ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

A METHODOLOGY FOR ASSESSMENT OF SPATIAL PERFORMANCE IN HOSPITAL BUILDINGS THROUGH IMMERSIVE VIRTUAL REALITY AND BEHAVIOURAL SEQUENCE ANALYSIS

M.Sc. THESIS

Elif Bahar OKUYUCU

Department of Informatics

Architectural Design Computing Program

JUNE 2024

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

A METHODOLOGY FOR ASSESSMENT OF SPATIAL PERFORMANCE IN HOSPITAL BUILDINGS THROUGH IMMERSIVE VIRTUAL REALITY AND BEHAVIOURAL SEQUENCE ANALYSIS

M.Sc. THESIS

Elif Bahar OKUYUCU
(523201020)

Department of Informatics

Architectural Design Computing Program

Thesis Advisor: Assoc. Prof. Dr. Sevil YAZICI

JUNE 2024

ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

KAPSAYICI SANAL GERÇEKLİK VE DAVRANIŞSAL DİZİ ANALİZİ YOLUYLA HASTANE BİNALARINDA MEKANSAL PERFORMANSIN DEĞERLENDİRİLMESİNE YÖNELİK BİR METODOLOJİ

YÜKSEK LİSANS TEZİ

Elif Bahar OKUYUCU
(523201020)

Bilişim Anabilim Dalı

Mimari Tasarımda Bilişim Programı

Tez Danışmanı: Doç. Dr. Sevil YAZICI

HAZİRAN 2024

Elif Bahar Okuyucu, a M.Sc. student of İTU Graduate School student ID 523201020, successfully defended the thesis/dissertation entitled "A METHODOLOGY FOR ASSESSMENT OF SPATIAL PERFORMANCE IN HOSPITAL BUILDINGS THROUGH IMMERSIVE VIRTUAL REALITY AND BEHAVIOURAL SEQUENCE ANALYSIS", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Assoc. Prof. Dr. Sevil YAZICI** ....
İstanbul Technical University

Jury Members : **Prof. Dr. Leman Figen GÜL** ....
Istanbul Technical University

Asst. Prof. Emirhan COŞKUN ....
Haliç University

Date of Submission : 22 May 2024
Date of Defense : 12 June 2024

To my family,

FOREWORD

First of all, I would like to express my gratitude to my advisor Assoc. Prof. Dr. Sevil Yazıcı for her guidance, patience and encouragement throughout my graduate education and thesis process. I would also like to thank jury members Prof. Dr. Leman Figen Gül and Asst. Prof. Emirhan Coşkun for their valuable feedback and contributions.

I am grateful to my entire family, especially my mother, sister and aunt, for their endless support throughout my education life. I would also like to thank all my friends who supported me, especially my companions during this process.

I would like to thank TÜBİTAK Scientist Support Programs Directorate (BİDEB) for the support they provided throughout the master's education within the scope of 2211-Domestic Graduate Scholarship Program.

June 2024

Elif Bahar OKUYUCU
(Architect)

TABLE OF CONTENTS

Page

FOREWORD ix
TABLE OF CONTENTS xi
ABBREVIATIONS xiii
LIST OF TABLES xv
LIST OF FIGURES xvii
SUMMARY xix
ÖZET xxi
1. INTRODUCTION 1
2. WAYFINDING AND SPATIAL PERFORMANCE IN ARCHITECTURAL DESIGN PROCESS 5
2.1 Spatial Layout and Performance 5
2.2 Space Syntax Theory 8
2.3 Computation and Evaluation Methods 10
2.3.1 Protocol Analysis 11
2.3.2 Behavioural Sequence Analysis 12
3. EXTENDED REALITY 15
3.1 Virtual Reality 16
3.1.1 Non-immersive VR 19
3.1.2 Semi-immersive VR 21
3.1.3 Immersive VR 22
3.2 Augmented Reality 24
3.3 Mixed Reality 25
4. METHODOLOGY 27
4.1 Hospital Building Selection 28
4.2 Implementing Space Syntax Analysis 30
4.3 Preparation of Virtual Environments 31
4.3.1 3D modeling principles 31
4.3.2 Signage system 33
4.4 Wayfinding Tasks 35
4.5 Experimental Setup 40
5. THE VR EXPERIMENT 43
5.1 Participant Selection 43
5.2 Data Collection 44
5.3 Data Arrangement 46
6. DATA ANALYSIS AND DISCUSSIONS 55
6.1 Space Syntax Analysis 55
6.2 Analysis 1- BSA 57
6.3 Analysis 2- Visibility and Behavioural Relationship 61
6.4 Analysis 3- Behavioural Frequencies 63
6.5 Analysis 4- Average Speed 65
6.6 Comparison of the Outputs 66
6.7 Discussion 68

7. CONCLUSIONS **71**
REFERENCES **75**
APPENDICES **85**
CURRICULUM VITAE **93**

ABBREVIATIONS

AR	: Augmented Reality
BSA	: Behavioural Sequence Analysis
HMD	: Head-Mounted Display
iVR	: Immersive Virtual Reality
MR	: Mixed Reality
P	: Participant
V	: Visibility
VE	: Virtual Environment
VR	: Virtual Reality
XR	: Extended Reality

