visible space, and thus it provides us the information about the approximation of the polyhedron form to a spherical shape. We created this parameter, assuming that spherical circularity values might be consciously interpreted in wayfinding and evacuation evaluations, especially when investigating spatial hesitations in human behavior.

In this study, the spherical circularity value is calculated by multiplying ‘4π’ with the cube of the average polyhedron radial length and dividing the result with the polyhedron volume three times (7). We can indicate that the possible results here are between 0 and 1. In this context, the value of 1 denotes the perfect sphere. On the other hand, we can mention that the spherical circularity value rises when the volumetric compactness increases and the three-dimensional spatial complexity decreases. The diagrammatic expressions of polyhedron volume, optimized polyhedron volume, and spherical circularity are shown in Figure 19.

$$Spherical\ Circularity = \frac{4.\pi.(\text{average polyhedron radial length})^3}{3.(polyhedron\ volume)} \qquad (7)$$

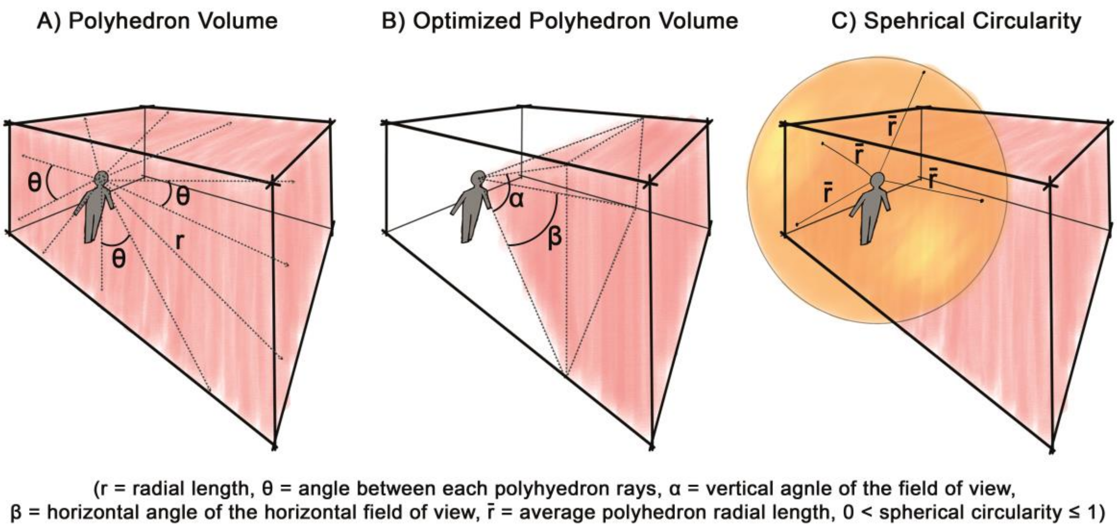



**Figure 19:** Diagrammatic expressions of polyhedron volume, optimized polyhedron volume, and spherical circularity

#### *3.3.1.3 Personal Data*

Personal data can be listed in two (2) subcategories: demographic data and competence data. In this case, age, gender, education, and profession are demographic data. On the other hand, the computer gaming experience can be regarded as part of the competence data. Hence, the participants' computer gaming experience would be one of the significant determinants of the wayfinding performances in experiments since these experiments are designed as virtual computer simulations that have similarities with some of the first-person games.

#### *3.3.1.4 Kinesthetic Data*

Kinesthetic data can be put forward in three (3) subcategories: manually observed node-based data, algorithmic and sequentially calculated node-based data, and route-based data. In this context, the frequency of interpasses, frequency of stepbacks or stops, and frequency of turns are considered as manually observed node-based data. On the other hand, average spent time, the average duration of stops, average frequency of head rotations, and average frequency of unmatched movement and looking directions can be handled as algorithmic and sequentially calculated node-based data. Moreover, distance passed, duration, average speed, number of stepbacks or stops, and number of turns are the route-based data.

If we continue with manually observed node-based data, the frequency of interpasses indicates how many times each participant passes a node. On the other hand, the frequency of stepbacks or stops implies how often each respondent makes stepbacks or stops in a node. This variable would be interpreted as hesitations about the wayfinding issues. Furthermore, the frequency of turns denotes how many times each participant turns in a decision-making point. These variables are manually counted, and the outcomes are evaluated in Chapter IV.

As algorithmic and sequentially calculated node-based data, the average spent time indicates how much time, on average, is spent in a node considering all participants' data. Besides, the average duration of stops implies how much time, on average, is spent by stopping in a node. Furthermore, the average frequency of head rotations denotes how many times, on average, the looking directions of the participants are changed in a node considering all participants' data.

On the other hand, participants might change their looking directions during the movement process, and they might not turn in the decision-making point but observe the other directions by turning their heads. In this case, this parameter would imply the attempt of discovery during the wayfinding and evacuation processes. Therefore, we measure the average frequency of unmatched movement and looking directions that indicate how many times, on average, head rotation behavior is revealed independently from a movement direction in a node.

As route-based data, the distance passed variable indicates the length of each participant's trajectory route. Moreover, the duration parameter indicates how much time it takes for each participant to complete the experiment. On the other hand, the average speed is measured by dividing each respondent's trajectory length by duration. Furthermore, the number of stepbacks or stops denotes the total number of stepbacks or stops that each participant makes during the wayfinding or evacuation process. Finally, the number of turns implies each participant's total number of turns during the wayfinding or evacuation simulations.

### 3.3.2 Processing the Raw Kinesthetic Data and Creating the Sequential Measurement Method

The previously obtained raw kinesthetic data are processed to be consciously evaluated in the analysis part of the study. In this framework, we created a series of algorithms in Grasshopper to convert these raw data to meaningfully interpretable values. On the other hand, we also recreated the routes of the respondents and produced normalized time diagrams of these trajectories with the processed behavioral data.

In this framework, we transferred all the kinesthetic data of the respondents from CSV files to the Grasshopper to obtain route-based data and created a script that reveals each participant's instant locations and looking directions during the wayfinding and evacuation processes (Figure 20). In this way, we combined these consecutive locations and reconstructed the respondents' routes revealed during the experiments. At this point, we measured the distance that each participant passed and calculated the time that each participant spent during the simulations. Thereby, we also revealed the average speed of each respondent during the experiments. These parameters are evaluated under the route-based kinesthetic data.

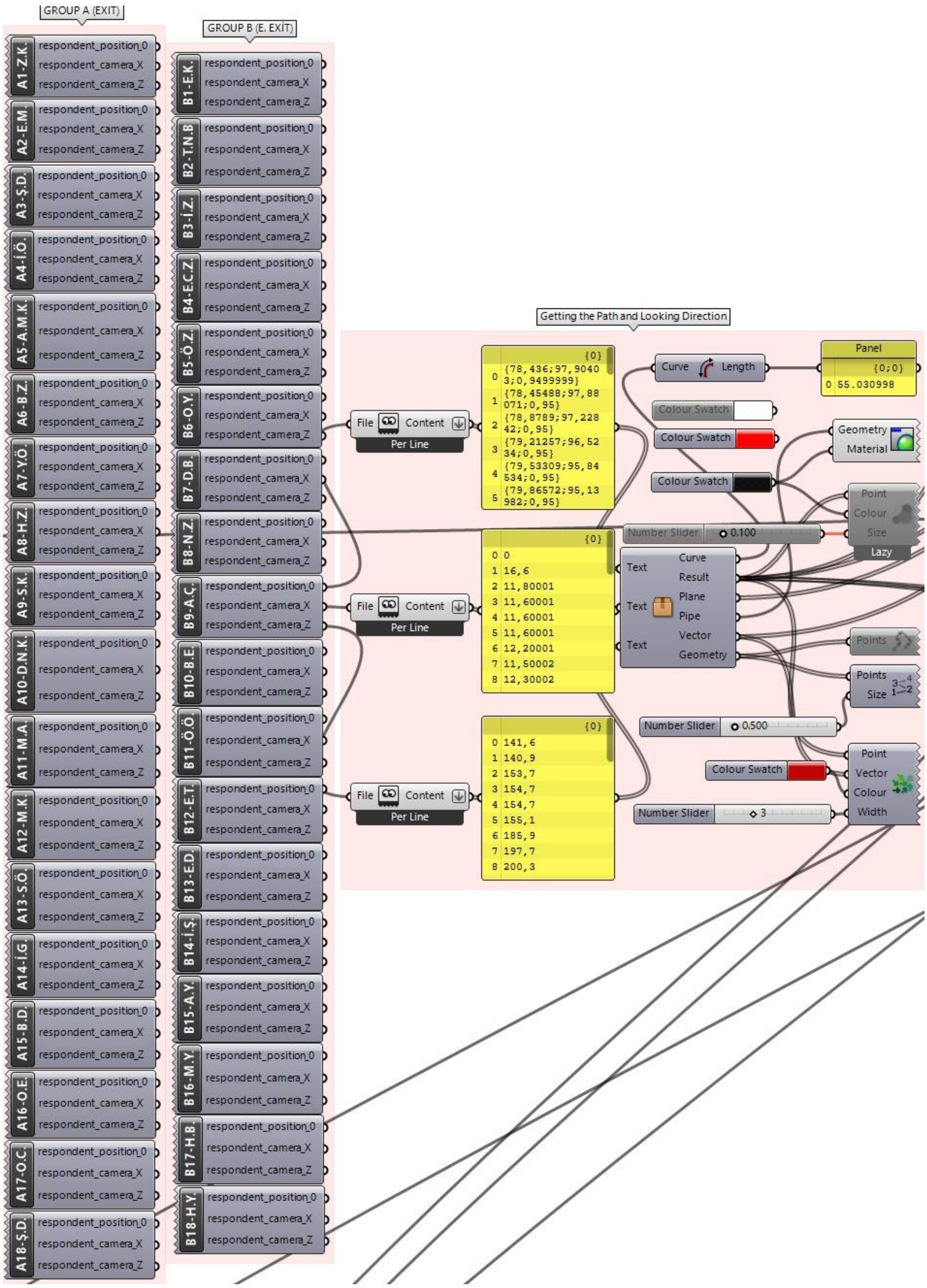


**Figure 20:** Grasshopper script that reveals participants' instant locations, looking directions, and routes during the experiments

Afterward, another Grasshopper script is prepared to make normalized time diagrams (Figure 21). In these diagrams, the time spent during the experiment is divided into ten equal steps for each participant. Then, participants' routes as footsteps are overlayed and visualized separately for each phase for wayfinding and evacuation groups. Accordingly, these diagrams are intended to reveal the collective tendencies in spatial decision-making in each normalized-time period to discover issues during the wayfinding and evacuation processes. On the other hand, this process also reveals the nodes and the areas passed during the simulations that might be only theoretically indicated.

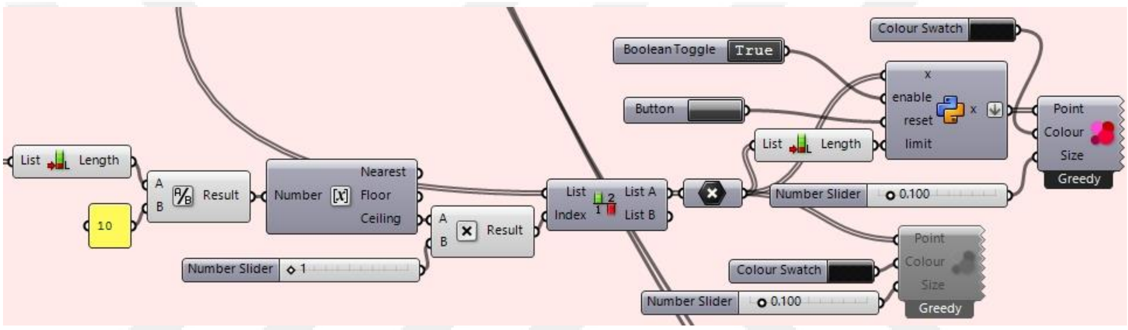



**Figure 21:** Grasshopper script that divides the participants' routes into ten equal pieces to create the normalized time diagrams

After these processes, a series of Grasshopper algorithms are produced to measure node-based kinesthetic data that is sequentially calculated through algorithms. These data can be listed as the average spent time, the average duration of stops, the average frequency of head rotations, and the average frequency of unmatched movement and looking directions. In this framework, we first created a control panel that allows managing the sequential measurements, such as starting or stopping the operations, recording the processed data, or resetting the recorded data. Then, we created a timer script that consecutively obtains each respondent's instant location and looking direction, and we produced another script that visualizes each participant's sequential vantage points and looking directions and distributes these data consecutively to further scripts

(Figure 22). We can indicate that these scripts are the core algorithms of the sequential measurements, and these algorithms are also used in sequential calculations of the 3D syntactic data parameters.

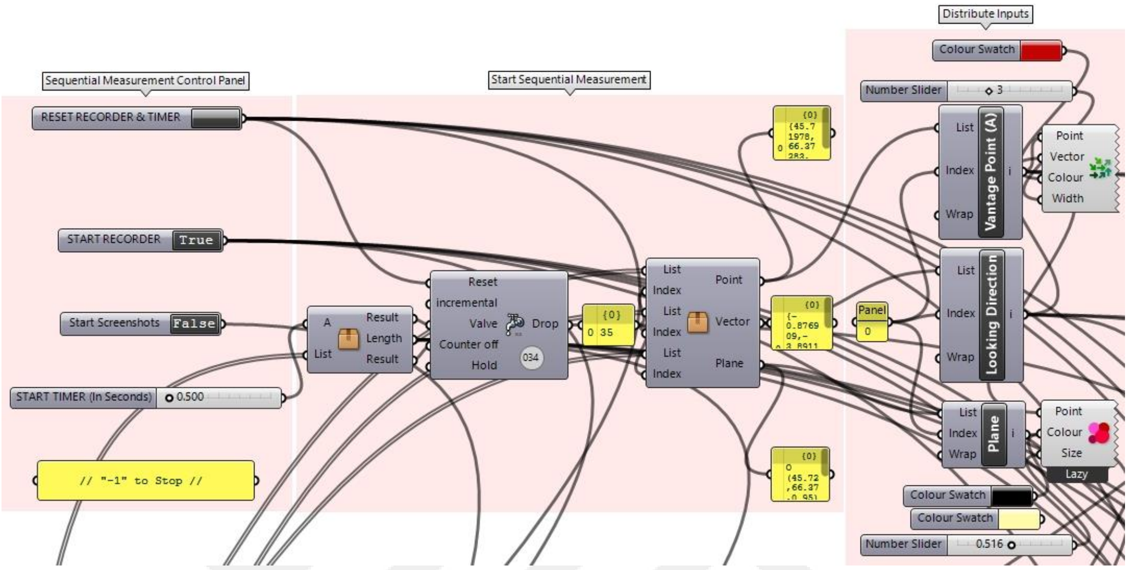



**Figure 22:** Grasshopper script that consecutively obtains each participant's instant location and looking direction and distributes these data sequentially to further scripts

Subsequently, another script is created to sequentially record each participant's instant angle of looking direction and angle of movement direction in degrees according to the X-axis (Figure 23). Besides, we also recorded the distance of the movement between one footstep to another with this script. Furthermore, the angular directional data are converted to main directional data as east, north-east, north, north-west, west, south-west, south, and south-east. In this context, while the first script converts the angle of looking direction, the other one converts the angle of movement. These scripts are similar to each other, and the second algorithm is demonstrated in Figure 24. On the other hand, we can express that the angular interval that corresponds to one main direction is 45º. Accordingly, the directional intervals in degrees and their corresponding main directions are shown in Table 3.

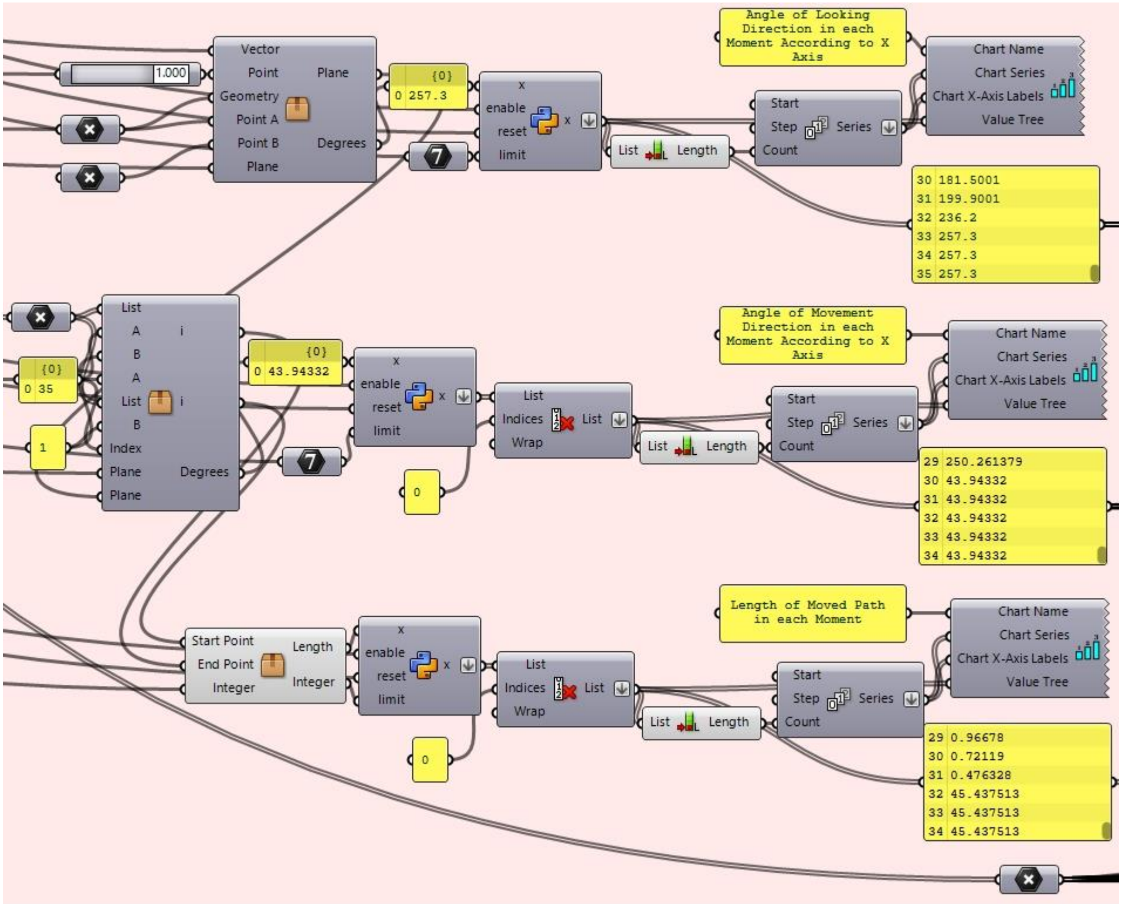



**Figure 23:** Grasshopper script that sequentially records each participant’s instant angle of looking direction and angle of movement direction in degrees according to the X-axis and measures the distance of the movement between two footsteps

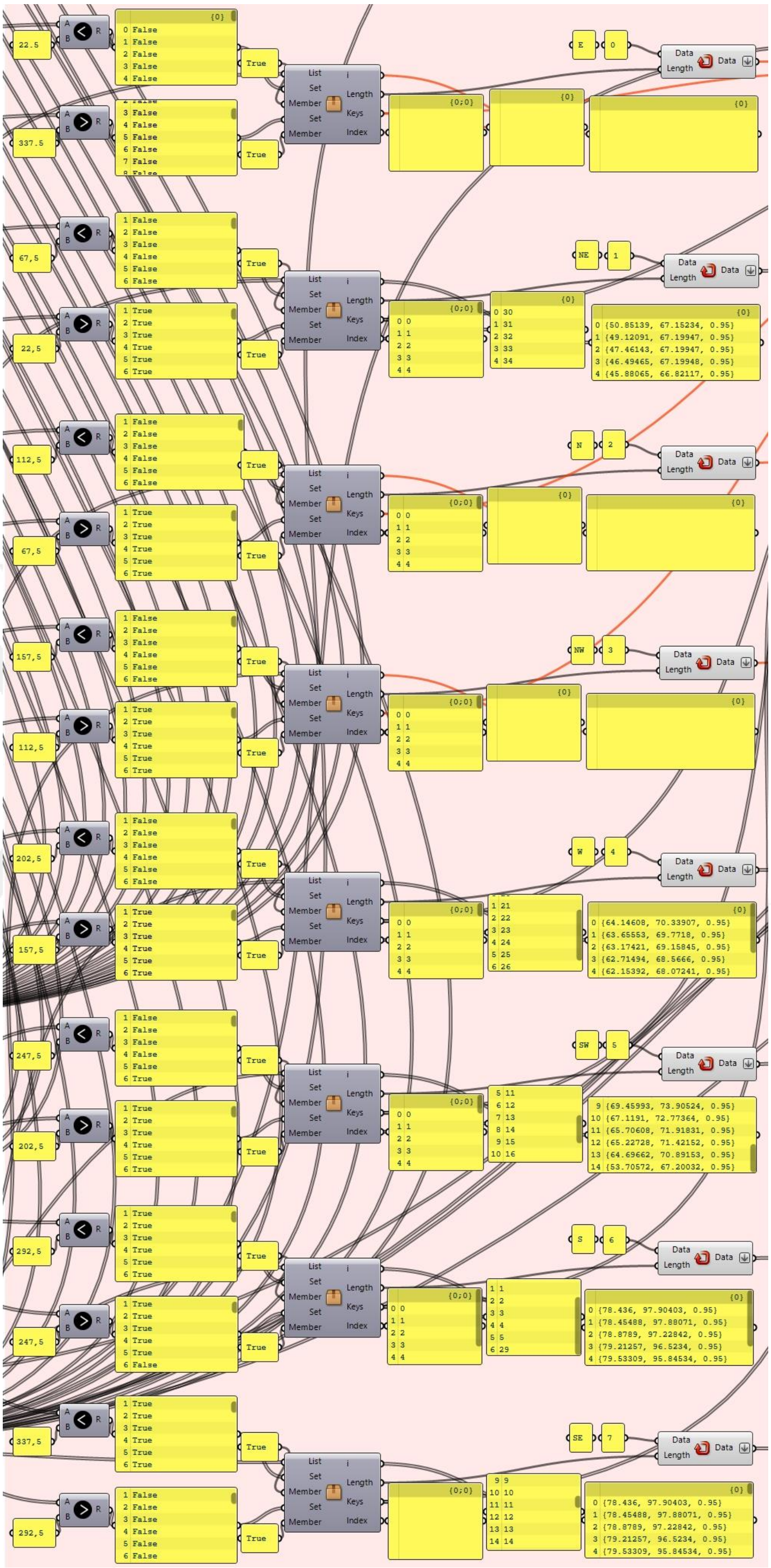



**Figure 24:** Grasshopper script that converts angular directional data to main directional data

**Table 3:** Angular directions and their corresponding main directions

| *Angular Directions* | *Main Directions* |
|---|---|
| 337,5º - 22,5º | East |
| 22,5º – 67,5º | North-East |
| 67,5º - 112,5º | North |
| 112,5º - 157,5º | North-West |
| 157,5º - 202,5º | West |
| 202,5º - 247,5º | South-West |
| 247,5º - 292,5º | South |
| 292,5º - 337,5º | South-East |

Furthermore, an additional algorithm is prepared to combine these main directional data in order of occurrence in two lists, one for looking directions and one for movement directions (Figure 25). In this way, we could distribute these data to the scripts that calculate the frequency of head rotations and frequency of unmatched movement and looking directions that are revealed in nodes. Accordingly, we defined a 7m-to-7m square for each decision-making point of the building to test whether the considered vantage points are inside these defined boundaries or not.