LIST OF TABLES

Page

Table 4.1 : Information about selected hospital buildings adapted from URL 1. ..... **29**
Table 5.1 : Participant information. **44**
Table 5.2 : Behavioural Codes Table. **47**
Table 5.3 : Selected Example : The behavioural table representing task 2 of P3 in Pars Hospital. **48**
Table 5.4 : Selected Example : Behavioural table including V values for Task 2 of P3 in Pars Hospital. **50**
Table 5.5 : Selected Example: Behavioural frequency table for Task 2 of P3 in Pars Hospital. **51**
Table 5.6 : Selected Example: The average speed table of P3. .... **52**
Table 6.1 : Visibility maps of each floor of buildings **54**
Table 6.2 : V values for each building. **55**
Table 6.3 : The transition matrices of three hospital buildings. **56**
Table 6.4 : The most observed transitions of three hospital buildings. From top to bottom: most observed to least observed. **58**
Table 6.5 : The cross-tabulation table implies the percentage of behaviours within each V value (0 percentage represents the values between 0-0.05). **60**
Table 6.6 : The durations of the behaviours in each hospital (0 seconds represents the seconds between 0-0.5). **62**
Table 6.7 : The percentages of frequencies of behavioural groups (%). **62**
Table 6.8 : The average speed of participants (P) based on the building. **63**
Table 6.9 : The average speed based on the tasks. **64**
Table 6.10 : The hospital buildings' plan layout characteristics , floor areas and the results of each analysis. **64**

LIST OF FIGURES

Page

Figure 1.1 : The scope of the study. **3**
Figure 2.1 : Weisman's drawing of ideal plan schemes for wayfinding (1981). **7**
Figure 2.2 : Space layout categorisation chosen as a part of the methodology. **7**
Figure 2.3 : Example of space syntax analysis from literature (Hadi and Zimring, 2016; Pouyan et al., 2021).. .... **8**
Figure 2.4 : Example of an isovist polygon on top, the pattern of connections in the middle and isovist field at bottom (Turner et al., 2001).. .... **9**
Figure 2.5 : Example of protocol analysis coding categories (Tang & Gero,2000).. **12**
Figure 2.6 : Example of BSA behavioural table (Marono et al., 2017). **14**
Figure 3.1 : The difference between AR, MR and VR (Osorto Carrasco & Chen, 2021). **16**
Figure 3.2 : Examples from VEs (Zhu et al., 2020; Shi et al., 2021; Feng et al., 2022). **19**
Figure 3.3 : Example of a non-immersive VR setup (Maranesi et al., 2022). **20**
Figure 3.4 : Example of a semi-immersive VR setup (Hwang et al., 2021). **21**
Figure 3.5 : iVR setup with an HMD and controllers, and the vision of the user on the right (Hamdi et al., 2022). **22**
Figure 3.6 : iVR setup with an HMD, controllers and the equipment that provides physical movement (Fully Immersive VR Entertainment Solutions, 2024). **23**
Figure 3.7 : An example of the use of AR through a tablet in a construction site (Augmented Reality Comes to Construction Industry, 2021). **24**
Figure 3.8 : A demonstration of a designer using MR through smart glasses to take the measurements of the existing stairs (Ho, 2018). **25**
Figure 4.1 : The methodology of the study. **28**
Figure 4.2 : : Images from 3D models of the buildings. At the top: 1st floor of Pars Hospital. In the middle: Ground floor of Radboudumc Hospital. At the bottom: Ground floor of Rocio's Hospital. **32**
Figure 4.3 : Two types of signage from the 3D models: main signage tables(on the left) and intermediate pointers(on the right). **33**
Figure 4.4 : Examples of various signage elements in all three buildings' 3D models. From top to bottom: Pars Hospital, Radboudumc Hospital, Rocio's Hospital. **34**
Figure 4.5 : Locations of main signage tables in each building. **35**
Figure 4.6 : 3 wayfinding tasks. **39**
Figure 4.7 : Oculus Quest 2 VR set including an HMD and two controllers. **40**
Figure 4.8 : The views from VEs. From top left to bottom right: The controllers in VE, the entrances of Rocio's Hospital, Radboudumc Hospital and Pars Hospital. **41**
Figure 4.9 : The functions of the buttons used during the experiment on the controllers. **42**

Figure 5.1 : Selected Example : The motion maps of 3 wayfinding tasks of P3 in Pars Hospital. **45**
Figure 5.2 : The collected raw data, the arranged data and the analyses they were used in. **46**
Figure 5.3 : Selected Example: The motion map of Task 1 of P3 and the visibility map of Pars Hospital ground floor overlaid. Examples of the point V values on the route are shown. **49**
Figure A.1 : Route maps of P1. .... **85**
Figure A.2 : Route maps of P2. .... **87**
Figure A.3 : Route maps of P3. .... **89**

A METHODOLOGY FOR ASSESSMENT OF SPATIAL PERFORMANCE IN HOSPITAL BUILDINGS THROUGH IMMERSIVE VIRTUAL REALITY AND BEHAVIOURAL SEQUENCE ANALYSIS

SUMMARY

The spatial and wayfinding performance of a building are key elements that affect how well a building functions. They play a crucial role in buildings' overall functionality, particularly in complex buildings like hospitals that contain interconnected units. Time loss and detrimental impact on user well-being arise when a building's wayfinding performance is insufficient. Understanding and incorporating wayfinding behaviour into the design process is essential for designing human-centred buildings. This study examines wayfinding behaviour in detail to comprehend the dynamics behind wayfinding thinking and its relationship with spatial characteristics. The thesis questions (1) the effects of spatial plan configuration on wayfinding behaviour, (2) the relationship between re-occurring behaviours during the wayfinding process depending on spatial characteristics, (3) the extent and level of detail in behavioural data that can be gathered about human wayfinding through virtual reality (VR). For this purpose, this study utilises Behavioural Sequence Analysis (BSA) and Space Syntax analysis to understand the relationship between wayfinding behaviours and spatial layout in hospital buildings through Immersive Virtual Reality (iVR).

BSA investigates behavioural sequences and identifies behavioural transition patterns. Space syntax analysis measures spatial features quantitatively. This study links wayfinding behaviours with spatial features and each other by employing these two analyses. An experiment was designed employing iVR since it delivers environments that are remarkably close to reality and brings together conditions that cannot be brought together in real life. The experiment aimed to observe and record user behaviour during the wayfinding process. Hospital buildings with three different plan layouts based on the centrality of the spatial configuration were selected and space syntax analysis was used to create visibility maps of these buildings, which were subsequently utilised for final assessments.

Virtual environments (VE) were prepared by creating partial 3D models of the buildings with the architectural information collected for the experiment. Wayfinding tasks with various target locations were given to the participants in each hospital building during the iVR experiment to gather behavioural data. The experiment was recorded and the routes of the participants were mapped on floor plans. After analysing experimental records, the relevant data was extracted and arranged for four types of analyses: (1) BSA, (2) visibility and behavioural relationship analysis, (3) behavioural frequency analysis and (4) average speed analysis. These four analyses investigated how wayfinding behaviours varied by space, how often they occurred, which trends emerged in behavioural sequence transitions, and how quickly participants moved through each building.

Following an evaluation of each analysis, a holistic approach was applied to these findings questioning the reliability of each analysis. The findings showed that each

type of plan layout directs the users to engage in different behavioural groups during the wayfinding process. The recurring transitions among the behaviours revealed the wayfinding thinking of participants for each hospital building. The centralised plan layout directs the users to a fast-paced decision-making process, whereas the semi-centralised leads to a slow and efficient one. On the other hand, the findings demonstrate that there is a directly proportional relationship between visibility and wayfinding performance. Integrated analysis results show that the semi-centralised plan layout with high visibility offers the most comfortable and efficient wayfinding experience comparatively and the decentralised plan layout with low visibility offers the worst. The results can be used to create human-centred buildings by employing the spatial characteristics that provide the most effective wayfinding outcomes, particularly in the early design stages. Furthermore, the spatial-behavioural connections detailed in this research can be used as a guide depending on the building typology and the desired user experience.

KAPSAYICI SANAL GERÇEKLİK VE DAVRANIŞSAL DİZİ ANALİZİ YOLUYLA HASTANE BİNALARINDA MEKANSAL PERFORMANSIN DEĞERLENDİRİLMESİNE YÖNELİK BİR METODOLOJİ

ÖZET

Bir yapının mekansal ve yön bulma performansları, onun ne kadar verimli çalıştığını etkileyen temel unsurlardandır. Özellikle hastaneler gibi birbirine bağlı birimler içeren karmaşık binaların işlevselliğinde çok önemli bir rol oynarlar. Mekansal performans, mekansal düzen, iç tasarım, iklim ve aydınlatma koşulları gibi birden fazla fonksiyonel veya ergonomik faktör tarafından belirlenip, bir mekânın kullanılabilirliğini temsil eder (Werner ve Schindler, 2004). Mekansal düzen, yani bir yapının kat planının düzeni, yön bulma performansında kritik bir rol oynar ve sosyal etkilere sahiptir (Hillier ve Hanson, 1984). Yön bulma, kullanıcıların bir yerden, hedef noktasına ulaşırken yaşadıkları süreçtir. Bir binanın yön bulma performansı yetersiz olduğunda zaman kaybı ve kullanıcı üzerinde olumsuz etkiler ortaya çıkar. Yön bulma davranışını anlamak ve tasarım sürecine dahil etmek, insan odaklı binaların tasarlanmasını sağlar. Yön bulmayı etkileyen 2 ana faktör olduğu varsayılabilir: insan faktörleri ve çevresel faktörler. İnsan faktörleri şu şekilde gruplandırılabilir: yön bulma bilişi; yön bulma davranışı, bireysel farklılıklar ve grup farklılıkları (Jamshidi ve diğ, 2020). Weisman (1981), yapılı çevrelerde yön bulma performansını etkileyen dört adet çevresel değişken tanımlamıştır: görsel erişim; mimari farklılaşma derecesi, işaretlerin kullanımı ve mekansal yerleşim. Bu çalışma temel olarak bir insan faktörü olan yön bulma davranışına ve çevresel faktörler olan görsel erişim ve mekansal yerleşime odaklanmaktadır.

Yön bulma üzerine çalışmalar genellikle daha üst bir bakış açısıyla davranışsal detayları ve davranışlar arasındaki ilişkileri göz ardı etmektedir. Ayrıntılı ve sıralı davranışsal verilerin Kapsayıcı Sanal Gerçeklik (Immersive Virtual Reality: iVR) aracılığıyla toplanması mümkündür. Bu çalışma, insan yön bulma davranışını daha iyi anlamak için hastane binalarındaki yön bulma davranışını iVR aracılığıyla mekânsal özelliklerle ilişkilendirerek detaylı bir şekilde incelemektedir. Bu şekilde yön bulma sürecinde düşünme biçiminin ardındaki dinamikleri ve mekansal özelliklerle ilişkisini ortaya koymayı amaçlamaktadır. Araştırma soruları, (1) mekansal plan yerleşiminin yön bulma davranışı üzerindeki etkileri, (2) mekansal özelliklere bağlı olarak yön bulma süreci sırasında tekrarlayan davranışlar arasındaki ilişki, (3) sanal gerçeklik (Virtual Reality: VR) aracılığıyla yön bulma süreci hakkında elde edilebilecek davranışsal verilerin detay seviyesi olarak sıralanabilir. Hastane binalarında yön bulma davranışları ile mekânsal yerleşim arasındaki ilişki iVR aracılığıyla incelenerek Davranış Dizisi Analizi (Behavioural Sequence Analysis: BSA) ve Mekan Dizimi Analizinden yararlanılmaktadır.