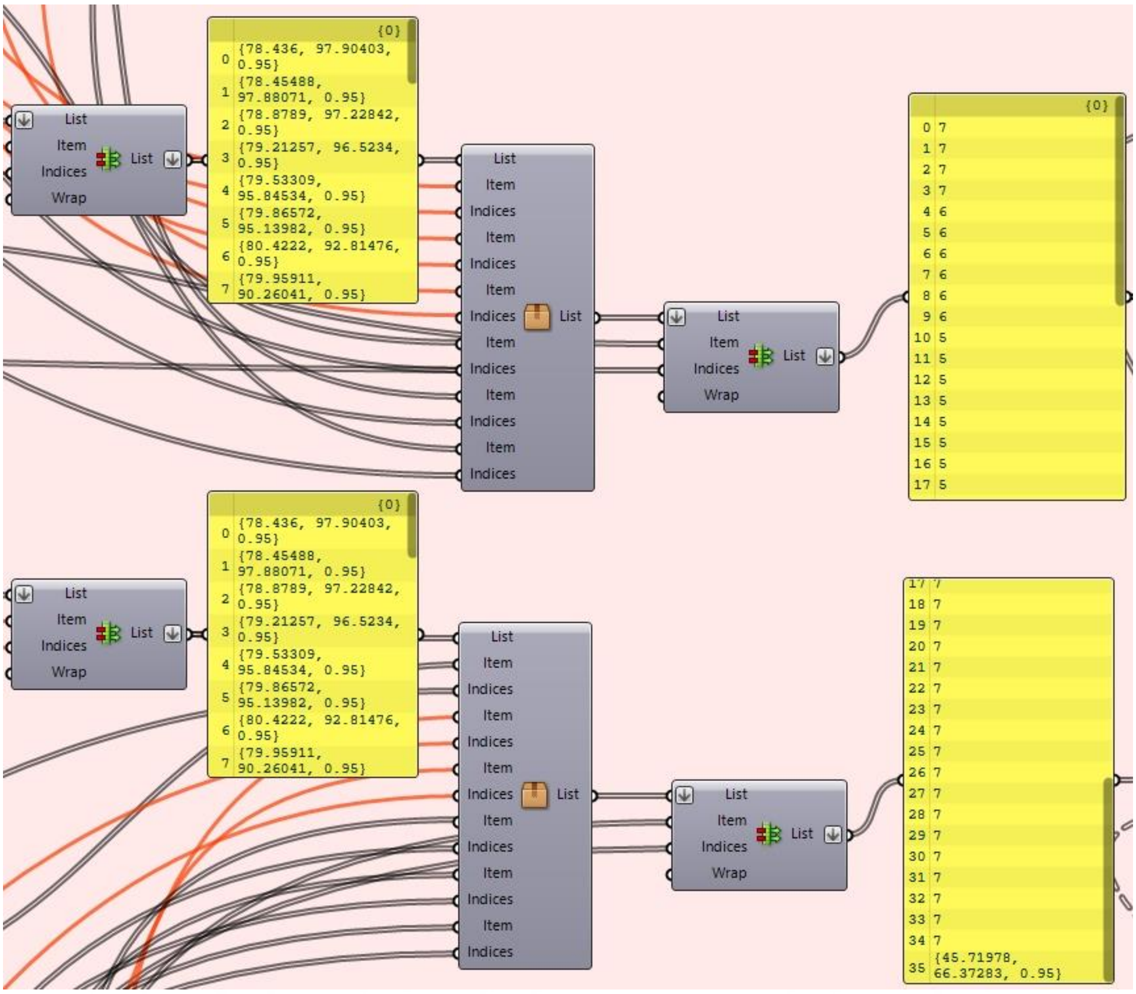



**Figure 25:** Grasshopper script that combines main directional data in the order of occurrence in two lists, one for looking directions and one for movement directions

Hence, we captured the sequential vantage points remaining inside these boundaries through several algorithms and calculated the participants' spent time, the duration of stops, the frequency of head rotations, and the frequency of unmatched movement and looking directions in these nodes (Figure 26). In this context, we used the 'ParPointInCurve' component of the Grasshopper plug-in, called Impala, to test if the regarded vantage points are inside the previously defined squares surrounding the nodes. In this way, we could also designate which sequential kinesthetic data occurred in which node. Consequently, a sample route and sequentially measured vantage points that remain in decision-making zones are shown in Figure 27.

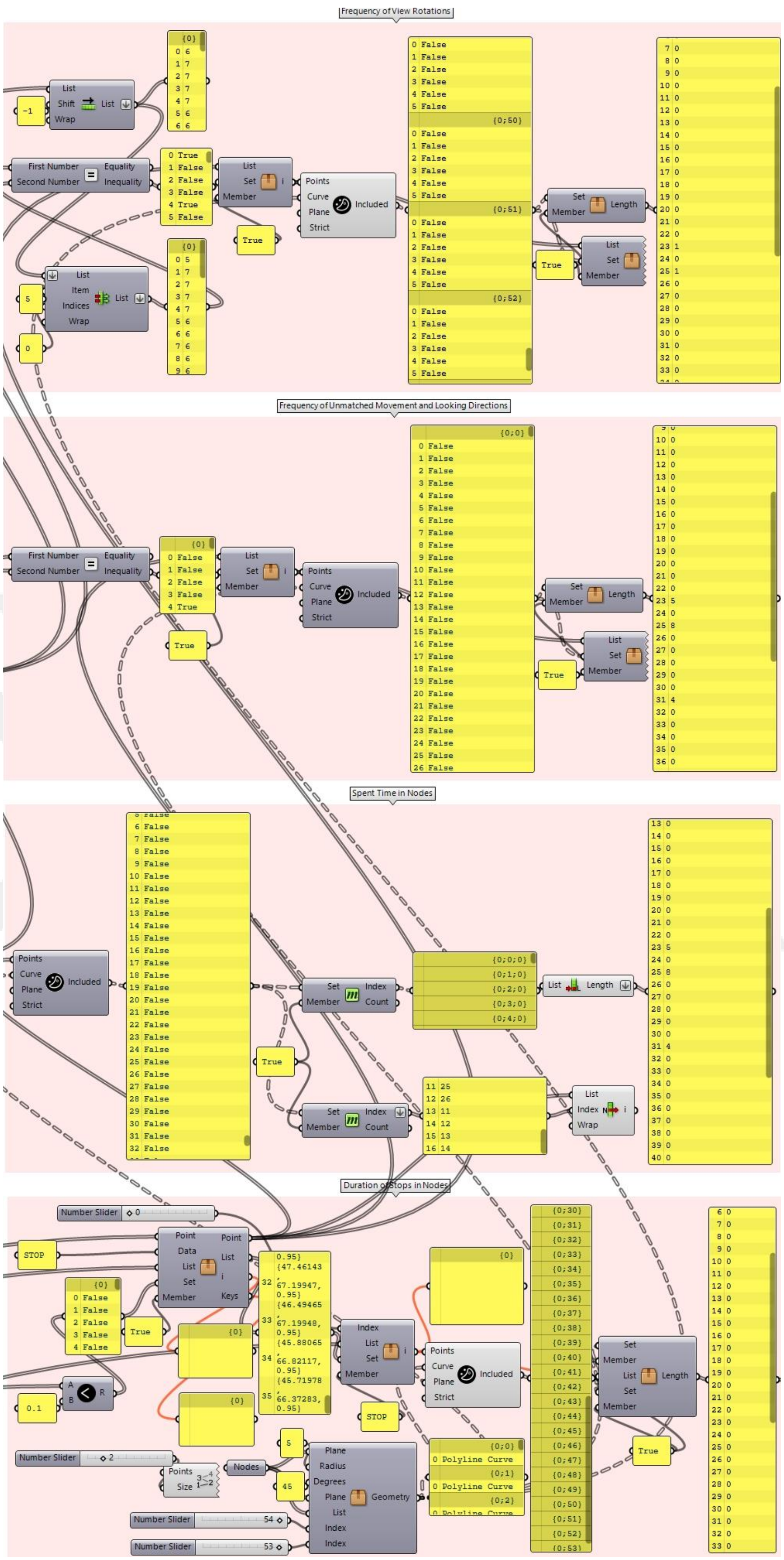



**Figure 26:** Grasshopper scripts that reveal the frequency of head rotations, frequency of unmatched movement and looking directions, duration of stops in each node, and how much time is spent in these nodes


**Figure 27:** A sample route and sequentially measured vantage points that remain in decision-making zones

In this framework, these algorithms compare whether two sequential vantage points' looking directions are matched or not inside these boundaries to clarify if the respondent turned his or her head while passing by the node. Similarly, these algorithms also uncover whether the direction of instant movement and the direction of sight are matched or not in these decision-making zones. Subsequently, we also calculated how much time each participant spent in these zones and how long they stopped during these processes through these Grasshopper scripts.

Accordingly, we can indicate that the duration of stops is measured by obtaining two sequential vantage points in each respondent's routes and comparing the distance between these two points. If the distance between these two points is less than 10cm, the script decides that the participant stops. Finally, we operated these previously mentioned scripts for each participant one by one and recorded the revealed kinesthetic data. Then we calculated the averages by another eight (8) algorithms. All these eight (8) scrips are similar, and one of them is shown in Figure 28.

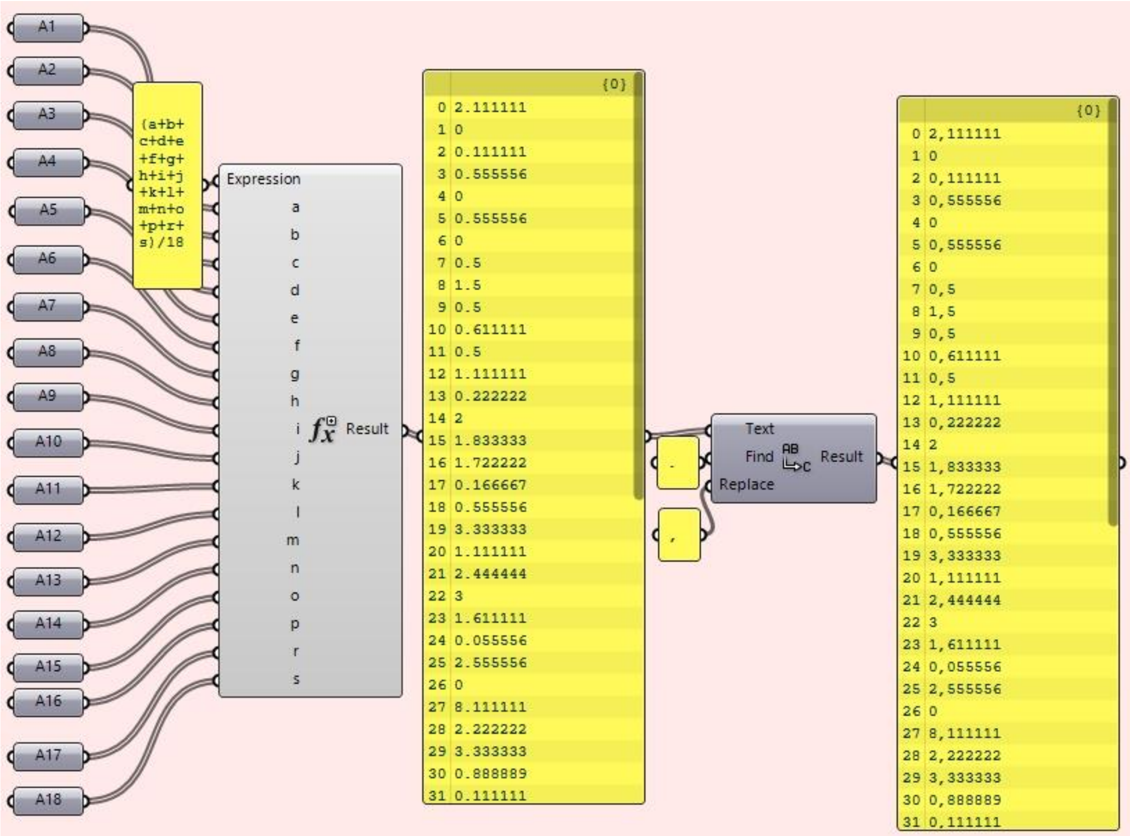



**Figure 28:** Grasshopper script that calculates the averages of the revealed node-based sequential kinesthetic data for each node

After these phases, we manually measured node-based kinesthetic data by reanimating each respondent's wayfinding or evacuation processes. In this context, the reanimation process is created with the previously prepared algorithms that are also used in sequential measurement operations. In this way, we could visualize each participant's footsteps sequentially in Rhinoceros 3D together with their trajectories. Thus, we manually counted how frequently a participant passed a node, how often each respondent made stepbacks or stops in a specific node, and how often a respondent turned from these nodes to another direction.

Consequently, we summed up each participant's number of turns and stepbacks or stops during the entire wayfinding or evacuation process. Furthermore, it can be indicated that the considered number of turns and number of stepbacks or stops are also regarded as route-based data. On the other hand, it should be noted that manual observations might not clearly determine some kinesthetic data, such as the frequency of stepbacks or stops, since they only remain as assumptions of the analysts, and these presumptions might not be as sharp as algorithmic measurements.

### 3.3.3 Measuring the 3D Syntactic Data Sequentially

In this phase, we created an algorithm that imports a previously designed 3D building model to Grasshopper to measure volumetric visibility data sequentially (Figure 29). To obtain the building model, we used the 'Reference by attributes' component of the Grasshopper plug-in, Horster. On the other hand, another script is prepared to determine the participant's instant three-dimensional optimized field of view according to his or her location and looking direction (Figure 30). Accordingly, the script gets each vantage point, scrutinizes the respondents' instant-looking direction, and creates a 90º rotated rectangular pyramid-like shape that aims to represent the three-dimensional space as observed momentarily.

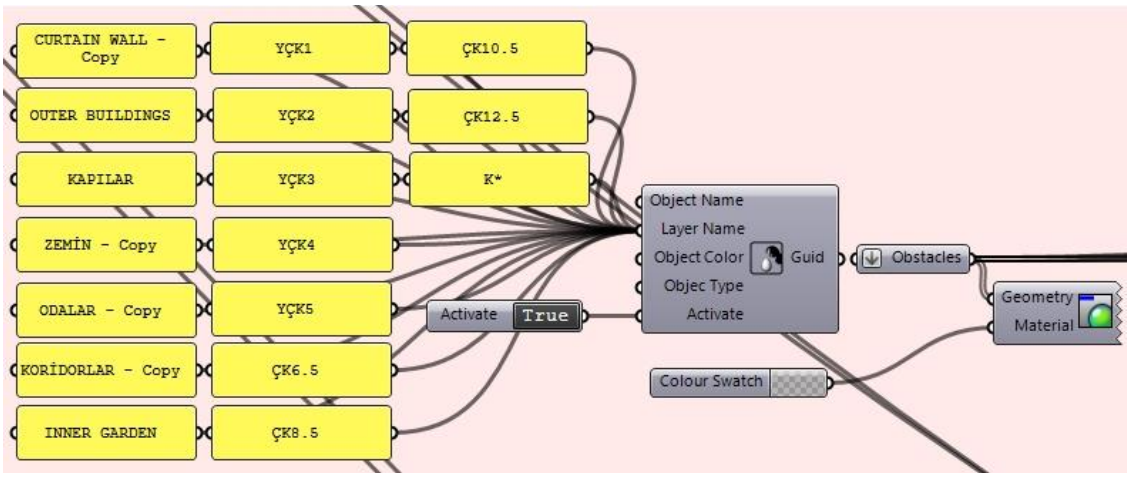



**Figure 29:** Grasshopper script that imports the 3D building model to Grasshopper

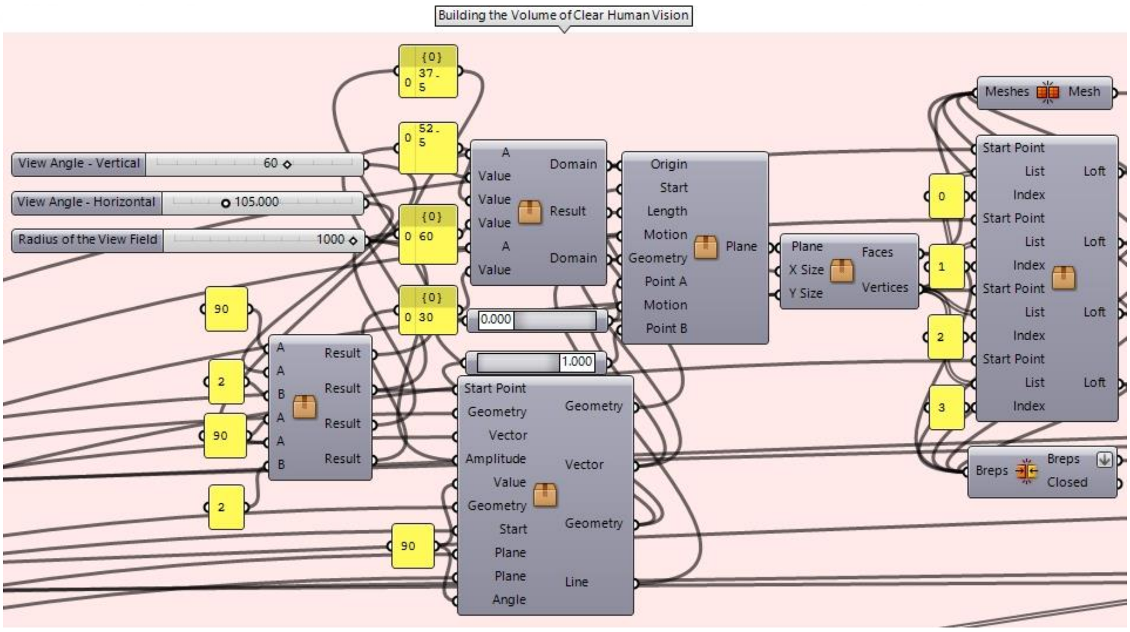



**Figure 30:** Grasshopper script that creates the representation of participants' three-dimensional sight based on the looking directions as observed momentarily

Hence, this volumetric space covers a 105º horizontal field of view and 60º vertical field of vision that corresponds to the avatars' field of sight in the experiments. On the other hand, the radius of this volumetric field is assigned as one thousand (1000) meters to encompass the whole building even if the vantage points are located relatively in the deepest points. Furthermore, it should be noted that this volumetric representation can be conceived as the visual field without any obstruction in the surrounding, and it is used for creating the optimized polyhedron form in further algorithms.

After these processes, another Grasshopper script is prepared to obtain vantage points remaining in the previously defined boundaries in the nodes for sequential volumetric visibility data calculations (Figure 31). We also used the ‘ParPointInCurve’ component of the Grasshopper plug-in, called Impala, for this operation in this script.

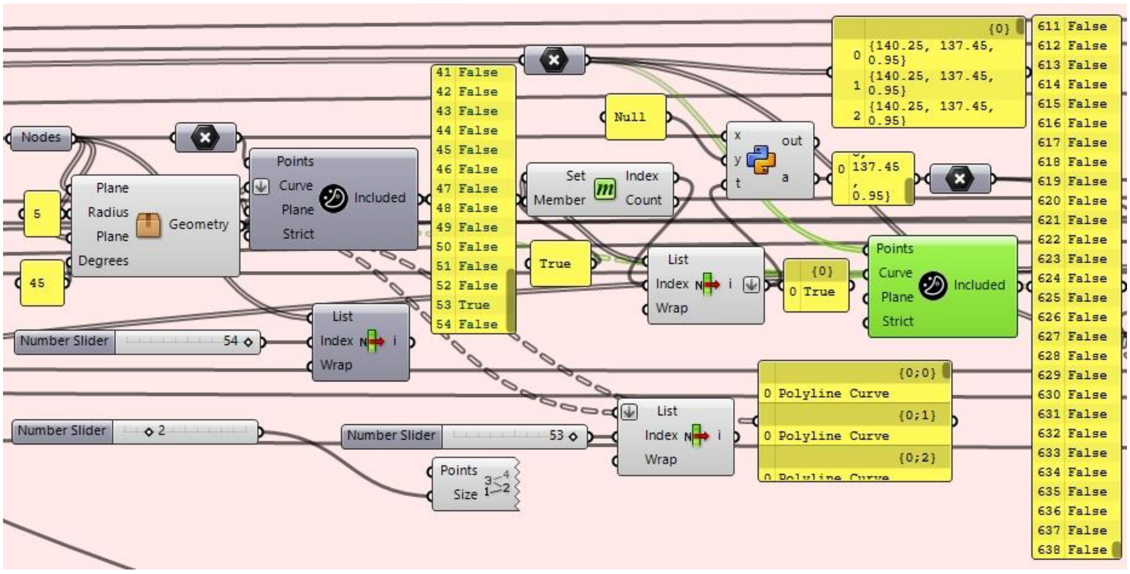



**Figure 31:** Grasshopper script that tests whether the considered vantage points are inside the decision-making boundaries or not

After determining the vantage points that remain inside the decision-making zones, the polyhedron and optimized polyhedron structure of the sight are created sequentially by another Grasshopper algorithm (Figure 32). Thus, we could sequentially calculate the polyhedron volume, polyhedron surface area, optimized polyhedron volume, optimized polyhedron surface area, and spherical circularity values.

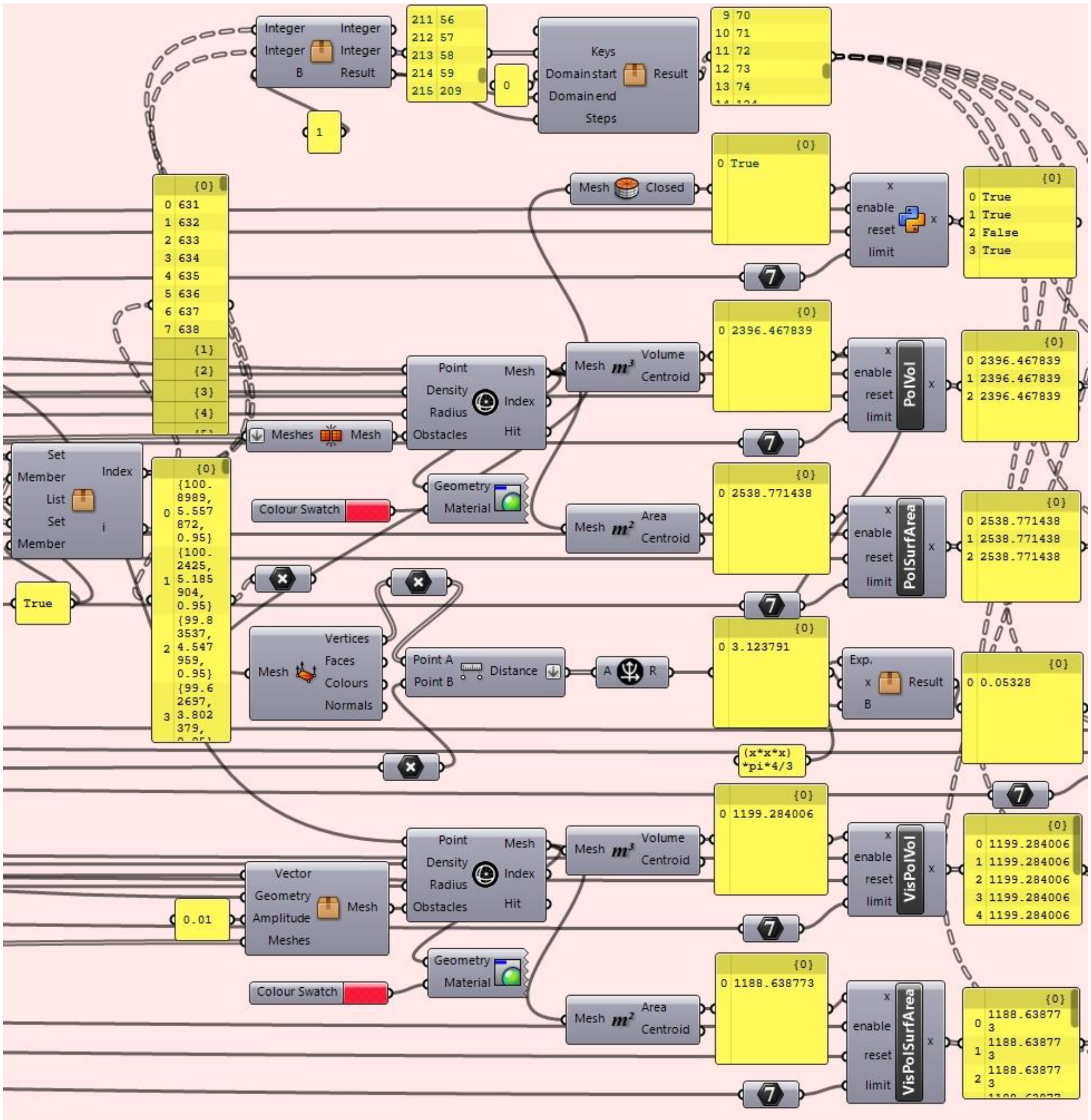



**Figure 32:** Grasshopper script that creates polyhedron and optimized polyhedron structure of the sight and calculates related volumetric visibility data

In this study, the creation of polyhedron form consists of two stages: scattering the rays from the observation point towards the volumetric space and covering the points with mesh surfaces where the rays intersect with obstacle surfaces. At this point, the radials are needed to be scattered as densely as possible to obtain a more accurate polyhedron form representing the actual space. Therefore, we assigned the density of these radials as three-hundred sixty (360) and the radius of these radials as two hundred (200) meters. Consequently, the shape of this visible volume covers any point in the observer’s 360º field of view (Figure 33). This polyhedron form is created by the 'ParIsoVist3D' component of the Grasshopper plug-in, called Impala.

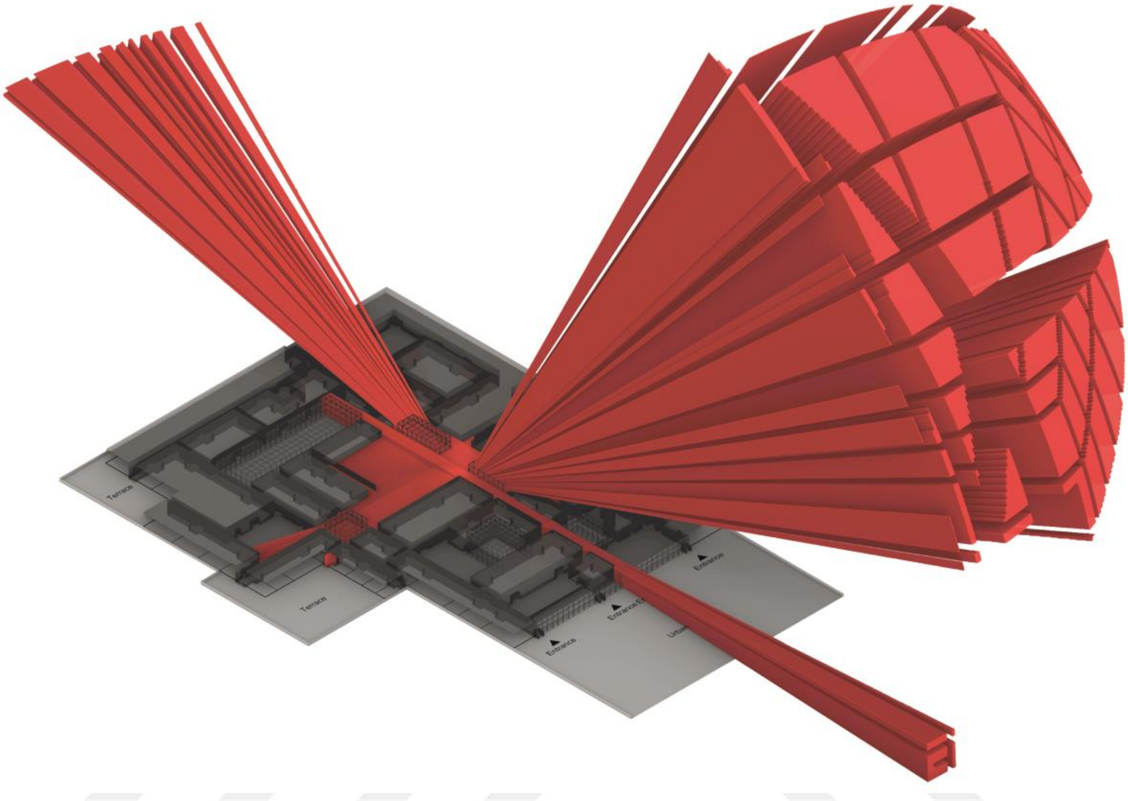



**Figure 33:** A sample of polyhedron form created during the measurements of the volumetric visibility data

On the other hand, we generated the optimized polyhedron form by taking the intersection zone of the polyhedron form and previously created a horizontal pyramid-like shape representing the viewed space according to the observer’s looking direction. Accordingly, a sample of optimized polyhedron form is shown in Figure 34. Finally, we started the sequential measurement operations for each participant, and we recorded the revealing data for each node.

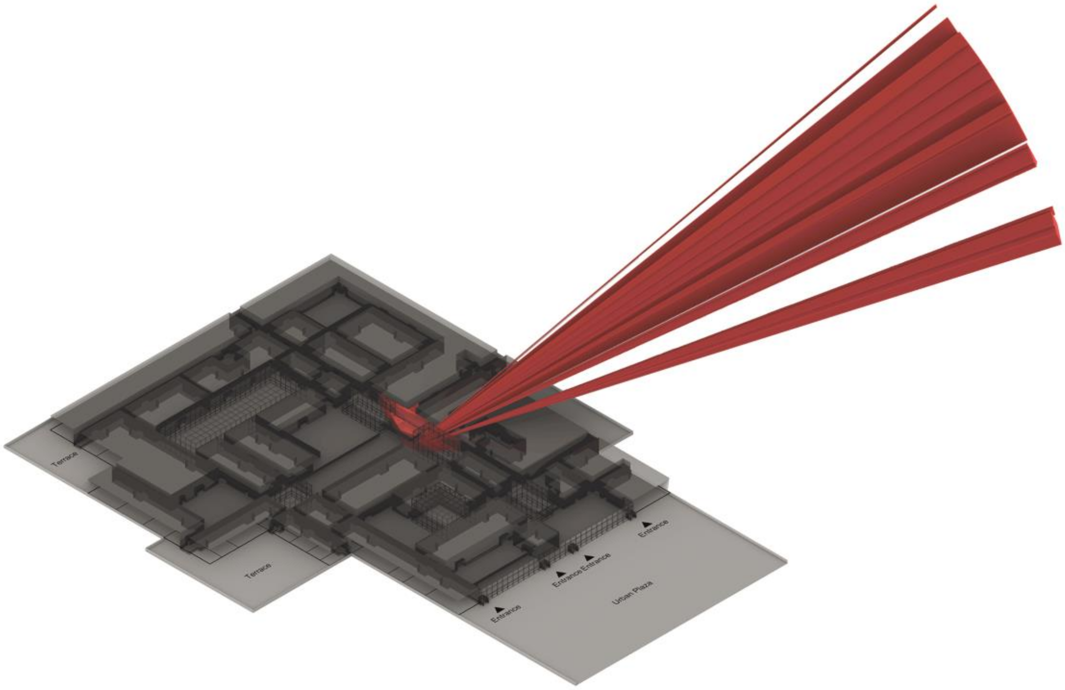



**Figure 34:** A sample of optimized polyhedron form created during the measurements of the volumetric visibility data

Hence, we measured the average values of polyhedron volume, polyhedron surface area, optimized polyhedron volume, optimized polyhedron surface area, and spherical circularity in each node for each participant (Figure 35). Moreover, we also created ten other (10) scripts to calculate the averages of the resulting volumetric visibility data regarding the whole wayfinding or evacuation groups. All these scripts are similar, and one of these algorithms is shown in Figure 36.

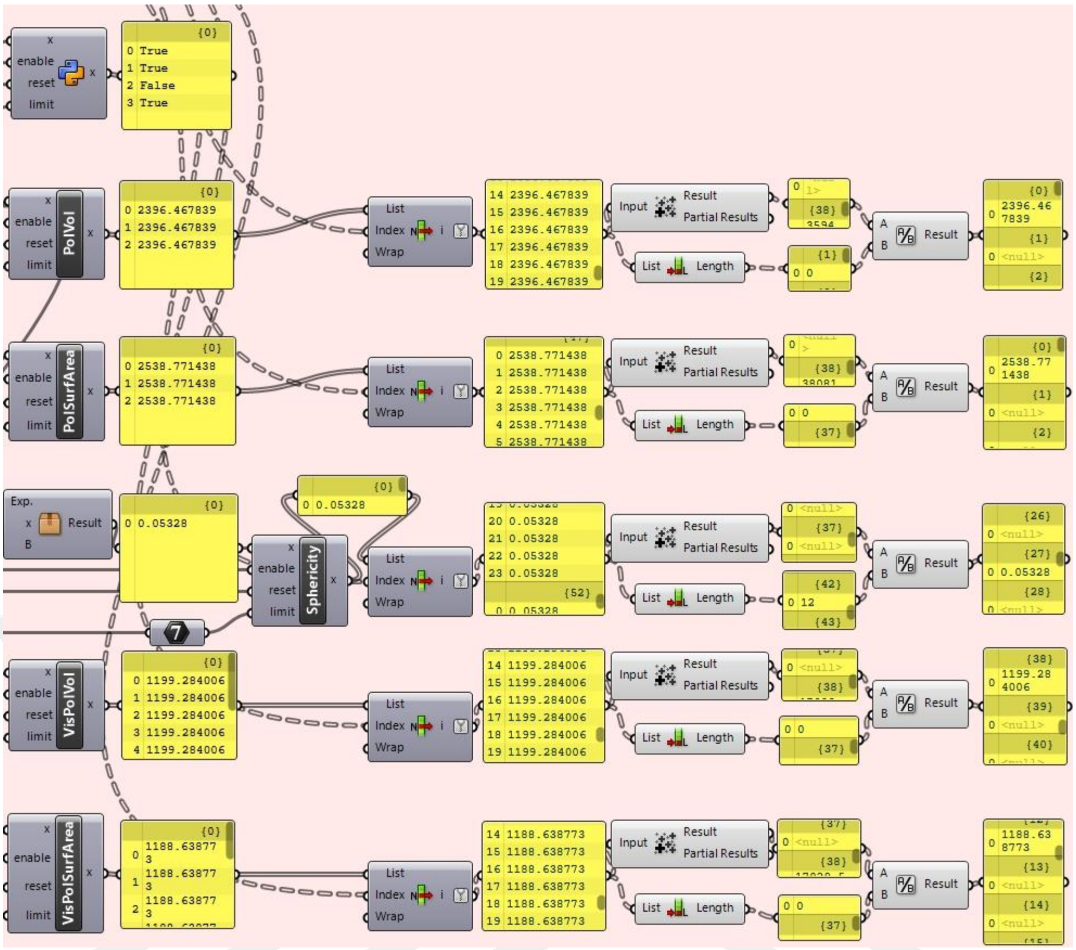



**Figure 35:** Grasshopper script that measures the averages of the sequentially revealed volumetric visibility data in each node for each participant

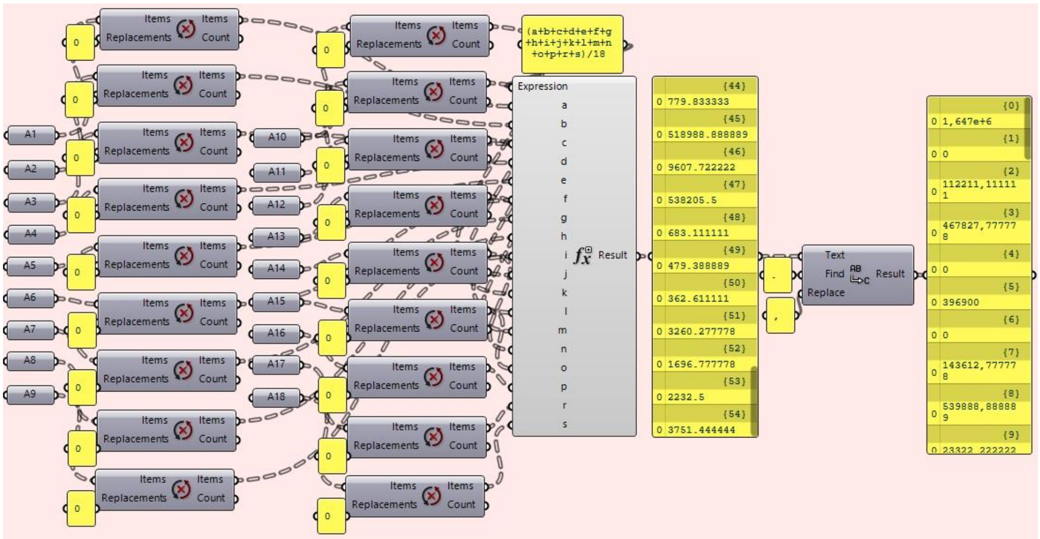



**Figure 36:** Grasshopper script that calculates the averages of the volumetric visibility data for each node regarding the whole wayfinding or evacuation groups

### 3.3.4 Computing the 2D Syntactic Data

To measure the 2D syntactic data, we created an algorithm that obtains the building plan layout by cutting the 3D structure from 170cm. After this process, another script is created to measure the 2D syntactic data as isovist area, isovist perimeter, circularity, drift, standard deviation, variance, and skewness (Figure 37). All these parameters are calculated for each node by the ‘Isovist’ component of the Grasshopper plug-in, called DeCodingSpaces.

In this case, we assigned the radius of the isovist as two hundred (200) meters and the viewing angle as 360º. On the other hand, the nodes’ depth, mean depth, and integration values are measured by the ‘SpaceSyntax’ plug-in of Grasshopper. Besides, axial integration and nodal integration diagrams are also made with this plug-in and related Grasshopper algorithm (Figure 38).

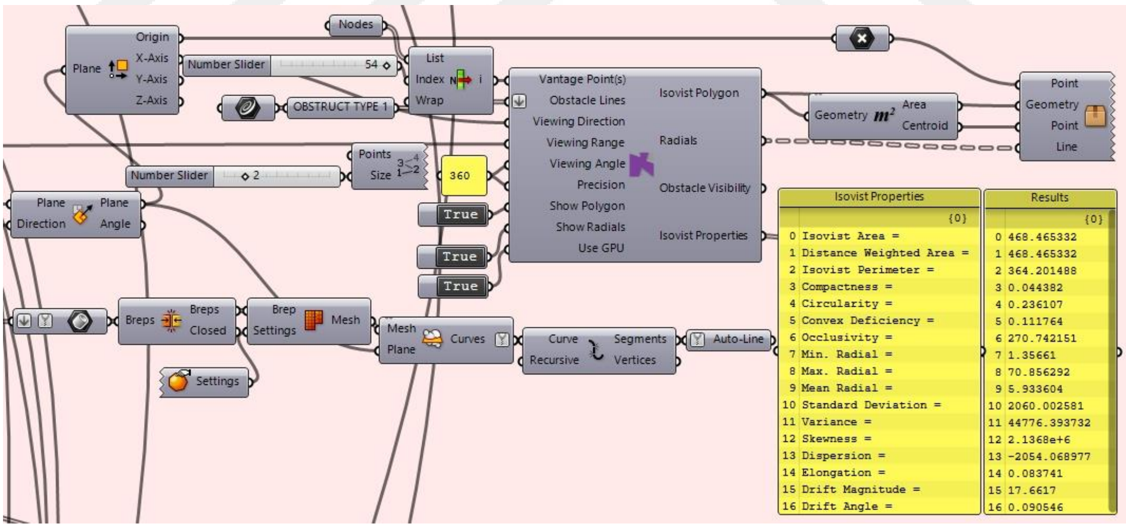



**Figure 37:** Grasshopper script that calculates 2D isovist and radial data

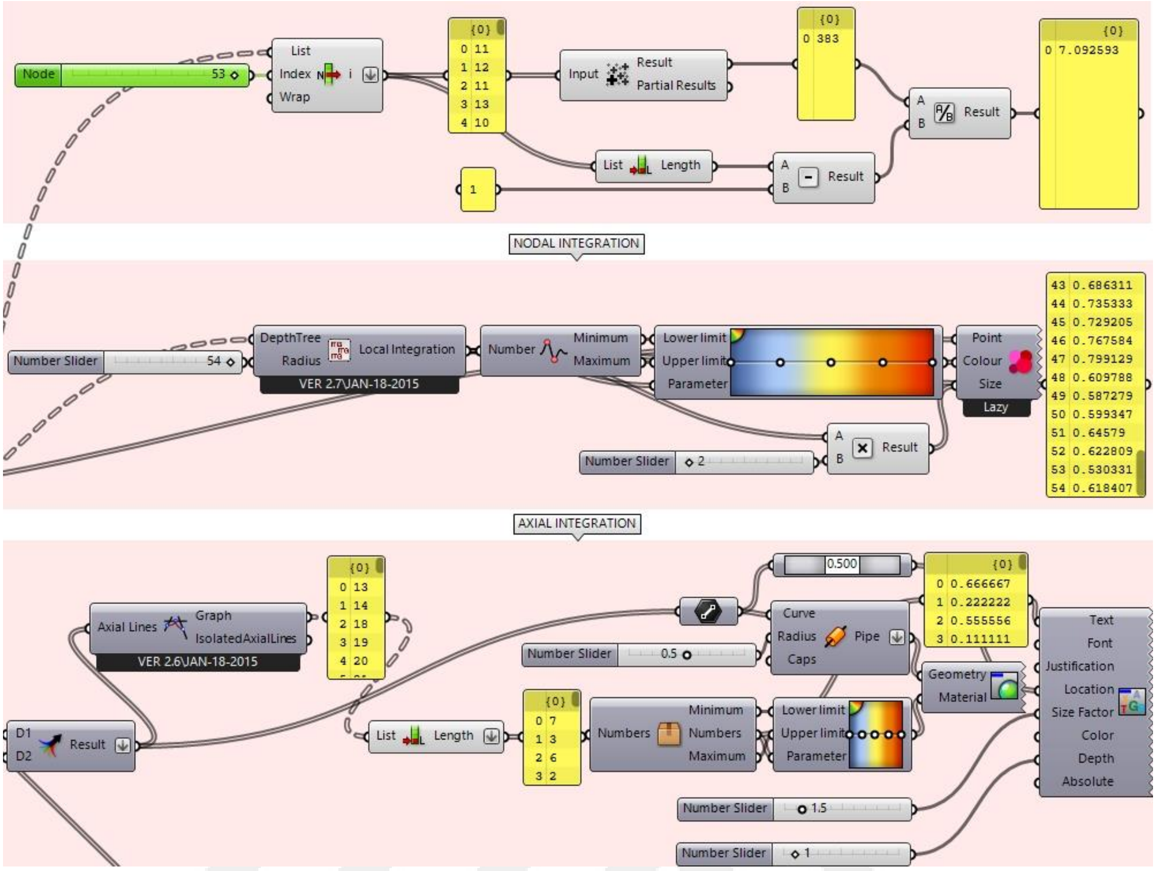



**Figure 38:** Grasshopper script that calculates mean depth and nodal and axial integration as the 2D syntactic graph data

## *3.4 Results of the Chapter*

Consequently, this study primarily focuses on the correlations between volumetric visibility properties and wayfinding and evacuation behaviors in complex and unfamiliar indoor environments. In this context, the research also concentrates on the effects of signages and two-dimensional syntactic data on spatial behaviors in these surroundings. Therefore, the study presents two different simulation experiments, one for wayfinding and the other one for evacuation processes.