BSA, davranış ve olay zincirlerinin zaman içinde birbirleriyle bağlantı şekillerini araştırmak için kullanılan bir yöntemdir (Marano ve diğ, 2020). Her bir davranışın veya olayın bağımsız olarak değil, birbirleriyle ve bağlamla ilişkili olarak analiz

edilmesini sağlarken, aralarındaki geçişler hakkında bilgi verir. Davranış geçişleri arasındaki tekrarlar, bu tekrarların sıklıkları ve davranışların sıklıklarını değerlendirerek kişinin düşünme şeklini irdeler. BSA öncelikle kişinin gözlemlenmesi ile başlar ve gözlemlenen her davranış karşılık gelen zaman verisi ile sıralı olarak listelenir. Bu gözlem sahada eş zamanlı gerçekleştirilebileceği gibi video kayıtlarından geriye dönük şekilde de yapılabilir. Bu çalışmada gözlem, video kayıtları incelenerek geriye dönük olarak gerçekleştirilmiş ve yön bulma sürecinde gözlemlenen davranışlar ele alınmıştır.

Mekan Dizimi Analizi, mekansal ve sosyal dinamikler arasındaki ilişkileri anlamaya ve nicel olarak modellemeye yarayan birden çok analizi kapsayan bir yöntemdir (Lee ve Ostwald, 2024). Bu analiz yön bulma literatüründe sıkça kullanılan bir yöntemdir. Bu çalışmada Mekan Dizimi analizlerinden biri olan görünürlük analizi kullanılarak, yapıların mekansal özellikleri nicel olarak ölçülmüştür. Görünürlük analizi, bir noktanın erişilebilir tüm konumlara bağlı olarak olarak görsel erişimini inceler ve bunu bir kattaki tüm noktalara uygulayarak kapsamlı bir görünürlük haritası oluşturur.

Bu çalışmada yön bulma davranışları, BSA ve Mekan Dizimi Analizi kullanılarak mekansal özelliklerle ve birbirleriyle ilişkilendirilmiştir. Yön bulma işlemi sırasında kullanıcı davranışını gözlemlemek ve kaydetmek amacıyla bir deney hazırlandı. Gerçeğe yakın ortamlar sunması ve gerçek hayatta bir araya getirilemeyecek koşulları bir araya getirmesi nedeniyle bu deney iVR üzerinde gerçekleştirmek üzere kurgulandı. Bunun için bir VR gözlüğü ve iki adet kumanda aygıtı kullanıldı. Sanal gerçeklik gözlüğü, sanal ortamda (Virtual Environment: VE) 360 derece görüntü sağlayarak ve fiziksel çevre ile bağlantıyı keserek kapsayıcı bir deneyim sunmakta ve kontrol aygıtları ise VE ile etkileşimi sağlamaktadır.

Deney için mekansal yerleşimin merkezilik seviyesine dayalı olarak üç farklı plan düzenine sahip, gerçek hayatta inşa edilmiş hastane binaları araştırıldı. İnternet ortamında plan düzenine göre hastaneler filtrelendikten sonra, bunlar arasından deneyde kullanılmak üzere, zemin alanı birbirleriyle yakın olan ve ulaşılabilen mimari verileri okunaklı, ölçekli ve sayı olarak yeterli olan üç hastane yapısı seçildi. İlk olarak hastane yapılarına ait imaj formatında olan mimari veriler, iki boyutlu çizgisel formatta çizildi ve ardından üç boyutlu olarak modellendi. Deneyin katılımcılar için yorucu olmaması ve zaman kısıtı sebepleri ile hastane yapılarının üç boyutlu modelleri, yalnızca ilk iki katı kapsayacak şekilde, kısmi üç boyutlu modeller olarak hazırlandı. Diğer yandan, iki boyutlu çizimler, Mekan Dizimi analizi aracılığıyla görünürlük haritalarının oluşturulması için kullanıldı. Bu haritalar ise daha sonra çalışmanın analiz kısmında değerlendirildi. iVR deneyi için gerekli olan VE'lerin hazırlanması için üç boyutlu modeller, VR gözlüğü üzerindeki programa aktarıldı. Bir yandan da deney süreci için her hastane yapısında katılımcılara atanacak üç yön bulma görevi oluşturuldu. Bu görevlerin bazıları tek bir katta dolaşımı gerektirirken, bazıları da merdiven veya rampa gibi sirkülasyon birimlerinin kullanımını sağlamak için her iki katta da dolaşımı gerektirmektedir. Her görev, yapıların sirkülasyon alanlarında farklı bölgeleri kullandırmak üzere tasarlandı. Deney üç katılımcı ile gerçekleştirildi ve kişilerin VR konusunda deneyim seviyelerinin deney sonuçlarını etkilememesi için katılımcılara deney öncesi kısa bir eğitim verildi. Her katılımcı üç hastane yapısında üçer yön bulma görevi tamamladı. Katılımcılara görevlerin başında herhangi bir yol tarifi yapılmadı ve yalnızca VE'lerde bulunan yön tabelalarını veya danışma masalarını kullanmaları istendi. Deney süreci boyunca kişilerin VR gözlüğünde gördükleri görüntü kayıt altına alındı ve izledikleri rotalar, kat planları üzerine işlendi.

Deney sonrasında davranışsal verilerin toplanması için video kayıtları incelendi. Katılımcıların yön bulma süreçlerinde gösterdiği davranışlar bu videolara bakılarak zaman verileri ile birlikte derlendi. Bu çalışmada veriler dört farklı şekilde analiz edildi. Bu analizler şu şekilde sıralanabilir: (1) BSA; (2) görünürlük ve davranışsal ilişki analizi; (3) davranışsal sıklık analizi; (4) ortalama hız analizi. Videolardan derlenen ve rota haritalarından elde edilen veriler bu dört analiz için ayrı ayrı düzenlendi. BSA için her göreve ait davranış sekansı tabloları oluşturuldu. Bu analiz sayesinde davranışlar arası geçişler ve bu geçişlerin ortaya koyduğu düşünme biçimleri irdelendi. 2 numaralı analiz için görünürlük haritaları kullanılarak katılımcıların görev boyunca davranışları ve bu davranışların gözlemlendiği konumlara ait görünürlük değerleri listelendi. Bu şekilde, görünürlük seviyesinin katılımcıları hangi davranışlara yönlendirdiği incelendi. 3 numaralı analiz, her hastane yapısında en sık gözlemlenen davranışları listeleyerek mekansal plan yerleşiminin yön bulma davranışı üzerindeki etkisini ortaya çıkarmayı amaçlamaktadır. 4 numaralı analiz ise, katılımcıların VR ortamındaki hızlarını karşılaştırmalı olarak yapı bağlamında incelemektedir. En son ise bu analizlerden elde edilen bulgular, her bir analizin güvenilirliğini sorgulayan bütüncül bir yaklaşım ile değerlendirilmiştir.