Hence, a large-scale and complex 3D building model is designed to create the experimental environment. This building model contains different sizes of circulation areas with diverse 2D and 3D syntactic features to reveal various spatial behaviors. On the other hand, the building is converted into a computer simulation, where the participants can roam freely inside the virtual building. Moreover, another 3D building is adopted to create the preliminary simulation for drills. The preliminary simulation aims to introduce participants to the virtual building environment and allow them to learn or practice how to move in these virtual environments through previously created avatars. On the other hand, these simulations are tested over pilot studies with eight (8) participants to reveal the possible technical errors during the actual experiments.

After the fixation of the software-based bugs, the experiments are conducted with forty-four (44) respondents as two sampling groups over online meetings. The first group is asked to find the regular exits, whereas the second group is requested to evacuate the building, whether from regular exits or emergency egresses, as quickly as possible. In this context, while the emergency exit signages are visible in the evacuation experiments, these signages are hidden in the wayfinding studies. During these experiments, the raw kinesthetic data, including participants' instant locations and looking directions, are extracted and saved in previously determined folders. On the other hand, personal data, such as age, gender, professions, and computer gaming experiences, are also obtained in this phase. However, the kinesthetic data of eight (8) participants could not be obtained during these experiments due to unexpected technical issues.

Accordingly, data processing and data producing phases are continued for the thirty-six (36) participants. In these phases, the previously obtained raw kinesthetic data are processed in Grasshopper to be appropriately examined in the analysis part of the study. As the node-based data, the frequency of interpasses, frequency of stepbacks or stops, and frequency of turns are observed manually after creating and reanimating participants' routes. Moreover, we also revealed the distance passed, duration, average speed, number of stepbacks or stops, and number of turns in this phase as the route-based data. Then, normalized time diagrams are created to be analyzed in the analysis part of the study. In addition, a sequential measurement method is developed at this point, and participants' kinesthetic data are revealed around the decision-making points. Accordingly, these data are captured by Grasshopper algorithms and measured sequentially.

Subsequently, the 3D syntactic data as the average polyhedron volume, average polyhedron surface area, the average optimized polyhedron volume, the average optimized polyhedron surface area, and the spherical circularity are created and measured through algorithmic measurements in Grasshopper. Subsequently, we also calculated the 2D syntactic data as isovist, radial, and graph data. Finally, we created the nodal and axial integration diagrams of the building.

# CHAPTER IV

# ANALYSIS AND SYNTHESIS

This chapter primarily focuses on the correlations between dependent variables as kinesthetic data and independent variables as personal data, 2D syntactic data, and 3D syntactic data. Accordingly, these correlations are investigated under the objective, subjective, and sequential objective assessments. In this context, objective assessments are intended to handle 2D syntactic data and manually observed node-based kinesthetic data, while subjective assessments are concentrated on the 2D syntactic data and route-based kinesthetic data. In addition, we also examined the correlations between 3D syntactic data and sequentially calculated node-based kinesthetic data under the sequential objective assessments part of this chapter.

Accordingly, these relations are established by SPSS [51] software, and significant correlations are found in the objective, subjective, and sequential objective assessments. In this case, we investigated each sampling group separately and compared the results of wayfinding and evacuation experiments accordingly, within the scope of the Space Syntax Theory. On the other hand, this chapter also reviews participants' wayfinding and evacuation behaviors over the building's nodal and axial integration diagrams and evaluates the participants' routes with the normalized time diagrams.

## *4.1 Preliminary Evaluations*

The preliminary evaluations are the initial arguments based on participants' choices about regular exit or emergency exit doors during the experiments. In this framework, these door decisions are investigated together with axial and nodal integration diagrams, as shown in Figure 39. On the other hand, respondents' wayfinding and evacuation routes are also examined through route-based normalized time diagrams to reveal the collective tendencies in peoples' spatial decision-making processes.

In wayfinding experiments, 11 out of 18 (%61) participants exited the building from node number 0, whereas 5 (%28) from 3 and 1 (%5,5) from node 2. On the other hand, 1 (%5,5) of the participants could not find the exit door and quit the experiment in node 12. In the evacuation experiments, 10 out of 18 (%55) respondents evacuated the building from node number 36, whereas 4 (%22,5) from 23, 1 (%5,5) from 0, 1 (%5,5) from 27, 1 (%5,5) from 35, and 1 (%5,5) from node 51. In this context, it should be indicated that those who left the building from node 36 and node 27 evacuated the building by the same emergency exit door since this emergency egress is located between those decision-making points.

In this context, the exit nodes, the depth levels of these nodes according to the starting points of the simulations, the number of participants who decided to leave the building from these egress points, and axial and nodal integration values corresponding to these nodes are shown in Table 4. In these experiments, all the nodes are on the two intersecting axial lines, and we demonstrated the highest axial integration values of the nodes in this Table 4.

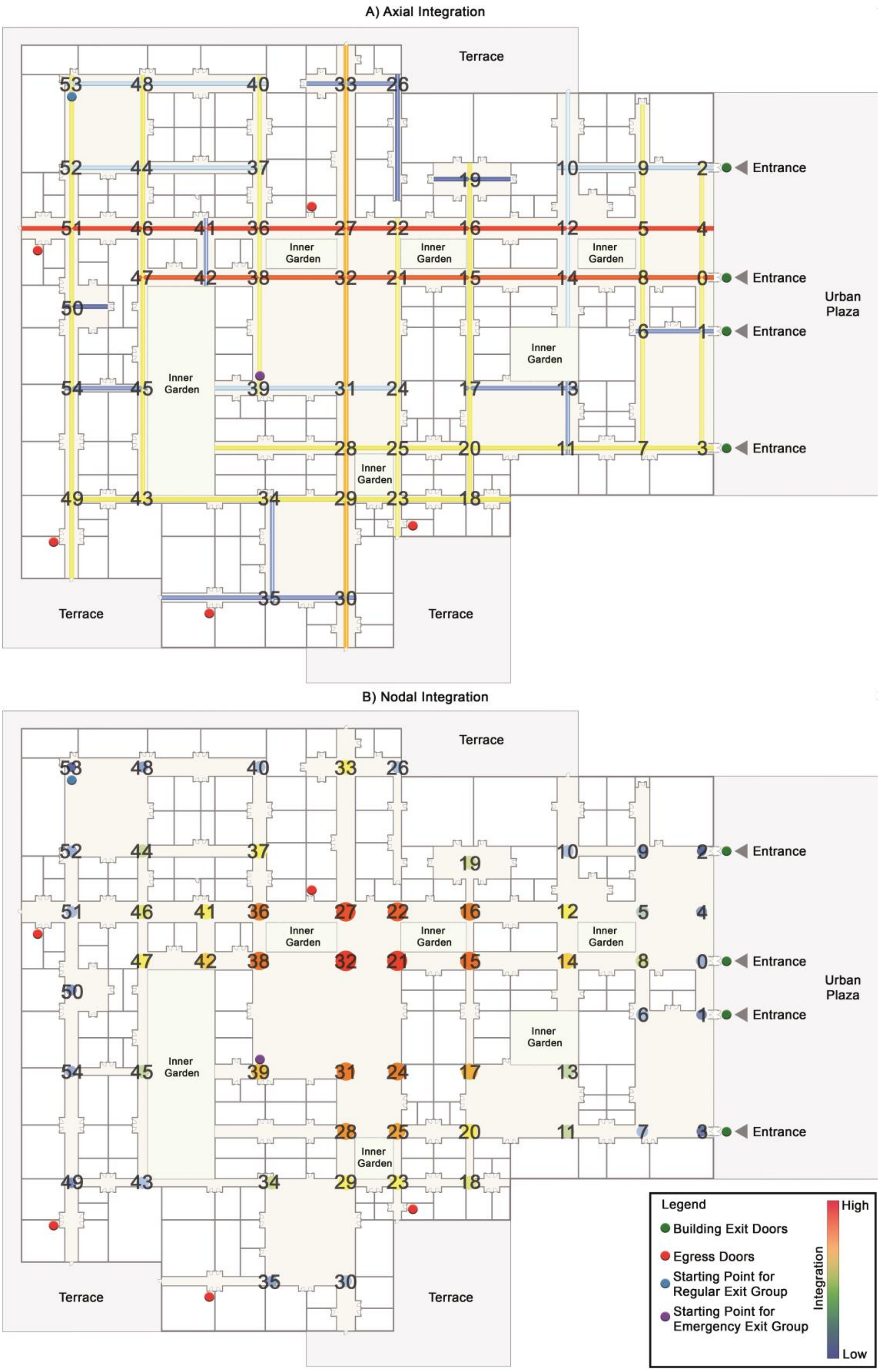



**Figure 39:** Axial and nodal integration diagrams of the building

**Table 4:** Exit nodes, depth levels, number of participants who left the building from these nodes, and axial and nodal integration values of these nodes

| *Regular Exits and Emergency Exits* | *Wayfinding Group (Node 53)* | *Evacuation Group (Node 39)* | *Axial Integration* | *Nodal Integration* |
|---|---|---|---|---|
| Node 0 (Exit & Emergency Exit) | 11 People (Depth:11) | 1 People (Depth: 7) | 0,88 | 0,18 |
| Node 1 (Exit & Emergency Exit) | 0 People (Depth: 12) | 0 People (Depth: 8) | 0,11 | 0,10 |
| Node 2 (Exit & Emergency Exit) | 1 People (Depth: 11) | 0 People (Depth: 9) | 0,22 | 0,01 |
| Node 3 (Exit & Emergency Exit) | 5 People (Depth: 13) | 0 People (Depth: 7) | 0,55 | 0,07 |
| Node 12 (No Exit) | 1 People (Depth: 8) | - | 1,00 | 0,52 |
| Node 23 (Emergency Exit) | - | 4 People (Depth: 4) | 0,44 | 0,48 |
| Node 27 (Emergency Exit) | - | 1 People (Depth: 3) | 1,00 | 0,89 |
| Node 36 (Emergency Exit) | - | 10 People (Depth: 2) | 1,00 | 0,73 |
| Node 35 (Emergency Exit) | - | 1 People (Depth: 5) | 0,11 | 0,15 |
| Node 49 (Emergency Exit) | - | 0 People (Depth: 6) | 0,55 | 0,12 |
| Node 51 (Emergency Exit) | - | 1 People (Depth: 5) | 1,00 | 0,21 |

Accordingly, 16 out of 18 (%89) participants in the wayfinding group went to the building exit doors in node 0 and node 3. These are the exit nodes over two of the most integrated axes in the virtual building. On the other hand, 11 (%61) of these respondents left the building from node 0, which is located in the most integrated axis as the shallowest exit node according to the starting point of the wayfinding experiments. Furthermore, node 3 is on the second most integrated axis, but at the deepest point according to the starting point of the wayfinding experiments, and 5 (%28) participants decided to exit from this node. Although node 2 has the same depth level value as node 0, only 1 (%5,5) person went to this point on the third most integrated axis.

On the other hand, nobody decided to go to node 1 to leave the building. Accordingly, although node 1 is on the second shallowest point according to the starting point of the wayfinding simulations, it is on the less integrated axis compared to other exits. In this case, the depth levels of the regular exit doors do not seem to correlate with the respondents' exit door decisions in the wayfinding group. On the other hand, it should be considered that the depth levels of these doors are close to each other, and therefore participants might have ignored the depth levels of these doors when leaving the building. Nevertheless, it may be argued that people tend to orient themselves to the most integrated axes during the wayfinding process, as it is also asserted and claimed by Peponis et al. (1990) [31].

In this framework, nodal integration values of the nodes also do not seem to be related to the door decisions of the participants in the regular exit group. Accordingly, while node 0 (as the most preferred exit point) has the highest nodal integration value, node 3 (as the second most preferred point) presents one of the lowest nodal integration values. On the other hand, while node 1 presents the second-highest nodal integration value, nobody preferred this point to exit the building. Moreover, although node 2 has the lowest nodal integration value, 1 (%5,5) respondent went to this point at the end of the wayfinding experiments.

On the other hand, 11 out of 18 (%61) participants in the emergency exit group evacuated the building from the egress door, which is on the most integrated axis. In this case, this most preferred door is in-between node 36 and node 27, and it is on the lowest depth level according to the starting point of the evacuation experiments. Furthermore, the subsequent most reached egress door in node 23 is in the second shallowest place, and this node is on the less integrated axis compared to the most preferred axis. In this context, we can express that there are emergency exits on the more integrated axes when compared to node 23, but these egresses are located in the deeper points accordingly. Still, 4 out of 18 people (%22,5) chose to evacuate the building from this node 23.

Furthermore, 1 (%5,5) person went to node 35, and this point presents the lowest axial integration value, and it is the third shallowest place according to the starting point of the evacuation simulations. Although node 49 is on the more integrated axis than node 23, nobody went to this egress to leave the building. Similarly, although node 51 is also on the most integrated axis of the building, only 1 (%5,5) person decided to evacuate the building from this point. In this context, node 49 is on the depth level of 6, whereas node 51 is on the depth level of 5 according to the starting point of the evacuation group.

Moreover, 1 (%5,5) participant decided to leave the building from node 0, which is also on one of the most integrated axes and in one of the deepest places regarding the starting point of the evacuation simulations. On the other hand, nobody evacuated the building from node 1, node 2, and node 3. These points are also in the deepest zones, presenting the lowest axial integration values. In this case, it might be argued that people tend to go to exits that have lower depth level values in the evacuation process.

In this framework, nodal integration values might also be related to the emergency exit preferences of the participants in the evacuation group. Accordingly, the door between node 27 and node 36 is the most preferred point to exit the building, and these nodes have the highest nodal integration values. In addition, node 23 is the second most preferred point for emergency egresses, and it has the second-highest nodal integration value. However, the other emergency exit nodes, such as node 35, node 51, and node 0, are preferred once, and nobody evacuated the building from node 1, node 2, node 3, and node 49 in evacuation experiments. According to the starting point of the emergency exit experiments, these nodes are at the deepest places, and they present the lowest nodal integration values.

On the other hand, it should be stated that the most preferred emergency exit doors are in the shallowest places according to the starting point of the evacuation experiments, and this starting point is also close to the most integrated nodes of the building. Therefore, it may also be asserted that egress signs greatly influenced the evacuation group by guiding and directing them to the closest egress doors during these experiments. In this case, it should be noted that the egress signs directing people to node 36 and node 23 are at equal distances and angles according to the starting point of the evacuation experiments. Besides, the locations of these egress signs (in node 38 and node 31) have almost the same nodal integration values, and it seems that most of the attendants could see the emergency exit signage guiding to node 36 at first. In this context, it would be asked here what syntactic parameter or parameters made this signage (located in node 38) more visible than the other, and this might be the essence of this argument.

When we continue with normalized time diagrams, it may be argued that people primarily tend to discover nearby places during the wayfinding processes (Figure 40). Furthermore, participants in the wayfinding group explored the shallowest areas until the fourth normalized time step. On the other hand, people traced almost all the spaces behind the center hall until the seventh normalized time period. Therefore, it would be argued that people spent most of their time exploring adjacent locations until they reached the center hall by also retracing the routes they had passed before. After that, they quickly headed towards the regular exit doors.

In this case, it may be expressed that human movement creates the understanding of the building configuration, and each action during the exploration leads to better performances in pathfinding, as stated by Haq and Zimring (2003) [35]. In addition, the building's topological complexity might have caused the tendency to explore the nearby surrounding at the beginning. Over time, respondents might have comprehended the building's spatial organization by tracing the shallower places through the deeper spaces with various directional trials around the integrated axes. Hence, O'Neill (1991) [34] puts forward that "…as topological floor plan complexity increases, people tend to experience greater difficulty not only enroute to the destination but in terms of absolute performance as measured by the amount of time it takes to reach destination.".

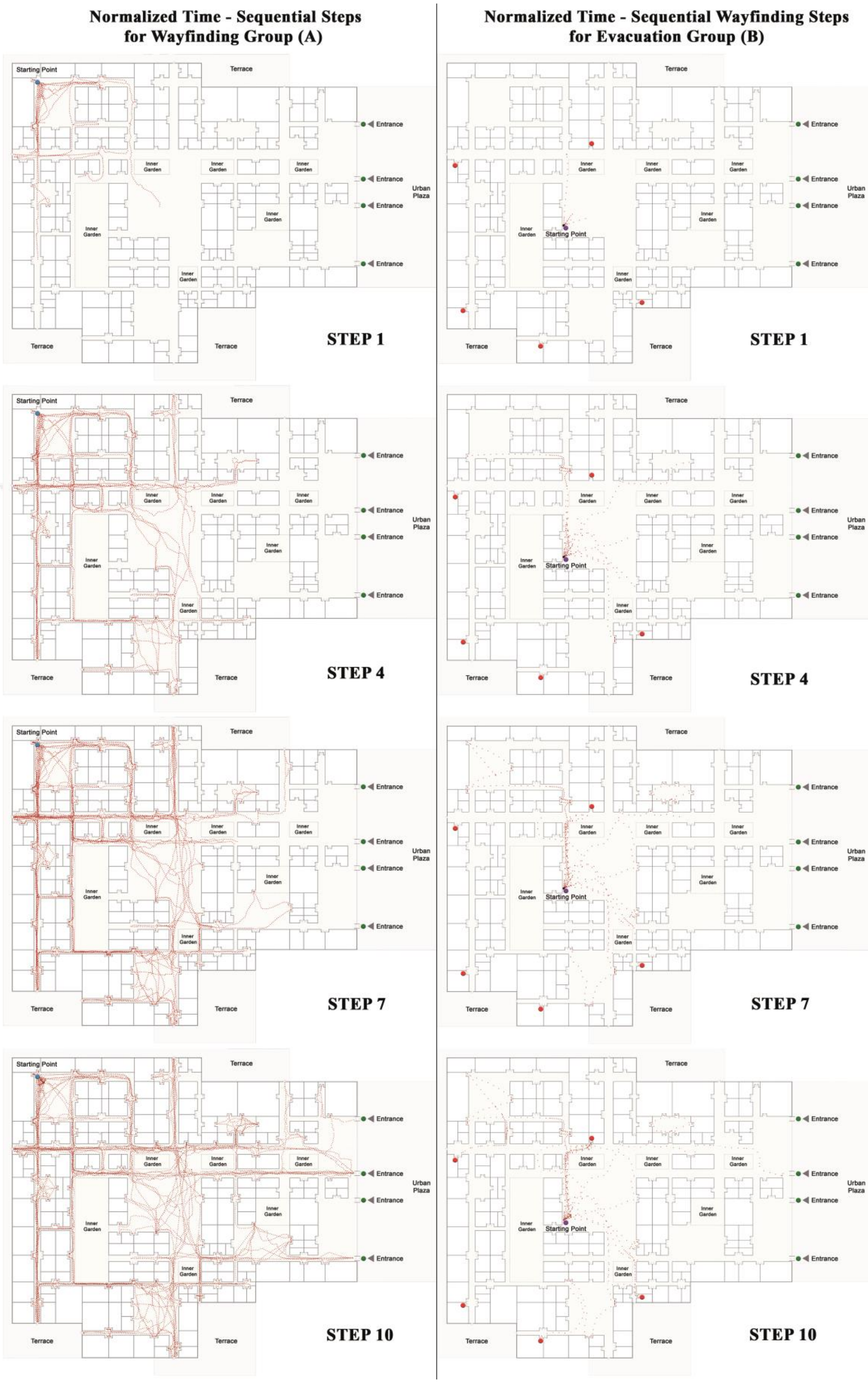



**Figure 40:** Normalized time diagrams for wayfinding and evacuation groups

Unlike wayfinding experiments, participants revealed an obvious path in the emergency exit experiments. Most participants preferred to exit the building from the shallowest point between nodes 36 and 27. Since the egress signs are assigned to guide people to the closest emergency exit doors, they might be highly effective in directing participants to these doors. Participants who evacuated the building from relatively deeper egress doors expressed in the informal interviews that they did not see the signs at the beginning of the experiments, but they headed towards the emergency exits after a while when they could see the egress signs.

## *4.2 Objective Assessments*

The correlations between 2D syntactic data and manually observed node-based kinesthetic data are investigated in the objective assessments. Accordingly, the isovist area, isovist perimeter, drift, circularity, standard deviation, variance, skewness, depth, mean depth, and integration variables are regarded as 2D syntactic data. Besides, the frequency of interpasses, the frequency of stepbacks or stops, and the frequency of turns are evaluated as the manually observed node-based kinesthetic data.

Moreover, the relations between 2D syntactic data and manually observed node-based kinesthetic data are established with the Pearson correlations over SPSS software. Accordingly, we found significant results with the circularity, drift, skewness, depth, mean depth, and integration in wayfinding simulations (Figure 41). On the other hand, isovist perimeter, depth, mean depth, and integration parameters are significant variables for the evacuation experiments (Figure 42).

## Objective Assessments - Wayfinding Group (A)

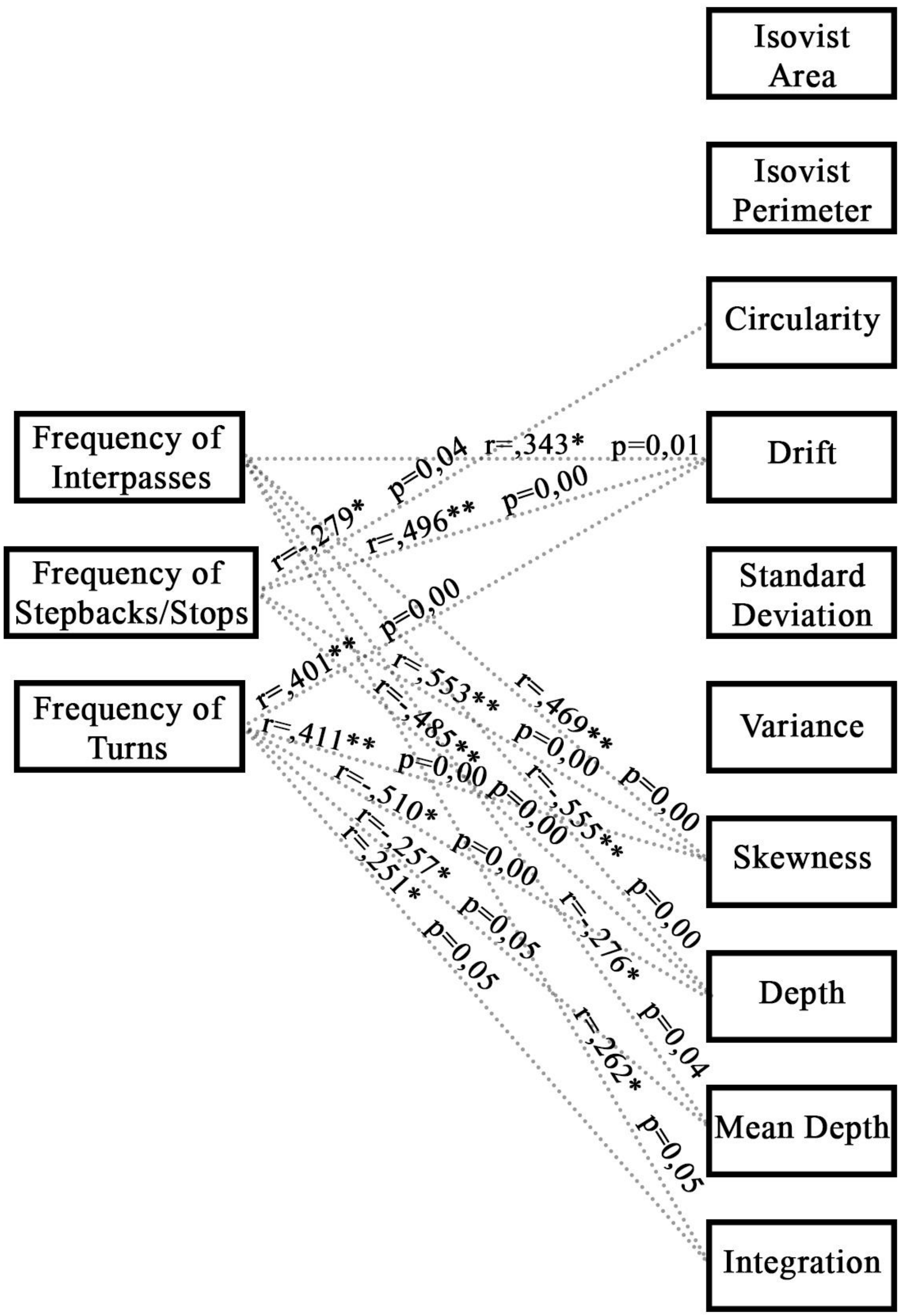



**Figure 41:** Objective assessments and significant correlations for wayfinding group

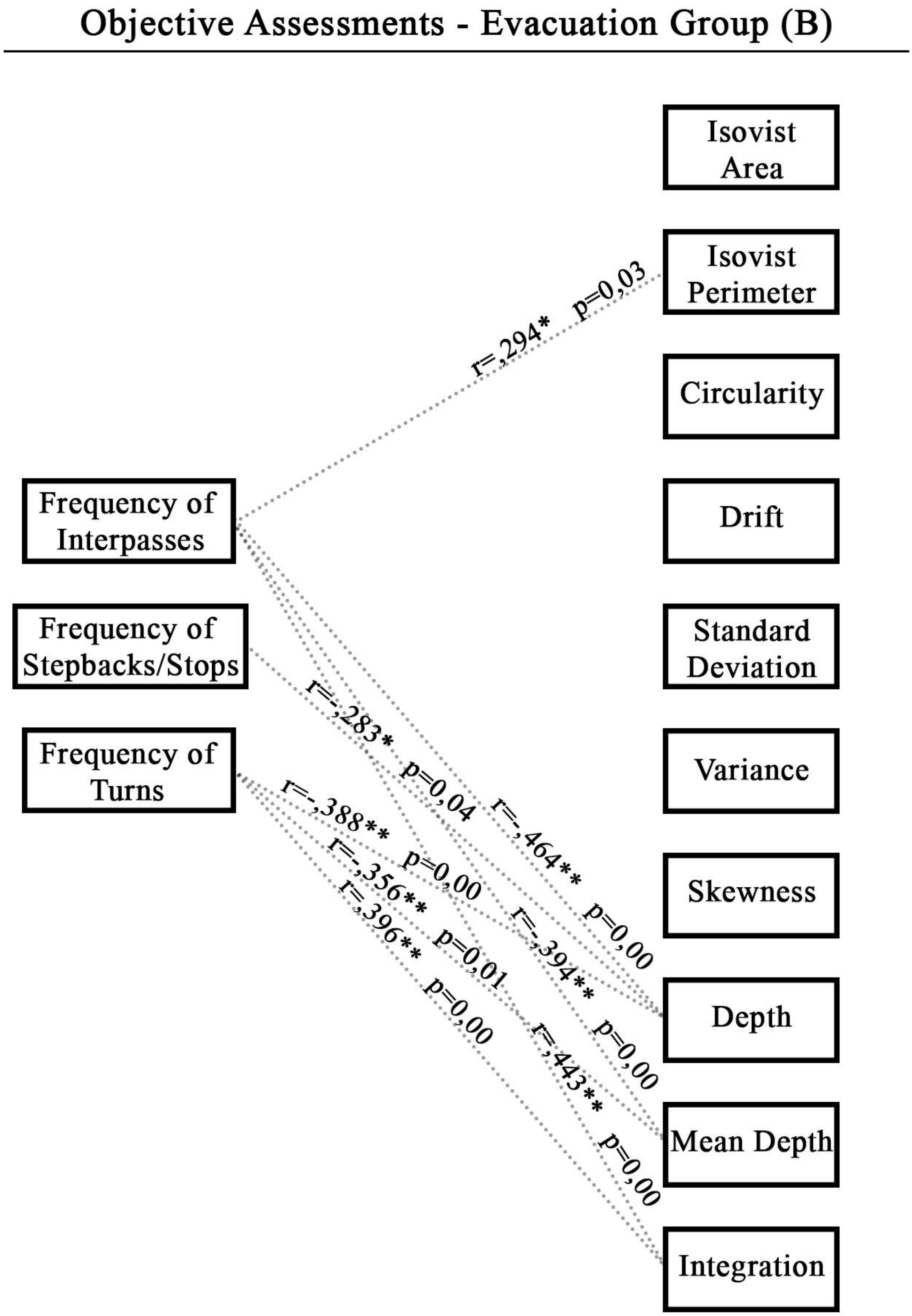



**Figure 42:** Objective assessments and significant correlations for evacuation group

### 4.2.1 Depth

It would be appropriate to start discussing wayfinding issues under the objective assessments with the depth variable that can be regarded as one of the prevailing graph data parameters. The depth variable can be conceived as the visual distance from one node to another decision-making point regarding the topological space, and we measured the depth levels of the nodes according to the starting points of the wayfinding and evacuation experiments in this study.

Thus, the wayfinding experiments showed that the respondents intended to pass low depth levels more frequently (r=-,555**, p ≤0,05). This result is also revealed in the normalized time diagrams, and it might be argued that people tend to explore the places nearby themselves at first. Moreover, participants made more stepbacks or stops (r=-,485**, p≤0,05), and they did more turns (r=-,510**, p≤0,05) in the areas on low depth levels. Accordingly, it could be expressed that participants show more hesitations in shallow places close to their initial locations in which they do not have any cognitive development about the space and, in sum, spatial memory yet.

The depth parameter is also found significant in the evacuation group. In this context, respondents in the evacuation group also frequently passed shallow levels (r=-,464**, p≤0,05). On the other hand, these people also made more stepbacks or stops (r=-,283*, p≤0,05) and more turns (r=-,388**, p≤0,05) in shallow places. It should be stated that most of the participants in the evacuation group exited the building from the shallowest nodes according to the starting point of the emergency experiment, as also previously demonstrated by the normalized time diagrams. Accordingly, most of the kinesthetic data are revealed in these shallow areas.

In this case, emergency exit signs might be influential on participants' spatial decision-making processes by preventing these people from heading towards deeper places. Therefore, the frequency of interpasses and the frequency of turns might have been significantly correlated with the depth parameter due to the effects of the egress signs on participants' evacuation processes. On the other hand, a high frequency of stepbacks or stops might have emerged in shallow nodes due to the hesitations revealed by the state of panic or the need to understand the environmental organization and perceive the directional signs, especially at the beginning of these evacuation experiments, as it is also implied by Lin et al. (2020) [10].

### 4.2.2 Mean Depth

The mean depth parameter is another essential graph data variable, and it is found significant in the wayfinding and evacuation simulations. The mean depth variable can be regarded as the average of the depth levels from one node to all other decision-making points in the whole topological system. In this framework, participants more frequently passed the nodes with low mean depth values ($r=-,276^{*}$, $p \leq 0,05$) in the wayfinding experiments. This result might be comprehended as contradictory to the outcomes revealed with the depth variable. In this context, it should be indicated that the depth values are measured according to the starting points of the wayfinding and evacuation experiments in this study, and therefore, places with low mean depth values might be close to these starting points of the experiments. Thus, there might be intersection zones where the mean depth and depth values are low at the same time.

Accordingly, this result would indicate that respondents in the wayfinding group primarily explored their nearby surroundings close to the central nodes that have less visual distance on average when compared to other nodes. In this case, it is expressed that participants in the wayfinding group started to pass the central points of the building approximately after the seventh normalized time period. Until this time, most of the participants discovered the places behind these central nodes or wandered around these nodes.

Although attendants turned more in the nodes with low mean depth values (r=-,257*, p≤0,05), we found no correlation between mean depth and frequency of stepbacks or stops (p>0,05), and this outcome might imply that participants show more hesitations around their initial locations of the unfamiliar and complex indoor environments, as also revealed by the depth parameter. However, it can be stated that they might have roughly developed a memory about the spatial configuration of the building, especially when they started discovering the central places. Therefore, we can argue that these respondents might show less hesitation in these central zones, where they do not fully comprehend the whole building, as Haq and Zimring (2003) [35] also implicated.

In other words, it could be expressed that the fear of being lost might be slowly disappeared when people start to develop a spatial memory. Accordingly, we can argue that participants can be initially indecisive about spatial decision-making processes, and their spatial hesitancy might be transformed into more confident spatial discovery processes in places presenting low mean depth values. The evidence of this situation can also be noticed by investigating the normalized time diagrams. According to these diagrams, participants reach the central points of the building almost in seven (7) normalized time periods, whereas they quickly find the exits in three (3) normalized time steps afterward.

The mean depth parameter is also significant in the evacuation group. In this case, this result might also contradict the outcomes revealed by the depth variable. However, the starting point and the most preferred egress doors are in places with low mean depth and low depth values in the evacuation experiments. Therefore, we can only argue that egress signs prevented people from going out of this central part of the building. As a result, subjects more frequently passed ($r=-,394^{**}$, $p\leq 0,05$) from the zone that presented low mean depth values, and they turned more ($r=-,356^{**}$, $p\leq 0,05$) in these places. As also stated before, since most of the actions happened around this central part of the building, most behavioral data are inevitably revealed in this zone.

Similar to the wayfinding experiments, we also found no correlation between the frequency of stepbacks or stops and mean depth variables ($p>0,05$) in the evacuation simulations. This situation also supports the argument that signages might be highly influential in guiding participants to the exits. Accordingly, we can state that these participants showed fewer hesitations after perceiving the egress signs, especially when getting close to the emergency exits, so these spatial hesitations emerged in the zones close to the starting point of the evacuation experiments.

### 4.2.3 Integration

The integration and mean depth are reversely correlated parameters, so as stated before, the integration value can be conceived as the inversed and normalized version of mean depth. Accordingly, the revealed results with the integration variable also confirm this fact in these experiments.

In the wayfinding experiments, participants more frequently passed by the nodes with high integration values ($r=,262^{*}$, $p\leq 0,05$). Moreover, these attendants also turned more in nodes with high integration values ($r=,251^{*}$, $p\leq 0,05$). On the other hand, we found no correlation between the integration and frequency of stepbacks or stops ($p>0,05$). In this case, Peponis et al. (1990) [31] discuss that people may try to go in different directions and come back to the integrated zones during the spatial exploration process due to the lack of spatial memory about the building.

Similar to the mean depth variable, the integration parameter is also significant in the evacuation group. As a result, subjects more frequently passed ($r=,443^{**}$, $p \leq 0,05$) by the most integrated zones and turned more ($r=,396^{**}$, $p \leq 0,05$) in these places. However, there revealed no correlation between the frequency of stepbacks or stops and integration variables in these nodes ($p>0,05$).

### 4.2.4 Isovist Area

As an essential isovist data parameter, the isovist area variable is not significantly correlated with manually observed kinesthetic data in wayfinding experiments ($p>0,05$). In this framework, it could be stated that the starting point of the wayfinding group and the nearby surrounding of this initial location mostly present low isovist area values compared to other building zones. Furthermore, most participants wandered in these shallow spaces for a long time during the wayfinding simulations. However, we can argue that respondents may not make spatial decisions specifically based on the visible area seen from the vantage point during the wayfinding process.

In addition, the isovist area variable is also not significant in the evacuation simulations ($p>0,05$). Although the starting point of these experiments and the nearby surrounding of this initial location mostly present the highest isovist area values, the revealed result can be considered an unexpected outcome. Therefore, it might be discussed that respondents do not substantially consider the amount of visible area even in a state of emergency. On the other hand, we can also argue that once respondents perceive the egress signs, they may neglect the magnitude of the visible area during the evacuation process.

### 4.2.5 Isovist Perimeter

When we consider the isovist perimeter variable, we can mention that although the starting point of the wayfinding group mostly presents low isovist perimeter values and participants discovered these shallow places for a long time, we could not find any correlation between manually observed kinesthetic data and isovist perimeter variable in wayfinding experiments ($p>0,05$). Accordingly, we can express that the graph data parameters might be more determinant in participants' wayfinding processes when compared to isovist area and isovist perimeter variables.

On the other hand, it is revealed that isovist perimeter and one of the manually observed kinesthetic data are correlated significantly in the evacuation experiments. As a result, participants more frequently pass from the nodes with high isovist perimeter values ($r=,294^*$, $p\leq 0,05$). In this context, most participants completed the simulations close to the starting location of the emergency exit experiments. Accordingly, it should be indicated that this area is one of the largest halls containing inner gardens with transparent surfaces and window frames. These window frames might have dispersed the isovist form, and therefore, the high isovist perimeter values inevitably correlated with the frequency of interpasses variable.

In this framework, dispersed isovist form may relate to spatial hesitations since respondents might perceive these types of spaces as visually inconsistent. However, there revealed no correlation between the frequency of stepbacks or stops ($p>0,05$) and the frequency of turns when compared with the isovist perimeter variable ($p>0,05$). In this context, it might be stated that participants already knew where they went when they passed the decision-making points that mostly present high isovist perimeter values by showing fewer hesitations. Accordingly, this result may also support the idea that signages are highly influential in evacuation issues.

### 4.2.6 Drift

The drift parameter is a significant variable for the wayfinding group. Respondents in wayfinding experiments more frequently passed from the nodes with the high drift values (r=,343*, p≤0,05). In this case, locations with high drift values may be conceived as points far from the center of an observer's field of view. Since the building exits should be at the intersection points between indoor and outdoor areas, respondents might have looked for these exit points by frequently passing through nodes far from the center of their field of view.

On the other hand, people made more stepbacks or stops (r=,496**, p≤0,05) and more turns (r=,401**, p≤0,50) in spaces with high drift values. In this case, the locations with high drift values may offer human beings a lot of visual information and various directions to discover. Thus, participants might have aimed to increase the opportunity for perceiving around for a while during the wayfinding experiments.

On the other hand, we found no significant correlation between the drift and manually observed kinesthetic data in the evacuation group (p>0,05). In this framework, we can express that the respondents may not make spatial decisions based on the drift parameter, although many participants ended the evacuation simulations around places with high drift values. Accordingly, we can discuss that emergency exit signages are highly effective additional elements for participants to obtain environmental knowledge, and these signages might be more determinant in the evacuation processes when compared to the isovist data.

### 4.2.7 Circularity

The circularity variable is one of the radial data that is significantly correlated with kinesthetic data in the wayfinding simulations. It is revealed that participants more frequently stepped back or stopped ($r=-,279^*$, $p \leq 0,05$) in the nodes with low circularity values. The value of circularity gives an idea of the 2D compactness or complexity of the space. In this sense, participants might have tended to show hesitations by stepping back or stopping in nodes where the spatial complexity is relatively high. In this context, it could be argued that these spatially complex places might have significant linearity in multiple directions and visual inconsistency. Therefore, these places might have confused people, which entailed hesitations about which direction to navigate.

Accordingly, it might be stated that, besides topological complexity, the two-dimensional visual complexity may also entail difficulties in wayfinding issues. On the other hand, we found no correlations between the circularity and the frequency of interpasses ($p>0,05$), as well as the frequency of turns ($p>0,05$). In this context, it can be indicated that participants might pass and turn from the nodes regardless of high or low circularity values, but they only show intense spatial hesitations in places that have low circularity values.

We found no correlation between circularity and manually observed kinesthetic data ($p>0,05$) in evacuation experiments. In this context, it should be stated that the starting point of the evacuation group and the nearby nodes mostly have high circularity values, which might also denote high spatial compactness and less complexity. Correspondingly, this situation might have prevented participants from showing hesitation through making stepbacks or stops in the most preferred places.

On the other hand, there revealed no positive or positive correlation between the circularity and the frequency of interpasses (p>0,05) and the frequency of turns (p>0,05). In this case, we can also argue that participants might make directional decisions regardless of the 2D compactness or complexity of the spaces where the emergency exit signages are presented in the environment.

### 4.2.8 Standard Deviation

The standard deviation parameter is not correlated with manually observed node-based kinesthetic data in wayfinding experiments (p>0,05). Although participants wandered around places mostly having low standard deviation values, these participants' spatial decision-making processes might not have been affected by this parameter.

Similar to the wayfinding experiments, we found no relationship between the standard deviation parameter and manually observed node-based kinesthetic data in the evacuation experiments (p>0,05). Although respondents navigated in spaces that mostly have low standard deviation values, the revealed results are insignificant. Accordingly, we can argue that the standard deviation parameter may not affect the participants' evacuation behaviors.

### 4.2.9 Variance

The variance parameter is not significant in the wayfinding group's orientation behavior. In this context, the variance parameter revealed no correlation with the manually observed kinesthetic data (p>0,05). We can express that the variance parameter measures how the isovist perimeter is dispersed in this context. Accordingly, it might be indicated that the participants wandered around places mostly having low variance values. In other words, we can argue that these participants spent most of their time in spaces that might not be visually dispersed. However, the participants' orientation during wayfinding experiments still seems to be uninfluenced by the variance parameter.