Analiz sonuçları, farklı mekansal plan yerleşimlerinin, yön bulma sürecinde insanları farklı davranış gruplarına yönlendirdiğini göstermektedir. Davranışlar arasındaki geçişlerin analizi, katılımcıların düşünce süreçlerini ortaya çıkarmış ve bu analiz, her hastanenin plan düzeniyle ilişkilendirilmiştir. Bütüncül değerlendirme sonuçlarına göre, merkezi olmayan kat planı düzeni, katılımcıların sık duraklamasına ve tabela kullanımına yol açmıştır. Merkezi kat planı düzeni, katılımcıların hareket halindeyken hızlı kararlar almasına ve sık duraklamalara yol açmıştır. Yarı merkezi kat planı düzeni ise, katılımcıları daha fazla yürümeye ve yavaş bir karar verme sürecine yönlendirmiştir. Belirli görünürlük değerlerinde gözlenen tekrar eden davranışlar, mekansal özellikler ile insanın yön bulma davranışı arasındaki ilişkiyi ortaya çıkarmıştır. Sonuçlar, yüksek görünürlük seviyelerinde katılımcıların daha fazla yürüdüğünü, anlık duraklamalar yaptığını ve daha kararlı olduklarını gösterdi. Düşük görünürlük seviyelerinde ise katılımcılar daha sık etraflarını incelemek için duraklamış, tabelaları kullanmış, yönlerini değiştirmiş ve daha kararsız bir tutum sergilemiştir. Özet olarak, yarı merkezi plan düzeni en verimli yön bulma performansını sunarken, merkezi ve merkezi olmayan kat planı düzenleri, yön bulma açısından nispeten daha verimsiz bir deneyim sunmaktadır.

VR yoluyla katılımcının kafa hareketlerini ve bakış açılarını takip edebilme yeteneği, katılımcıların yön bulma süreçleri boyunca davranışları hakkında ayrıntılı veriler elde edilmesini sağladı. Bu sayede, katılımcının duraklama sürecinde gösterdiği davranışlar ayırt edilebilmiş ve duraklama sebepleri sınıflandırılmıştır. Gerçek hayatta gözlem sırasında gözden kaçabilecek anlık yönelme ve kafa dönme hareketleri VR kaydı sayesinde gözlemlenebilmiş ve davranış sekanslarına dahil edilmiştir. Bu ayrıntılı davranışsal veriler, kişisel yorumdan uzak olup bu veriler arasındaki geçişlerin incelenmesi, yön bulma sırasındaki gömülü düşünce sürecini ortaya çıkmasını sağlamıştır.

Bu çalışma, yön bulma davranışının detaylı incelenerek mekansal özelliklerle ilişkilendirilmesi ile literatürdeki boşluğu doldurmayı amaçlamaktadır. Yön bulma çalışmalarına özellikle BSA'yı entegre eden yaklaşımı özgün değer taşımaktadır. Buna ek olarak, Mekan Dizimi Analizi, BSA ve iVR'yi bir araya getiren metodolojisi orijinal niteliktedir. Ayrıca, bütüncül analiz yaklaşımı, bulguların geçerliliğini kendi aralarında değerlendirdiği için farklıdır. Dört farklı analiz ayrı ayrı gerçekleştirilmiş

ve ardından doğrulama için bütünsel olarak değerlendirilmiştir. Sonuçlar, özellikle erken tasarım aşamalarında en etkili yön bulma sonuçlarını sağlayan plan düzeni tipolojisini kullanarak insan merkezli yapılar oluşturmak için kullanılabilir. Ayrıca, bu çalışmanın metodolojisi kullanılarak kullanıcı deneyimini iyileştirmek için mevcut binalardaki kullanıcı davranışları analiz edilerek doğru tasarım yaklaşımlarında bulunulabilir. Erken tasarım aşamasında en uygun plan şemasının kullanılmasının yanı sıra, bu araştırmada detaylandırılan mekânsal-davranışsal bağlantılar, bina tipolojisine ve arzu edilen kullanıcı deneyimine bağlı olarak bir rehber olarak kullanılabilir.

Kullanıcıların yön bulma sürecinde kullandıkları bilgi türünü ve ilkelerini tanımlayan yön bulma stratejileri veya stres faktörü bu çalışmanın kapsamı dışındadır. Gelecek çalışmalar, BSA'yı kullanarak stresin izlerini inceleyip kapsamı genişletebilir ve insanın yön bulmasına ilişkin daha kapsamlı bir yorum elde edebilir. Görünürlük, bu çalışmada nicel olarak analiz edilen tek mekansal unsurdur. Mekansal unsurların yön bulma üzerindeki etkilerini ölçmek için renk, şeffaflık veya tavan yüksekliği gibi diğer özellikler de nicel olarak çalışmanın kapsamına dahil edilebilir. Yön bulma performansını etkileyen bir diğer önemli faktör, kalabalık etkileşimidir. Bu çalışma, donanım ve zaman kısıtlamaları nedeniyle deneye kalabalık etkileşimini dahil etmemiştir. Gelecek çalışmalar, VE'lere kalabalık simülasyonlarını dahil edebilir ve binaların yön bulma performansı üzerindeki etkisini değerlendirebilir.