Similarly, the variance variable is not significantly correlated with the frequency of interpasses ($p>0,05$), the frequency of stepbacks or stops ($p>0,05$), and the frequency of turns ($p>0,05$) in evacuation experiments. In this context, these results may conflict with the results revealed by the isovist perimeter variable. Accordingly, we mentioned that the isovist perimeter might be dispersed in the most preferred nodes in the evacuation experiments due to the window framings. Nevertheless, it might be indicated that the variance of the radials does not seem to be related to the participants' spatial decision-making processes during the evacuation experiments.

### 4.2.10 Skewness

The skewness parameter is another radial data that is significant in wayfinding experiments. Accordingly, we can state that participants more frequently passed from the decision-making points with high skewness values ($r=,469^{**}$, $p\leq 0,05$). In this context, skewness defines the asymmetry of the dispersion, and positive skewness values indicate that short radials are more than longer ones in an isovist. Accordingly, the revealed result may indicate that respondents tended to orient to the peripheries of the building borders at first since the exit doors must be positioned in the intersection zones between indoor and outdoor environments, as also mentioned when we evaluate the drift parameter.

In addition, respondents made more stepbacks or stops ($r=,553^{**}$, $p\leq 0,05$) and more turns ($r=,411^{**}$, $p\leq 0,05$) in the places with high skewness values in wayfinding simulations. Correspondingly, participants might have hesitated and aimed to prolong the decision-making process to determine which direction to go in these nodes. Because once they decided to take action, they must walk long distances.

On the other hand, the skewness parameter is not significantly correlated with manually observed kinesthetic data in evacuation experiments ($p>0,05$). In this context, the starting point and most preferred decision-making points are close to the central nodes having both high and low skewness values. In this context, we might express that the participants do not consider the asymmetry of the space in emergency conditions. From another point of view, it can be put forward that these respondents may overlook the asymmetry or the dispersion of the space where the emergency exit signages are visible.

## *4.3 Subjective Assessments*

The correlations between the personal and route-based kinesthetic data are examined in the subjective assessments part of the study. In this context, participants' gender, age, education level, and profession are considered the personal demographic data, whereas respondents' computer gaming experience is handled as the competence data. On the other hand, the distance passed, the duration, the average speed, the number of stepbacks or stops, and the number of turns parameters are regarded as the basis of the route-based kinesthetic data. Accordingly, these relations between the personal and route-based data are established with ANOVA tests over SPSS software. In this way, significant results are found with the gender and the computer gaming experience variables in evacuation experiments (Figure 43).

On the other hand, we found that there is no correlation between the personal data and route-based kinesthetic data in the wayfinding experiments. However, we also evaluated the averages of the considered parameters in this part of the study, and they might be important for further studies. Accordingly, the averages for the wayfinding group are shown in Table 5. On the other hand, the averages for the evacuation group are shown in Table 6.

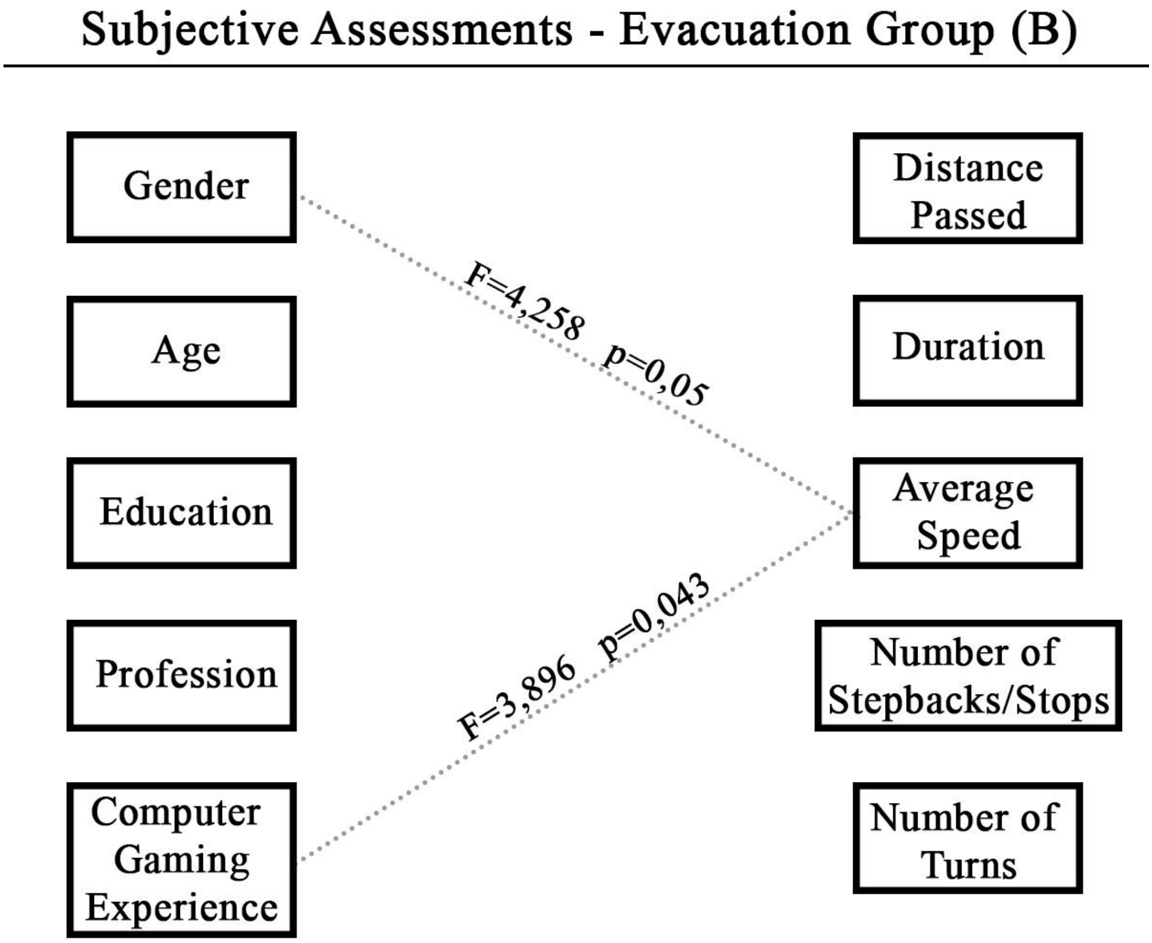



**Figure 43:** Subjective assessments and significant correlations for evacuation group

**Table 5:** Route-based kinesthetic data averages of the wayfinding group

| | *Averages* | *Distance Passed (m)* | *Duration (S)* | *Average Speed (m/s)* | *Number of Stepbacks or Stops* | *Number of Turns* |
|---|---|---|---|---|---|---|
| Gender | W (9) = | 560m | 417s | 1,38m/s | 7,33 | 14,00 |
| | M (9) = | 523m | 356s | 1,73m/s | 5.11 | 13.55 |
| Age | 15-25 (6) = | 551m | 380s | 1,46m/s | 5,83 | 13,00 |
| | 26-40 (10) = | 493m | 347s | 1,66m/s | 6,50 | 12,80 |
| | 40+ (2) = | 752m | 601s | 1,30m/s | 6,00 | 21,00 |
| Education | High School (1) = | 170m | 114s | 1,49m/s | 0,00 | 5,00 |
| | Undergraduate (10) = | 582m | 416s | 1,66m/s | 6,00 | 15,20 |
| | Graduate (7) = | 536m | 383s | 1,42m/s | 7,42 | 13,00 |
| | Postgraduate (0) = | - | - | - | - | - |
| Profession | Architect (7) = | 468m | 336s | 1,43m/s | 7,42 | 10,57 |
| | Engineer (2) = | 865m | 625s | 1,38m/s | 9,00 | 21,00 |
| | Lawyer (2) | 950m | 649s | 1,49m/s | 8,00 | 29,50 |
| | Business Manager (2) = | 676m | 542s | 1,35m/s | 2,00 | 19,50 |
| | Student (1) = | 463m | 320s | 1,44m/s | 6,00 | 14,00 |
| | Others (4) = | 255m | 163s | 2,02m/s | 4,00 | 5,00 |
| Computer Gaming Experience | High (13) = | 521m | 364s | 1,68m/s | 7,07 | 13,84 |
| | Low (4) = | 669m | 505s | 1,36m/s | 4,25 | 14,25 |
| | No (1) = | 289m | 206s | 1,40m/s | 3,00 | 11,00 |

**Table 6:** Route-based kinesthetic data averages of the evacuation group

| | *Averages* | *Distance Passed (m)* | *Duration (S)* | *Average Speed (m/s)* | *Number of Stepbacks or Stops* | *Number of Turns* |
|---|---|---|---|---|---|---|
| Gender | W (9) = | 93m | 45s | 2,60m/s | 0,88 | 2,66 |
| | M (9) = | 57m | 17s | 3,56m/s | 0,22 | 1,66 |
| Age | 15-25 (5) = | 50m | 16s | 3,37m/s | 0,20 | 1,80 |
| | 26-40 (12) = | 74m | 24s | 3,12m/s | 0,41 | 2,08 |
| | 40+ (1) = | 216m | 192 | 1,12m/s | 4,00 | 5,00 |
| Education | High School (1) = | 55m | 18s | 3,05m/s | 0,00 | 2,00 |
| | Undergraduate (10) = | 74m | 35s | 3,28m/s | 0,80 | 2,10 |
| | Graduate (6) = | 86m | 29s | 2,90m/s | 0,33 | 2,50 |
| | Postgraduate (1) = | 41m | 18s | 2,29m/s | 0,00 | 1,00 |
| Profession | Architect (5) = | 95m | 28s | 3,41m/s | 0,40 | 2,80 |
| | Engineer (4) = | 58m | 16s | 3,77m/s | 0,25 | 1,50 |
| | Lawyer (1) | 41m | 29s | 1,44m/s | 0,00 | 1,00 |
| | Business Manager (1) = | 55m | 18s | 3,05m/s | 0,00 | 2,00 |
| | Student (4) = | 57m | 21s | 2,85m/s | 0,50 | 1,75 |
| | Others (3) = | 106m | 75s | 2,49m/s | 1,66 | 3,00 |
| Computer Gaming Experience | High (12) = | 75m | 22s | 3,49m/s | 0,25 | 2,25 |
| | Low (3) = | 41m | 23s | 1,88m/s | 0,66 | 1,00 |
| | No (3) = | 108m | 74s | 2,66m/s | 1,66 | 3,00 |

### 4.3.1 Gender

The gender parameter is not significantly correlated with route-based kinesthetic data in the wayfinding experiments ($p>0,05$). However, it might be stated that men (1,73m/s) seem to be faster than women (1,38m/s), and these men made fewer stepbacks or stops (5,11 times) in these wayfinding simulations when compared to women participants (7,33 times). On the other hand, it can be indicated that men (13,55 times) turned from the decision-making points almost equally as women (14,00 times).

On the other hand, we found a significant correlation between gender and the average speed parameters in the evacuation experiments ($F=4,258$, $p\leq 0,05$). Accordingly, we can state that men (3,56m/s) are faster than women (2,60m/s) if we consider the evacuation processes. On the other hand, according to the averages, men made fewer stepbacks or stops (0,22 times) and turned less (1,66) compared to women (stepped back or stopped 0,88 times and turned 2,66 times). Accordingly, this result may emphasize that men hesitate less and make quicker spatial decisions than women in evacuation processes.

### 4.3.2 Age

The age variable is not significantly correlated with the route-based kinesthetic data in the wayfinding experiments ($p>0,05$). However, we can still mention that participants aging between twenty-six (26) and forty (40) (1,66m/s) are the fastest ones in the wayfinding experiments when we consider the averages. In contrast, according to these averages, participants over forty (40) years old (1,30m/s) are the slowest respondents in the wayfinding group. Moreover, participants whose ages are between twenty-six (26) and forty (40) made more stepbacks or stops (6,50 times) than others.

On the other hand, respondents aging between fifteen (15) and twenty-five (25) made fewer stepbacks or stops (5,83 times) in the wayfinding experiments. In addition, participants over forty (40) years old turned more (21,00 times) in the decision-making points, whereas the other participants turned from these nodes almost equal amount of times (Ages between 15-25 turned 13,00 times, and ages between 26-40 turned 12,80 times).

There is also no significant correlation between the age parameter and route-based kinesthetic data in the evacuation experiments ($p>0,05$). In this case, according to the averages, respondents whose ages are between fifteen (15) and twenty-five (25) (3,37m/s) are the fastest, while the participants over forty (40) years old (1,12m/s) are the slowest in these emergency experiments. Moreover, respondents aging between fifteen (15) and twenty-five (25) turned less (1,80 times) and made fewer stepbacks or stops (0,20 times), while the participants aging over forty (40) turned more (5,00 times) and made more stepbacks or stops (4,00 times) in the decision-making nodes of the building.

### 4.3.3 Education

We found no correlation between the education level variable and the route-based kinesthetic data in the wayfinding experiments ($p>0,05$). In this context, according to the averages, it may be expressed that participants who have undergraduate degrees (1,66m/s) are the fastest people in the wayfinding experiments, whereas respondents who have graduate degrees (1,42m/s) are the slowest ones. On the other hand, the only participants who graduated from high school (0,00 times) never stepped back or stopped and turned (5,00 times) less in the wayfinding experiments, whereas participants who have graduate degrees (7,42 times) made more stepbacks or stops in these wayfinding simulations.

Accordingly, it might be indicated that participants who have undergraduate degrees (15,20 times) turned more when compared to other respondents.

Similarly, there is no significant correlation between the education parameter and route-based kinesthetic data in the evacuation experiments ($p>0,05$). However, if we consider the averages, participants who have undergraduate degrees (3,28m/s) are the fastest persons in these evacuation experiments, whereas the only participant who has a postgraduate degree (2,29m/s) is the slowest one. On the other hand, the participant who graduated from high school and another respondent with a postgraduate degree (0,00 times) never stepped back or stopped at the decision-making points. In contrast, respondents with undergraduate degrees (0,80 times) made more stepbacks or stops in these evacuation experiments. Besides, the participant who has a postgraduate degree (1,00 times) turned less by the nodes, whereas participants who have graduate degrees (2,50 times) turned more in these simulations.

### 4.3.4 Profession

The profession parameter is not significantly correlated with the route-based kinesthetic data in the wayfinding experiments ($p>0,05$). On the other hand, when we consider the averages, it is revealed that business managers (1,35m/s) are the slowest participants, and the respondents who are categorized as the 'others' (2,02m/s) are the fastest ones in these wayfinding simulations. In this context, the professions such as psychologists, e-commerce specialists, automation technicians, communication designers, product owners, tourism professionals, and accountants are considered under the 'others' category.

On the other hand, the business managers (2,00 times) made fewer stepbacks or stops, whereas the engineers (9,00 times) made more stepbacks or stops than others in the wayfinding group. Moreover, while lawyers turned more (29,50 times) in the decision-making points, the participants we consider as the ‘others’ (5,00 times) turned least.

There is no correlation between the profession parameter and the route-based kinesthetic data in the evacuation experiments ($p>0,05$). However, according to the averages, engineers (3,77m/s) are the fastest people in the evacuation group, while those categorized as ‘others’ (2,49m/s) are the slowest ones. Moreover, while the ‘others’ (1,66 times) made more stepbacks or stops, the lawyer and the business manager (0,00 times) never stepped back or stopped in the evacuation simulations. On the other hand, the ‘others’ (3,00 times) turned more in the decision-making points, and the lawyer turned less (1,00 times) on these nodes compared to other participants.

### 4.3.5 Computer Gaming Experience

The computer gaming experience variable is not significantly correlated with the route-based kinesthetic data in the wayfinding experiments ($p>0,05$). According to the averages, participants with high computer gaming experience (1,68m/s) are the fastest people in the wayfinding simulations, while the participant with low computer gaming experience (1,36m/s) is the slowest one.

On the other hand, respondents with high computer gaming experience (7,07 times) made more stepbacks or stops in the nodes. In contrast, the participant with no computer gaming experience (3,00 times) stepped back or stopped less. Furthermore, it can be expressed that the participant with low computer gaming experience (14,25 times) turned more in the decision-making zones, while the participant who had no experience in computer gaming (11,00 times) turned less in these nodes.

On the other hand, we found a significant correlation between computer gaming experience and the average speed parameter in evacuation experiments ($F=3{,}896$, $p\leq0{,}05$). Accordingly, we may express that participants with high computer gaming experience (3,49m/s) are faster in the evacuation simulations. In contrast, respondents with low computer experience (1,88m/s) are the slowest ones.

Besides, when we consider the averages, it is revealed that participants with no computer gaming experience (1,66 times) stepped back or stopped more, and the participants with high computer gaming experience (0,25 times) made fewer stepbacks or stops in these experiments.

Moreover, participants with no computer gaming experience (3,00 times) turned more in the nodes, whereas the participants with low computer gaming experience (1,00) turned less in these decision-making points in the evacuation simulations. Accordingly, this case might indicate that people with high computer gaming experience could control the avatar easier than others.

## *4.4 Sequential Objective Assessments*

After investigating objective and subjective assessments, we handled sequential objective assessments, and these evaluations revealed significant correlations. Accordingly, we focussed on the relations between the 3D syntactic data and sequentially calculated node-based kinesthetic data. In this framework, the polyhedron volume, polyhedron surface area, optimized polyhedron volume, and the optimized polyhedron surface area variables are regarded as the polyhedron data. Besides, we consider the spherical circularity parameter as polyhedron radial data. On the other hand, we considered the spent time, duration of stops, frequency of head rotations, and frequency of unmatched movement and looking directions as sequentially calculated node-based kinesthetic data.

Accordingly, the volumetric visibility and kinesthetic data are sequentially calculated within the borders of decision-making points through a series of computer-aided algorithms in these assessments, and the relations are established with Pearson correlations over SPSS software. In this way, we found significant results with the averages of the polyhedron volume, polyhedron surface area, optimized polyhedron volume, and spherical circularity. Accordingly, the significant correlations that are related to wayfinding experiments are shown in Figure 44, whereas other significant relations revealed in the evacuation simulations are demonstrated in Figure 45.

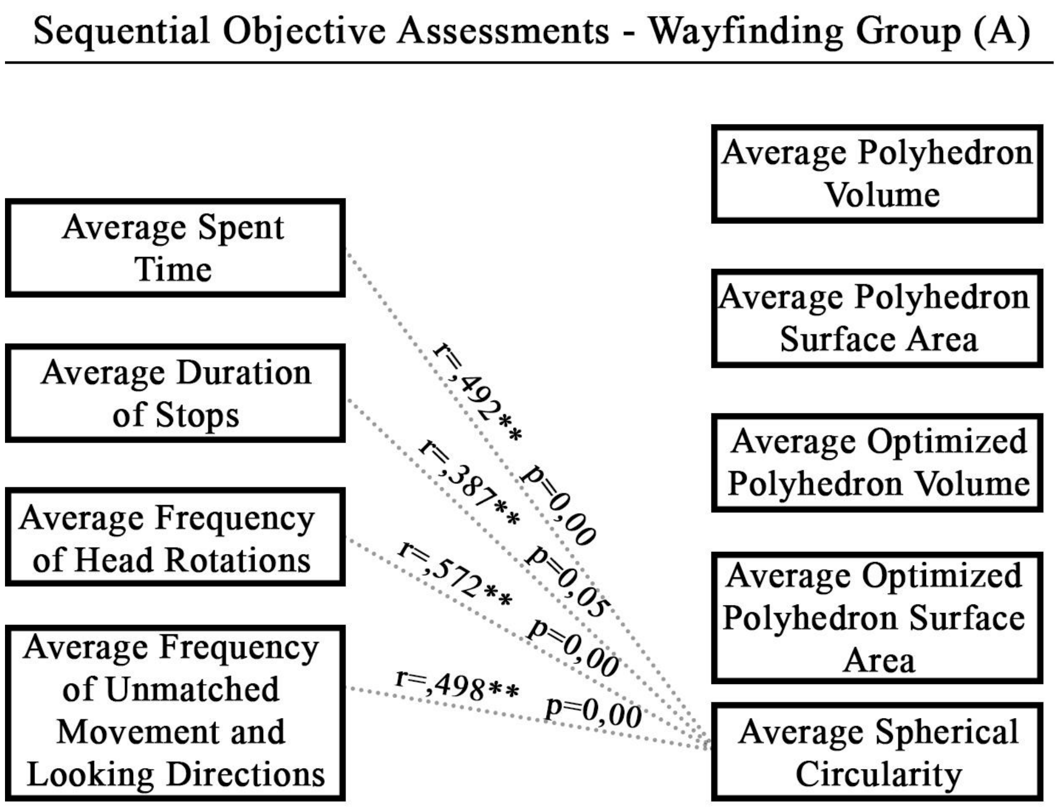



**Figure 44:** Sequential objective assessments and significant correlations for wayfinding group

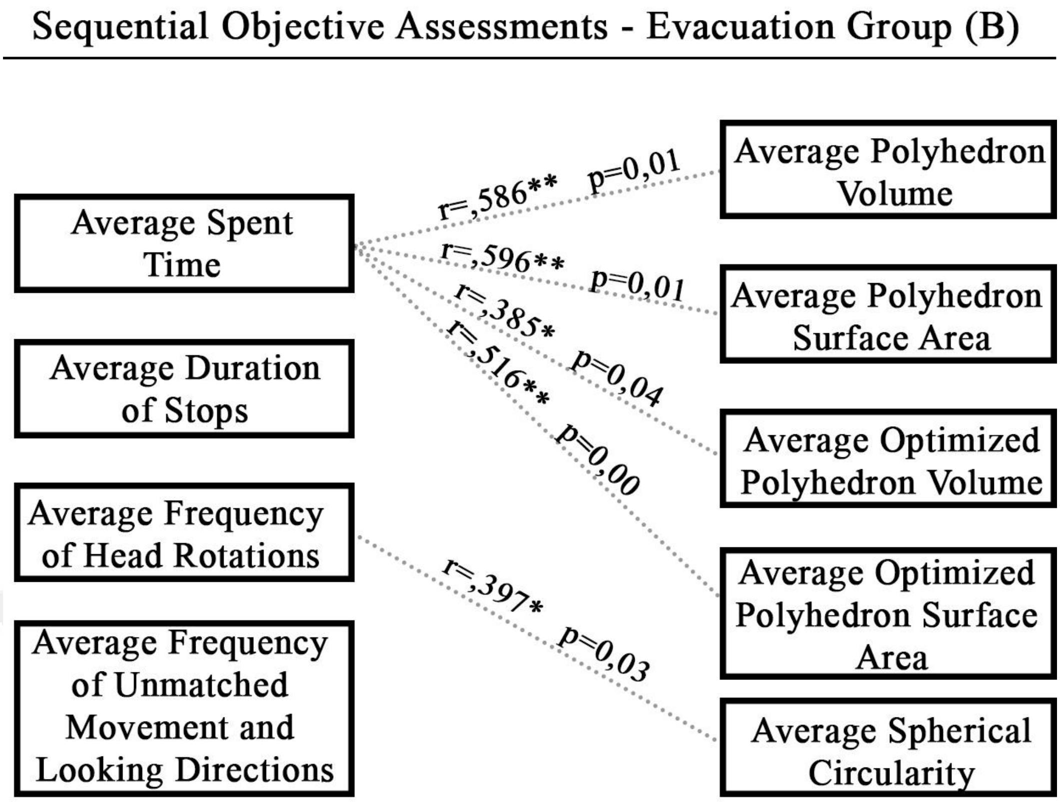



**Figure 45:** Sequential objective assessments and significant correlations for evacuation group

Before continuing the sequential objective assessments, we can argue that architectural elements such as doors, windows, and signages might be highly effective environmental knowledge providers. Accordingly, although there is no signage in wayfinding experiments, the other architectural elements might influence participants' wayfinding behaviors, especially when respondents try to find an exit from this unfamiliar and complex indoor environment.