Özetle bu çalışma, kendine özgü metodolojisi ile yön bulma literatürüne katkıda bulunmuştur. Bulgular, kat planı düzeninin yön bulma davranışı üzerindeki etkisi hakkında önemli katkılar sağlamaktadır. Bulguların pratikte uygulanması, yön bulma sürecindeki verimsizlikten kaynaklanan zaman kaybını azaltabilir.

1. INTRODUCTION

Hospital buildings are complex buildings consisting of interconnected units. Insufficient architectural planning in these buildings can lead to poor wayfinding experience that causes stress and time loss for users. Within the realm of hospital infrastructure, the significance of plan layout design transcends mere architectural aesthetics; it serves as a fundamental determinant of navigation ease, patient experience, and operational efficiency. The plan layout organisation includes an effective spatial arrangement of corridors, departments, and amenities within a building that shapes the wayfinding experience of the users. Wayfinding is the ability to find a way to a particular destination or location in an expedient manner and to recognise the target when approaching it (Chen et al., 2009). When it comes to wayfinding, two primary factors come into play: human factors and environmental factors. There are three main human factors: wayfinding cognition, wayfinding behaviour, and individual/group differences (Jamshidi et al., 2020). In his early study of environmental factors, Weisman (1981) classified four sets of variables that impact wayfinding performance within built environments: visual access; the degree of architectural differentiation; the use of signs and room numbers to provide identification or directional information; and plan configuration. This study particularly focuses on the wayfinding behaviour as a human factor, and visual access and plan configuration as environmental factors.

If we take into account the fact that patients spend a significant amount of time in hospitals searching for directions, walking between units, and waiting for their appointments, while healthcare workers use the same circulation routes every day, we can see the importance of spatial planning for multiple stakeholders more clearly. It is proven that patients asking staff for directions causes significant time and financial loss annually (Peponis et al., 1990). On the other hand, it is stated that difficulty in wayfinding causes emotional problems such as frustration and anxiety which affect wayfinding behaviour and wayfinding performance. (Deng et al., 2023). Literature on wayfinding covers various topics such as wayfinding cognition, strategies, signage,

and spatial organisation at different scales, from urban to building scale. Most of these studies involve experiments and observations in either real-life or virtual environments (VE) to assess wayfinding performance.

On the other hand, spatial performance is often assessed to better understand the relation between wayfinding performance and spatial configuration. The most common method used to measure spatial performance is space syntax analysis which consists of a set of analytical techniques for the calculation of spatial inter-relationships in the built environment (Yamu et al., 2021). The utilisation of space syntax analysis provides detailed insights into the impact of spatial elements on wayfinding performance. The spatial performance assessment is important, especially in the early design stages. Soliman (2017) defines the design process of architectural practice in four stages which are (1) the programming phase, (2) the schematic design phase, (3) the design development phase and (4) the construction documents phase. The methodology of this study is not limited to the measurement of wayfinding performance but also aims to provide a base that designers can use to experience their design ideas during the schematic design process.

Virtual Reality (VR) has become a common tool in architectural studies, especially in wayfinding to simulate multiple real-world environments and assess navigational behaviours and interventions. It has opened up new avenues for conducting experiments, wherein scenarios that are otherwise difficult or impossible to replicate in real life can be simulated. This approach has significantly expanded the scope of research and development and has proven to be highly effective in optimising the outcomes. Although human behaviour differs between real life and VEs, virtual testing benefits ecological validity, experimental control, and behavioural response tracking (Diersch & Wolbers, 2019). VR has been used as a tool for wayfinding performance assessment in this study. It hasn't been evaluated as a main topic and its effects on wayfinding haven't been examined.

Wayfinding literature often overlooks important details and relationships between behaviours, taking a more superior perspective. Collecting detailed and sequential behavioural data with the help of immersive Virtual Reality (iVR) experiments is possible. On the other hand, there is a gap in the literature where wayfinding gets associated with spatial characteristics more in the means of human behaviour. To understand human wayfinding better, this study examines wayfinding behaviour in

detail by associating it with spatial characteristics in hospital buildings through iVR. This research questions the following:

- The effects of spatial plan configuration on wayfinding behaviour.
- The relationship between re-occurring behaviours during the wayfinding process depending on spatial characteristics.
- The extent and level of detail in behavioural data that can be gathered about human wayfinding through VR.

The scope of the study as seen in Figure 1.1, is limited to examining wayfinding behaviour in hospital buildings by focusing on spatial performance through iVR. This study does not consider other factors that affect wayfinding such as signage system, crowd interaction, emotional situation and cultural factors.

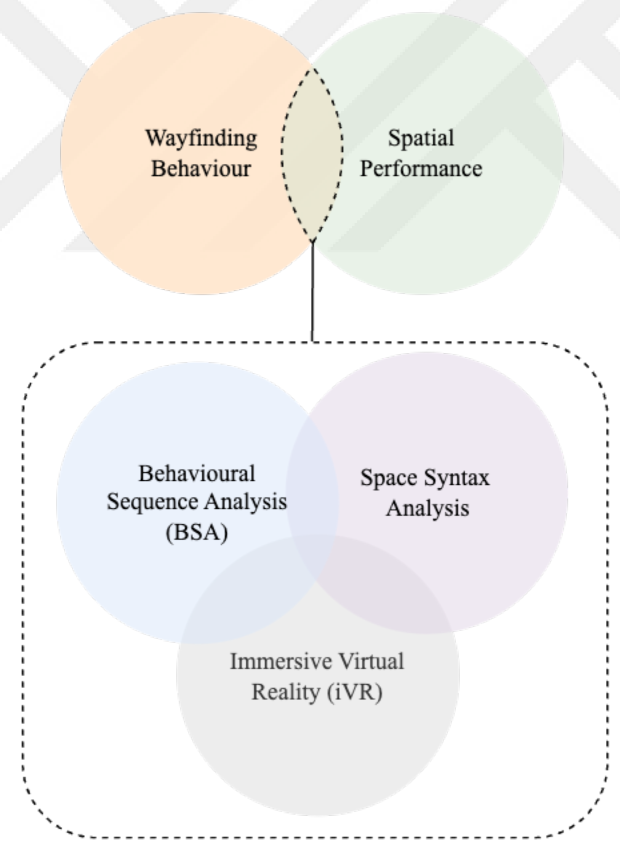


Figure 1.1: The scope of the study.

This study investigates wayfinding behaviour in hospital buildings by focusing on spatial performance through an iVR experiment. The research method as seen in quantitatively correlates human wayfinding behaviours with space syntax analysis and assesses their interrelations based on spatial performance. The common plan schemes

in the literature are examined and built hospital structures are selected accordingly. To conduct the experiment more efficiently and due to time constraints, only the first two floors of these buildings are considered. These buildings are modelled in 3D and transferred to the VR software. Different wayfinding scenarios are created to facilitate the use of different parts of the building. With a VR headset, an experiment is conducted and the process is recorded. Data obtained from experimental records are arranged according to specific outlines for different analyses. The study utilises Behavioural Sequence Analysis (BSA) to analyse behaviours in detail and associate spatial performance data together to reach a holistic conclusion. According to the analysis results, it is aimed to find the most efficient plan layout typology by determining the pros and cons of each and what behaviours it directs people to.

2. WAYFINDING AND SPATIAL PERFORMANCE IN ARCHITECTURAL DESIGN PROCESS

Wayfinding is a broadly studied topic in architecture and social sciences. It was first named in the book Image of the City by Kevin Lynch as the process by which people perceive, understand, and navigate through the physical environment (1960). It can be assumed that 2 main factors affect wayfinding: human factors and environmental factors. Human factors can be grouped as follows: wayfinding cognition; wayfinding behaviour; and individual and group differences (Jamshidi et al., 2020) In an early categorization of environmental factors, Weisman (1981) identified four classes of environmental variables that influence wayfinding performance within built environments: visual access; the degree of architectural differentiation; the use of signs and room numbers to provide identification or directional information; and plan configuration. Wayfinding studies are predominantly conducted in hospital buildings (Lee & Ostwald, 2024) due to their complexity and the critical nature of health-related activities within them. This study mainly focuses on a human factor: wayfinding behaviour and environmental factors which shape spatial performance such as visual access and plan configuration in hospital buildings.

2.1 Spatial Layout and Performance

Spatial performance indicates the usability of a space which is determined by multiple functional or ergonomic factors such as spatial layout, interior design, climate, and lighting conditions (Werner & Schindler, 2004). Spatial layout, specifically the layout of a building's floor plan, plays a crucial role in wayfinding performance and has social impacts (Hillier & Hanson, 1984). One of the core claims of space syntax theory is that space layout affects human movement (Aydoğan & Şalgamcıoğlu, 2015). In an early study on this relationship, Doğu and Erkip (2000) examined the spatial configuration of a shopping mall and associated it with user experience and behaviour. Baskaya et al. (2004) examined the sketches of wayfinders and revealed that asymmetrical and consistent plan layouts perform better in wayfinding than

symmetrical and regular ones. Cheng and Newcombe (2005) discovered that wayfinding behaviour is influenced by spatial geometry information along with multiple human factors. Aydoğan and Şalgamcıoğlu (2015) investigated whether people's decisions are influenced by the spatial layout of shopping malls and what type of dominating effects these layouts have on user mobility. Lacanna et al. (2018) observed users of a real hospital building on site and examined where in the layout most of the interactions among users occur and the effects on the well-being of the users. Kuliga et al. (2019) conducted a real-world experiment to evaluate participants' multi-level wayfinding performance associated with the analysis of spatial characteristics of one of the most disorienting buildings. Schaumann et al. (2020) observed user interactions on the field to improve the ward layout of a hospital thus reducing staff–visitor interactions and visitor density. Aksoy et al. (2020) examined the relationship between wayfinding decisions and space layout by releasing their subjects in real hospital buildings while tracking them with a head-mounted camera. They revealed that the spaces with high accessibility increase the wayfinding behaviour of the users positively. Li et al.(2020) observed user interaction in shelter hospitals and revealed that even in the most private and isolated parts, the spatial configuration impacts patients' well-being. Nicoletta et al. (2022) compared two different spatial settings for birth environments in hospitals and assessed user experience as well as wayfinding performance. They found significant differences and some connections in behaviours between the two configurations emphasising spatial characteristics impact human well-being. Liou et al. (2024) examined the spaces with different levels of publicity through the utilisation of space syntax analysis. They assessed the navigational experience of the users and found that each space has an optimum publicity value according to its function. Jideofor et al. (2024) compared hospital buildings with different complexity levels and revealed that more complex planning leads to more disorientation rate.

In this study spatial layout is examined as the spatial performance parameter. The optimal plan schemes for improved navigation are illustrated by Weisman (1981) (Figure 2.1), which also shows the frequently used space layouts of today. Building morphologies and space layouts have evolved, but common plan schemes that have existed for a while and whose significance has been established have continued to be in use.