As revealed with the depth parameter and demonstrated by the normalized time diagrams, participants showed intense hesitation in shallow places when they tried to leave the building in wayfinding experiments. Thus, these respondents spent much more time in wayfinding processes than in the evacuation experiments. While the average duration of completing the experiments is approximately six and a half (6,5) minutes for the regular exit group, it is thirty (30) seconds for the emergency exit group.

During these intense spatial discovery processes, respondents in the wayfinding group tried to leave the building from some of the regular room doors. One of the reasons for these attempts might be that the participants in the wayfinding group might have assumed that these doors as the actual exits. The other reason for this behavior might be that the participants might have been exhausted while searching for the regular exit doors and possibly made random door decisions where the environmental knowledge is insufficient for guiding the participants to the exits. Hence, it can be indicated that the importance of visual cues in wayfinding issues is also highlighted by Vandenberg (2016) [24] and Natapov and Gewirtman (2016) [38].

In this case, it should be expressed that some of these doors are nearby the decision-making zones, and thus, the previously created algorithms inevitably captured the revealed kinesthetic data around these zones. Hence, the revealed results in the wayfinding experiments might have deviated under these circumstances. Therefore, the correlations between volumetric visibility data and sequentially calculated node-based kinesthetic data might be misleading for the wayfinding experiments at specific points. On the other hand, participants in the emergency simulations rarely intended to try the regular room doors to evacuate the building. In this context, the positive effect of signages on participants' orientation behavior is revealed once again for the evacuation group.

### 4.4.1 Average Polyhedron Volume

Polyhedron volume can be explained as the volumetric measure of the 360º three-dimensional visible field of a particular vantage point. On the other hand, we found no correlation between the average polyhedron volume variable and the sequentially calculated node-based kinesthetic data in the wayfinding experiments. ($p>0,05$). Hence, we can argue that although the starting point of the wayfinding experiments and the nearby surroundings mainly present low polyhedron volume values, participants seem to be not making spatial decisions mainly based on the volume of the visible area from the point of their view during the wayfinding process. Nevertheless, it might be stated that the polyhedron volume parameter seems to reveal similar results with the isovist area variable since both parameters do significantly correlate with the kinesthetic data.

On the other hand, the polyhedron volume variable is significant for the evacuation group. In this case, it is revealed that participants in the evacuation simulations spent more time in the nodes with high polyhedron volumes ($r=,586^{**}$, $p\leq 0,05$). Accordingly, we might argue that participants in the evacuation group consider the visible volume of the space rather than the visible area since we could not find any correlation with the isovist area in the objective assessments.

In this context, we can discuss that polyhedron volume, as the 3D syntactic visibility data, may represent human perception and clarify the spatial behavior in orientation more accurately. On the other hand, it might also be indicated that the volume of the space plays an essential role in participants' orientation behaviors during the emergency processes since respondents might intend to head towards more open places for safety considerations in these emergency cases.

On the other hand, the starting point of these experiments, the nearby surroundings of this initial location, and the most preferred nodes present high polyhedron volume values. Correspondingly, from another perspective, the signages might have also guided participants to these most preferred nodes, and therefore, a distinctive route might have been revealed through the emergency exit located between node 27 and node 36.

Nevertheless, the average polyhedron volume parameter is not correlated with the average duration of stops, the average frequency of head rotations, and the average frequency of unmatched movement and looking directions ($p>0,05$). Accordingly, we might argue that participants in the evacuation group showed less hesitation when navigating to the emergency egresses.

### 4.4.2 Average Polyhedron Surface Area

Polyhedron surface area can be explained as the surface area of the 360º three-dimensional visible field of a particular vantage point. On the other hand, the polyhedron surface area is not significantly correlated with sequentially calculated node-based kinesthetic data in wayfinding experiments ($p>0,05$). Accordingly, we can argue that although the starting point of the wayfinding experiments and the nearby surroundings mainly present low polyhedron surface values, it seems that participants did not make spatial decisions specifically based on the surface area of the visible volume from the vantage point during the wayfinding process. In this context, we can argue that this result might be expected since the isovist perimeter did not also correlate with the manually observed node-based kinesthetic data in the objective assessments.

On the other hand, we found a significant correlation with polyhedron surface area in the evacuation experiment. Accordingly, participants spent more time in the nodes with high polyhedron surface area ($r=,596^{**}$, $p\leq0,05$). We expected this result since the isovist perimeter is also found significant in the evacuation group in objective assessments. In this context, most participants completed the simulations close to the starting location of the emergency exit experiments. As mentioned before, this area is one of the largest halls containing inner gardens with transparent surfaces and window frames. These window frames might have also dispersed the polyhedron form, and therefore, the high polyhedron surface area values might have been inevitably correlated with the average spent time variable in these evacuation experiments.

In this framework, dispersed polyhedron form may be related to spatial hesitations, and respondents may perceive these spaces as visually inconsistent. However, polyhedron surface area did not correlate with the average duration of stops ($p>0,05$), the average frequency of head rotations ($p>0,05$), and the average frequency of unmatched movement and looking directions ($p>0,05$). In this context, it might be stated that participants already knew where they went when they passed the decision-making points that mostly present high polyhedron surface area values by showing less spatial hesitation. Accordingly, this result might also support the idea that signages are highly influential in evacuation issues.

### 4.4.3 Average Optimized Polyhedron Volume

Optimized polyhedron volume can be defined as the volumetric measure of the instantly viewed side of the visible field of view. In this perspective, the wayfinding experiments revealed no relationship between optimized polyhedron volume and sequentially calculated node-based kinesthetic data ($p>0,05$). Correspondingly, it might be stated that respondents did not consider either the visible volume of the space or the volume of the viewed field in the wayfinding simulations. However, we can also argue that the participants' exploration process for finding the exits, including the attempts to leave the building from regular room doors, might also have altered the revealed results with the optimized polyhedron volume parameter, just as with the polyhedron volume variable.

On the other hand, we found a significant correlation between optimized polyhedron volume and the sequential node-based kinesthetic data in the evacuation experiments. According to the revealed result, participants in the evacuation group spent more time in the decision-making zones with high optimized polyhedron volumes (r=,385*, p≤0,05). In this framework, we might argue that these respondents considered the volume of the visible field that is instantly viewed when making their spatial decisions during emergency conditions.

Thus, it might be stated that respondents not only headed towards the places that present high volumetric visibility values but also intended to orient themselves to the areas where the volume of the viewed field of sight is also high. On the other hand, this can be the reason why most participants could see the signage guiding the closest exit at the beginning of the experiments and ignored the other sign close to this signage.

However, the optimized polyhedron volume did not correlate with the averages of the duration of stops, frequency of head rotations, and the frequency of unmatched movement and looking directions (p>0,05). This result may indicate that there is no relation between spatial hesitation and the optimized polyhedron volume parameter. As it is mentioned before, the signages might also have played an essential role in preventing participants from revealing spatial hesitations in the evacuation experiments.

### 4.4.4 Average Optimized Polyhedron Surface Area

Optimized polyhedron surface area can be described as the surface area of the instantly viewed side of the visible field of view. Similar to the polyhedron surface area variable, we found no correlations between optimized polyhedron surface area and the sequentially calculated node-based kinesthetic data in wayfinding experiments (p>0,05). According to these results, we can argue that the whole polyhedron data as polyhedron volume, polyhedron surface area, optimized polyhedron volume, and optimized polyhedron surface area parameters might be insignificant in wayfinding experiments.

On the contrary, we might state that the graph data variables still seem to be the prevailing parameters in the wayfinding experiments containing no guiding signages, as also mentioned by Mavridou et al. (2009) [36]. In addition, we can also explain that these participants' wayfinding behaviors might also be more explicitly evaluated based on the drift, circularity, and skewness variables as parts of the isovist and radial data.

On the other hand, the average optimized polyhedron surface area is significant in the evacuation simulations. Accordingly, we can indicate that participants spent more time in the decision-making areas with high optimized polyhedron surface areas in the evacuation experiments ($r=,516^{**}$, $p\leq 0,05$). In this context, it might be noticed that the optimized polyhedron surface area is closely related to the polyhedron surface area variable and, therefore, reveals similar results in the evacuation experiments, just as the optimized polyhedron volume reveals similar results with the polyhedron volume parameters.

Correspondingly, we also found no correlation between optimized polyhedron surface area and the sequential node-based kinesthetic data ($p>0,05$). Hence, people in the evacuation group showed almost no hesitation in these decision-making areas of the building. Accordingly, we can express that signages are highly effective in the evacuation processes, and it can be argued that symbols may reduce the effects of spatial syntactic parameters on human perception, as mentioned by Natapov and Gewirtzman (2016) [38].

### 4.4.5 Average Spherical Circularity

Spherical circularity values might indicate how close the observation point is to the center of the three-dimensional visible space and how closely a polyhedron form approximates a spherical shape. In the wayfinding experiments, attendants spent more time ($r=,492^{**}$, $p\leq 0,05$), made more stops ($r=,387^{*}$, $p\leq 0.05$), and did more head rotations (r=,572**, p≤0,05) in nodes with high spherical circularity values. Furthermore, participants' movement and looking directions are not frequently matched (r=,498**, p≤0,05) in the nodes with high spherical circularity values. The results may be conceived as contradictive to the 2D circularity results. This inconsistency might have been caused by the height and volume factors added to the planar isovist concept or the sequential calculation method. In this case, the second option might be a more possible reason to consider, and we can explain the revealed spherical circularity correlations in wayfinding experiments accordingly.

We can discuss that most participants tried to leave the building from some of the regular room doors in these experiments, and these doors are located inside the decision-making zones, as mentioned before. Accordingly, the sequentially calculated node-based kinesthetic data might have deviated during the process of the exit door explorations since these respondents headed towards some of the regular room doors, touched them to end the simulation, and realized that these doors were not the actual exits. Therefore, these participants stepped back or rotated their heads to move in other directions and continue the spatial discovery process.

As a result, most of these participants spent some time in these nodes when trying to leave the building from these doors. In this context, some of these doors have remained inside the previously defined decision-making boundaries for sequential calculations. Moreover, it can be indicated that these zones, such as node 53, node 52, node 50, and node 48, present the highest spherical circularity values in the virtual building. Therefore, the sequential computation method through algorithms inevitably captured the revealed kinesthetic data as hesitations in these zones.

As a result, these circumstances might have altered the correlations between the spherical circularity and the sequential node-based kinesthetic data in this direction. However, these results may also justify the evidence that the architectural elements such as doors might be great environmental knowledge providers and target points when there is limited information about the surroundings. On the other hand, it might be expressed that we captured these results due to the door niches for the rooms since these niches restrict the polyhedron radials and create a compact visible volume when participants tried to exit the building from these doors.

The spherical circularity variable is also found significant in the evacuation experiments. In this context, we can put forward that there is a relationship between the average frequency of head rotations and average spherical circularity parameters ($r=,397^*$, $p \leq 0,05$). Accordingly, it might be argued that participants more frequently rotated their looking directions in the nodes where the spherical circularity values are high. However, it should be noted that the starting point of the evacuation experiments and the most preferred nodes present high spherical circularity values, and this result might have inevitably been revealed in the experiments.

On the other hand, the spherical circularity parameter did not correlate with the average spent time, the average duration of stops, and the average frequency of unmatched movement and looking directions in these evacuation experiments ($p>0,05$). In this case, we can argue that the revealed result might not represent the whole evacuation group but several participants who might have statistically altered the kinesthetic data results by rotating their heads more frequently by also showing no hesitations as stopping or looking in different directions while moving to other directions in the decision-making zones. As a result, we can express that the spherical circularity parameter may not be as significant in the evacuation experiments as the signages.

## 4.5 *Results of the Chapter*

This chapter mainly examined the relationships between dependent variables as kinesthetic data and independent variables as personal data, 2D syntactic data, and 3D syntactic data resulting from the wayfinding and evacuation experiments. Hence, we investigated all the revealed data under the objective, subjective, and sequential objective assessments. Accordingly, we found significant correlations in each assessment. Before these assessments, we initially evaluated the participants' wayfinding and evacuation behaviors over participants' routes under the preliminary evaluations as the sub-part of this chapter. In this phase, we also investigated these participants' regular exit or emergency exit door choices regarding the building's axial and nodal integration diagrams.

According to these evaluations, it might be argued that participants in the wayfinding group tended to leave the building from the exits on the most integrated axes. On the other hand, participants in the evacuation group tended to exit the building from the shallowest egresses. Moreover, normalized time diagrams revealed that the participants in the wayfinding group primarily aimed to discover the diverse parts of the nearby surrounding close to the initial location of the wayfinding experiments. However, we demonstrated that most respondents in the evacuation group decided to proceed on a distinctive path when going to the egresses. In this context, it might be expressed that the emergency exit signages effectively guided these respondents to the closest emergency exit doors.

In the objective assessments, it is discovered that the circularity, drift, skewness, depth, mean depth, and integration are significant variables for the wayfinding simulations, whereas the isovist perimeter, depth, mean depth, and integration parameters might be important for evacuation issues. Correspondingly, participants in the wayfinding and evacuation group tended to move around the shallow places according to the starting points of these experiments. On the other hand, it is also revealed that these participants more frequently passed the nodes that present low mean depth and high integration values. However, they mostly showed spatial hesitations on the decision-making points at the low depth levels.

We can argue that respondents might reveal orientational hesitations in shallow places where they do not have any spatial memory of unfamiliar and complex indoor environments. On the contrary, these respondents might develop a memory about the spatial organization over time, especially when they identify the integrated zones of the building. Correspondingly, we can state that the fear of being lost might disappear in these zones, and therefore, participants in the wayfinding group can do fewer stepbacks or stops due to these circumstances. On the other hand, respondents in the evacuation group might have shown spatial hesitation in the shallow nodes due to both the unfamiliarity of the building and the feeling of panic. However, their environmental anxiety might have been reduced after perceiving the emergency exit signages, which can be conceived as highly effective environmental knowledge providers.

Furthermore, participants in the evacuation group more frequently passed by the nodes that present high isovist perimeter values. This result might have inevitably occurred since the signages are adjusted to guide these people to the closest egresses, and participants needed to pass the nodes with high isovist perimeter values to reach these exits. On the other hand, it is revealed that participants in the wayfinding group more frequently passed and turned by the nodes with high drift and skewness values and also revealed more spatial hesitations in these zones.

Accordingly, we can argue that participants might have searched for a regular exit door in the areas that are close to the peripheries of the building at the beginning of the experiments, where the center of visible area is far from the vantage point and where the long isovist radials are more than short ones. In this case, it can be discussed that these spatial discovery processes might have revealed intense hesitations about the orientation issue, especially at the beginning of the wayfinding experiments. On the other hand, people in the wayfinding group may have more frequently stepped back or stopped at the decision-making points, especially those that present low circularity values. The spatial complexity as significant linearity in multiple directions and visual inconsistencies might have led participants to a state of uncertainty cases, especially when considering directional decisions.

The subjective assessment revealed only gender and computer gaming experience as the significant parameters for the evacuation experiments. In this context, we can put forward that men passed less distance in a much shorter time, turned less, and made fewer stepbacks or stops than women. Hence, we can state that men might make quicker spatial decisions without hesitating as much as women do under emergency considerations. On the other hand, it is revealed that participants that have high computer gaming experience are the fastest in these evacuation simulations. Besides, these respondents also turned less and made fewer stepbacks or stops in decision-making areas. Accordingly, it might be indicated that people with high computer gaming experience can control the avatars easier than others, and this result is revealed even though we conducted a preliminary simulation to eliminate the gaming experience factor in the experiments.

In the sequential objective assessments, we found significant correlations related to averages of the polyhedron volume, polyhedron surface area, optimized polyhedron volume, optimized polyhedron surface area, and the spherical circularity. Accordingly, participants spent more time in places presenting high polyhedron volume and high polyhedron surface area values in the evacuation experiments.

In this context, we can discuss that these results might have inevitably emerged since the egress signs guided most respondents to the nodes where these parameters reveal high results. Accordingly, these respondents showed fewer spatial hesitations in these zones. On the other hand, we can also argue that people in the evacuation group might have considered the visible volume of the space rather than the isovist area. Therefore, it might also be indicated that polyhedrons as 3D syntactic data can represent human perception more precisely and indicate the behaviors more clearly than the 2D isovist data. In this case, the people in the evacuation group might be intended to orient themselves to the visually more open zones due to the safety considerations.

Moreover, we also might clarify the situation where these participants have intentionally oriented themselves to these zones by revealing the positive correlations with sequentially calculated node-based kinesthetic data and optimized polyhedron volume and optimized polyhedron surface area. Accordingly, participants in the evacuation group more frequently spent time in nodes where their viewed field of sight and these viewed spaces' surface area measures were higher than in other places.

As we mentioned earlier, these results may answer what syntactic parameters made signages more visible than others. At the beginning of the evacuation experiments, the zone with a higher volume and polyhedron surface area may have attracted people's attention. People may need to focus more deeply to perceive, comprehend, and evaluate these kinds of spaces in their surroundings. Therefore, the signage in these zones may have been perceived first, and thus, they might have guided people to the closest egress door.

On the other hand, the spherical circularity parameter is also revealed as significant in these evacuation simulations. In this framework, participants in the evacuation group more frequently rotated their heads in the nodes with high average spherical circularity values. Accordingly, we can state that this result can be seen as contradictory to the results related to the 2D circularity parameter. Thus, we can consider that this result might have coincidentally emerged due to some respondents who rotated their heads more frequently and altered the results dominantly in these evacuation experiments.

On the other hand, participants spent more time, stopped more, and rotated their heads more in the decision-making zones with high spherical circularity values in the wayfinding experiments. Besides, it is revealed that these participants' movements and looking directions also did not match in these zones. In this case, we suspect that these results might be misleading in clarifying the orientation behavior since most participants in the wayfinding group tried to exit the building from the regular room doors at the beginning of the experiments, and these doors are located nearby the decision-making points. However, we might have justified that the architectural elements such as doors might be great attractors during the wayfinding processes where the environmental knowledge is insufficient.

Consequently, although some of the results might be misleading for the wayfinding evaluations, we can still argue that sequential algorithmic measurement methods can capture the behavioral data more precisely than the manual observations because some human behaviors, such as the degree of the head rotations and unmatched movement and looking directions remain pretty obscure in manual observations. Therefore, it should be noted that the computer algorithm or the experiment should be adjusted to avoid capturing these types of misleading data.

# CHAPTER V

# CONCLUSION

This master thesis mainly focused on the correlations between volumetric visibility data and kinesthetic data by adopting the sequential measurement method for investigating the wayfinding and evacuation processes in complex and unfamiliar indoor environments within the scope of the Space Syntax Theory and Environment-Behavior Studies. Thus, we investigated these correlations under the sequential objective assessments.

Besides, we also included the 2D syntactic data in these investigations and evaluated the results under the objective assessments. However, we examined these data not sequentially but as the syntactic values obtained from the midpoints of our experimental building's nodes. In this case, it should be indicated that the related behavioral data is collected by counting the kinesthetic movements around these decision-making points. Moreover, the research also focused on the correlations between personal and kinesthetic data as wayfinding and evacuation behaviors under subjective assessments.

Thus, we found considerable outcomes in these assessments, and this study revealed significant 2D and 3D syntactic results related to wayfinding and evacuation issues. It may be argued that these results are consistent with the outcomes of previous investigations conducted by Peponis et al. (1990) [31], O'Neill (1991) [34], Haq and Zimring (2003) [35], Mavridou et al. (2009) [36], Bhatia et al. (2013) [15], Shushan et al.

(2014) [22], Natapov and Gewirtzman (2016) [38], Li et al. (2019) [12], Lin et al. (2020) [10], and Natapov et al. (2022) [28]. On the other hand, the results of our experiments are also in accordance with the theoretical discussions about wayfinding and evacuation issues expressed by Gluck (1991) [1], Miller (1992) [3], Raubal (2001) [25], Golledge (2004) [5], Hajibabai et al. (2007) [6], Hunter et al. (2016) [27], Vandenberg (2016) [24], Ünlü et al. (2019) [2], Bae et al. (2020) [11], Lin et al. (2020) [10], Zhu et al. (2020) [4], and Natapov et al. (2022) [28].

At this point, it should be indicated that this study is carried out with an experimental method in a virtual simulation environment. One of the highlightings of these experiments is that the experiments are done on an online platform. Accordingly, the simulated environment is projected through the participants' computer screens, and these participants can move freely in the virtual building. In future studies, conducting experiments with VR glasses will be an essential issue for the respondents to perceive the spaces better so that we may better understand their spatial behaviors.

The point to be emphasized in this study is that sequential volumetric visibility and behavioral data computations are made within the specific boundaries of the nodes of the building with the aid of a series of Grasshopper algorithms.  In this context, further studies may not be limited to the borders of decision-making zones but all the revealed data during the experiments. In this way, the correlations between syntactic data and kinesthetic data might be revealed more profoundly, especially about the issues such as human perception and spatial decision-making in wayfinding or evacuation or processes.

We can also underline that the study aimed to handle volumetric visibility parameters such as the polyhedron volume, polyhedron surface area, optimized polyhedron volume, and optimized polyhedron surface area. It can be stated that while the polyhedron volume refers to the volumetric measure of the 360º visible space from a specific observation point, optimized polyhedron volume denotes the volume of the viewed side of this visible space. Moreover, we may indicate that polyhedron surface area and optimized polyhedron surface area are the surface area measures of these considered visible volumes.

On the other hand, we also focused on the spherical circularity variable as another volumetric visibility data generated explicitly for this master's thesis. Hence, we assumed that the revealed results with the spherical circularity variable might represent the three-dimensional spatial complexity and meaningfully interpreted regarding the spatial hesitations during movement. We created this parameter by converting Dalton and Dalton's (2001) [9] 2D circularity formulation into a three-dimensional expression based on the sphere volume formula. On the other hand, we targeted to answer these research questions in this study:

- Can volumetric visibility properties capture and reveal spatial behaviors more accurately than 2D syntactic visibility properties?
- Besides, how are the wayfinding and evacuation processes affected by the volumetric visibility features of unfamiliar complex indoor environments?
- On the other hand, how do directional signages affect wayfinding and evacuation processes in unfamiliar and complex indoor environments?
- Consequently, how do people behave in unfamiliar and complex indoor environments during wayfinding and evacuation processes?

Hence, the depth, mean depth, and integration parameters seem to be highly important factors in wayfinding processes in unfamiliar and complex indoor environments containing no guiding signages. Accordingly, wayfinding experiments revealed that participants primarily tended to explore the shallow places close to the more integrated zones by spontaneously heading forward in different directions and retracing the paths they had selected before. Nevertheless, volumetric visibility data might also be considered one of the essential parameters when the signboards are allocated in the surrounding, especially in emergency conditions.

In this case, it could be argued that participants are guided to the closest egresses through directional signs in evacuation experiments, and these people tended to pay more attention to spaces that have high polyhedron volumes and polyhedron surface areas. Furthermore, it is also revealed that people move forward to the directions where the optimized polyhedron volume and the optimized polyhedron surface area values are comparatively higher, especially in the evacuation experiments. As a result, unlike the wayfinding group, these respondents revealed a distinctive route going through the closest exit. Thus, we can also argue that signages are highly essential environmental knowledge providers for people, especially in unfamiliar and complex buildings.

In conclusion, this research has primarily taken the concept of 3D isovist as polyhedrons and intended to present the results of a series of wayfinding and evacuation experiments regarding the environment-behavior issues by sequentially calculating the volumetric visibility features. Thus, we could reveal significant results related to wayfinding and evacuation issues in complex buildings, and one of them can be expressed as the signs almost eliminate the negative effects of spatial features on wayfinding. On the other hand, we can also express that although 2D syntactic parameters can sufficiently represent spatial perception at some points, polyhedrons can reveal more accurate results, especially when considering the third dimension of space.

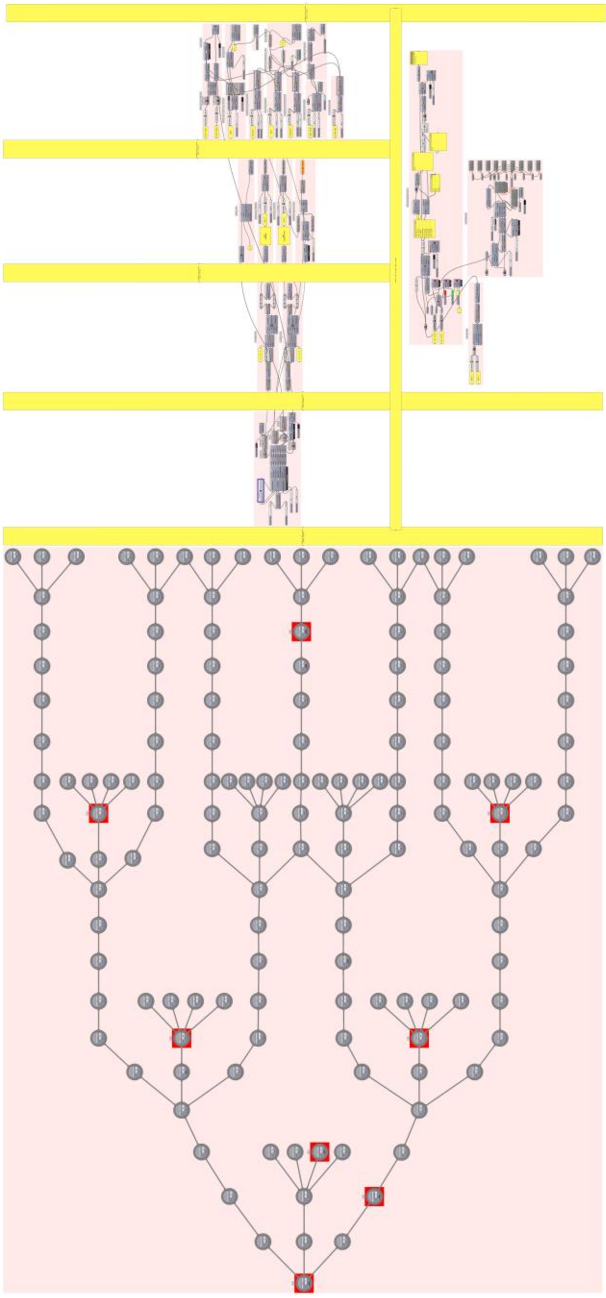
In the light of these results, the architects may reconsider the wayfinding and evacuation issues while designing a complex building. Accordingly, the building's spatial organization might be arranged in a way that the functions used by common visitors or inhabitants of the building can be located in the deepest and most segregated zones. Thus, the possible high depth levels that novice visitors may confront during orientation might be restained by decreasing the topological complexity of the building for these people. Besides, the visibility of the exits can be increased by using the transparent surfaces between the deeper vantage points and the exits. On the other hand, creating different sizes of halls and inner courtyards nearby the integrated axes might be regarded as architectural differentiation and can be influential in developing cognitive maps of the environment. Hence, signages can be adjusted to guide people to these places, and the number of emergency exits can be increased in these zones.

Finally, we may indicate that today, with the developments in computer technologies, vast amounts of data can be computed very quickly. Hence, with the algorithm-based sequential computation methods and online experiments, researchers may reach the spatial and behavioral information regarding wayfinding and evacuation issues in a short period of time even though there might be a great distance between the researcher and the experimental group.

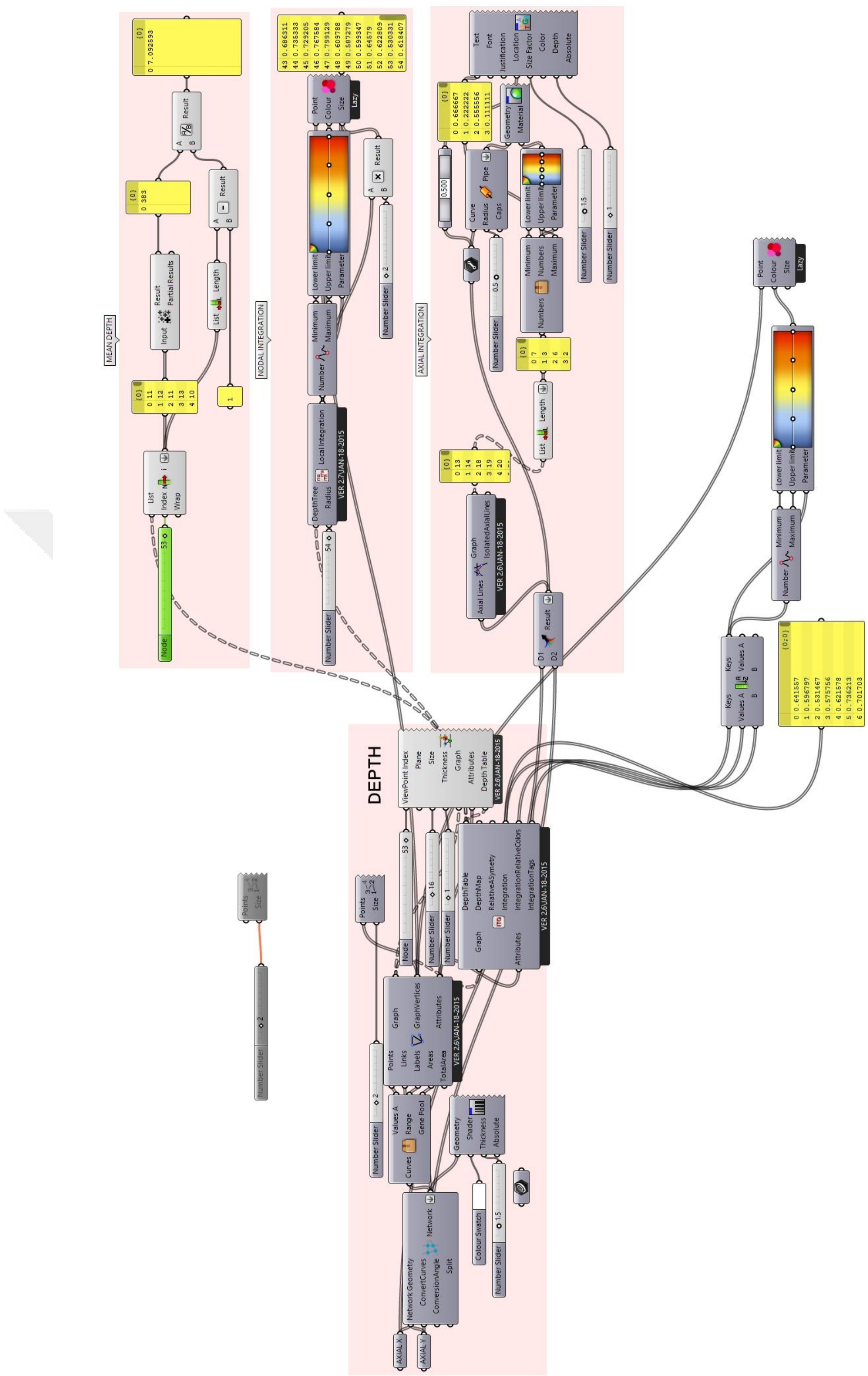
However, we should also indicate that experimental investigations, especially those conducted in physical environments regarding the wayfinding and evacuation issues, are still crucial for the architectural research field. Thus, conducting experiments in actual complex buildings, such as courthouses and city hospitals in Turkey, by adopting the research model implemented in this thesis and comparing the results of these studies with the outcomes revealed by our simulation experiments would be a highly beneficial contribution to the existing literature on wayfinding and evacuation issues.

# APPENDIX A

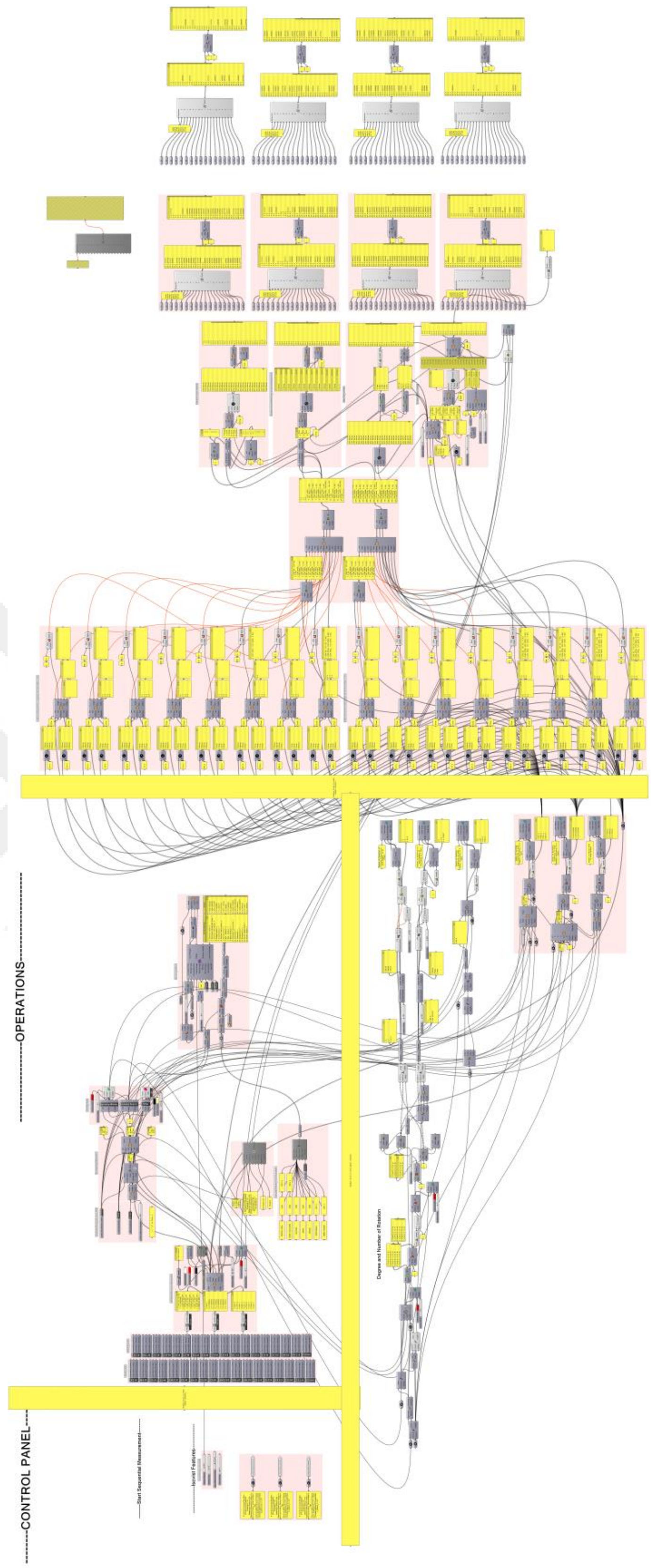
# COMPLETE GRASSHOPPER SCRIPTS



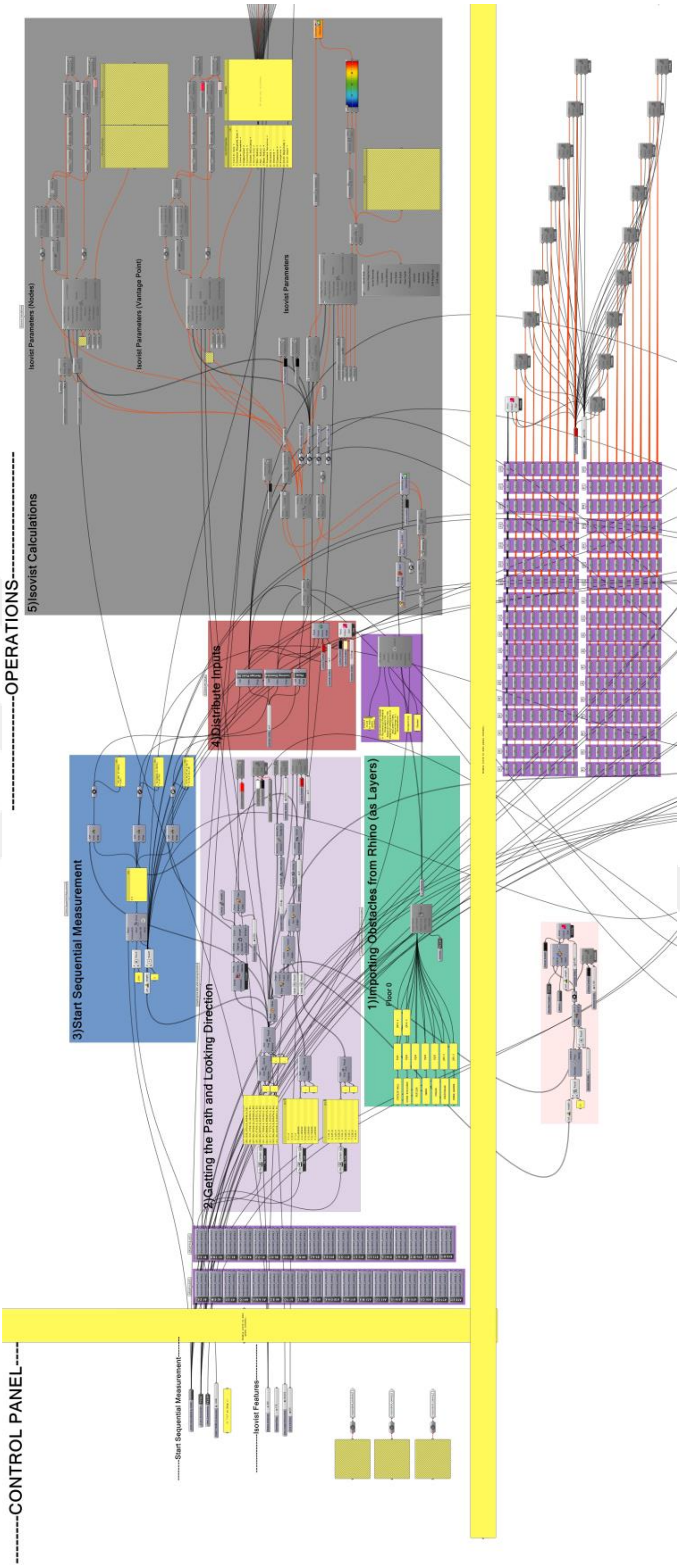
**Appendix A1:** The complete Grasshopper script through which we aimed to create the 3D virtual building model



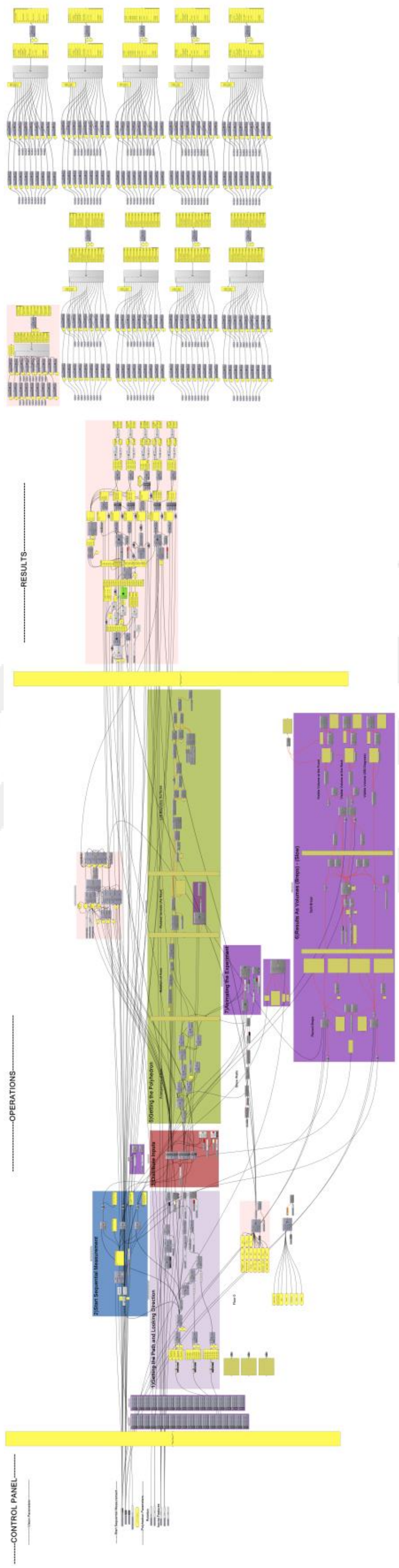

**Appendix A2:** The complete Grasshopper script through which we aimed to obtain graph data values of the nodes and create justified maps, axial and nodal integration diagrams of the 3D virtual building model



**Appendix A3:** The complete Grasshopper script through which we aimed to obtain 2D isovist data values of the nodes and make sequential kinesthetic data calculations




**Appendix A4:** The complete Grasshopper script through which we aimed to create normalized time diagrams of the participants




**Appendix A5:** The complete Grasshopper script through which we aimed to make sequential volumetric visibility data calculations

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