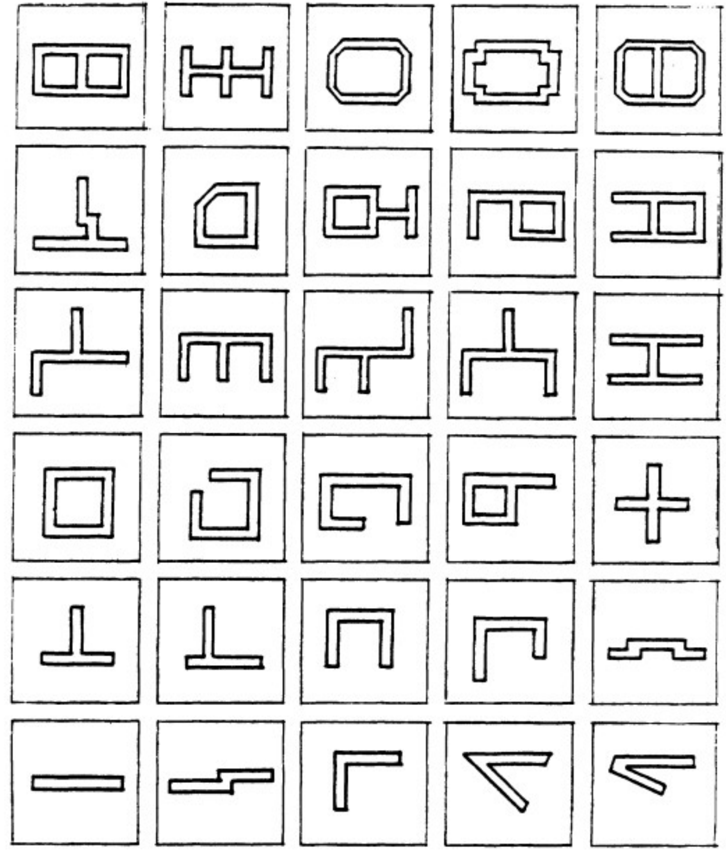


Figure 2.1: Weisman's drawing of ideal plan schemes for wayfinding (1981).

These can be divided into three broad categories based on their circulation patterns: (1) decentralised, (2) semi-centralised, and (3) centralised layouts (Figure 2.2). The unit arrangement is shaped by the circulation patterns, which form the basis of this layout classification. The decentralised layout consists of irregularly distributed and sized corridors while the semi-centralised layout has orderly and consistent corridors within itself. The centralised layout has a main area with connected consistent corridors. This study used this floor plan layout classification and assessed their wayfinding performance. The next chapters explain the space syntax theory and the literature on wayfinding with space syntax analysis.

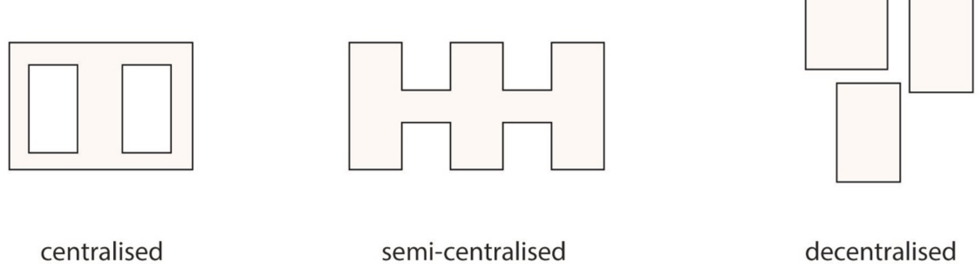


Figure 2.2: Space layout categorisation chosen as a part of the methodology.

2.2 Space Syntax Theory

Human movements and behaviours give the space an identity that can direct the arrangement of the space. To get a better understanding of these complex relations and to measure them, Hillier and his colleagues combined tangible and intangible factors under the term of space syntax with a theory and its method in their research starting from 1970. Their contribution to understanding the built environment through an operational method to analyse spatial relationships between built objects allowed for new refined knowledge about the relationship between space and society.

Space syntax analysis consists of a set of methods, which use topology and graph theory mathematics, and is a quantitative method for understanding and modelling the relationships between space and social patterns (Lee & Ostwald, 2024). These methods appear as analyses that can be made by various space syntax tools that enable numerical measurement over different concepts and can be used in combination with each other or alone. Space syntax tools help architects to measure how well their design works in post-occupancy considering social behaviour from a spatial point of view, especially in early design phases. Some of the analyses that can be made within space syntax tools can be listed as follows: visibility, centrality, and visual integration. The visibility graph provides a comprehensive analysis of the visual access of an entire floor regarding all accessible locations. The higher the visibility of a location, the better its visual access is (Li et al., 2012). Examples of the visibility maps can be seen in Figure 2.3.

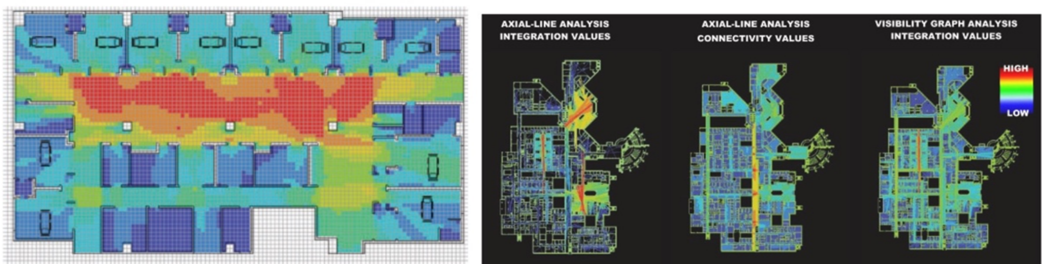


Figure 2.3: Example of space syntax analysis from literature (Hadi and Zimring, 2016; Pouyan et al., 2021).

Turner et al.(2001) proposed the methodology for visibility graph analysis used today. Polygon representations of the space observable from a specific point in space which are called isovists are the base of the visibility graph analysis. They improved the

isovists by applying mathematical calculations and with the help of intermediate outputs and isovist fields, the visibility graph analysis was created (Figure 2.4).

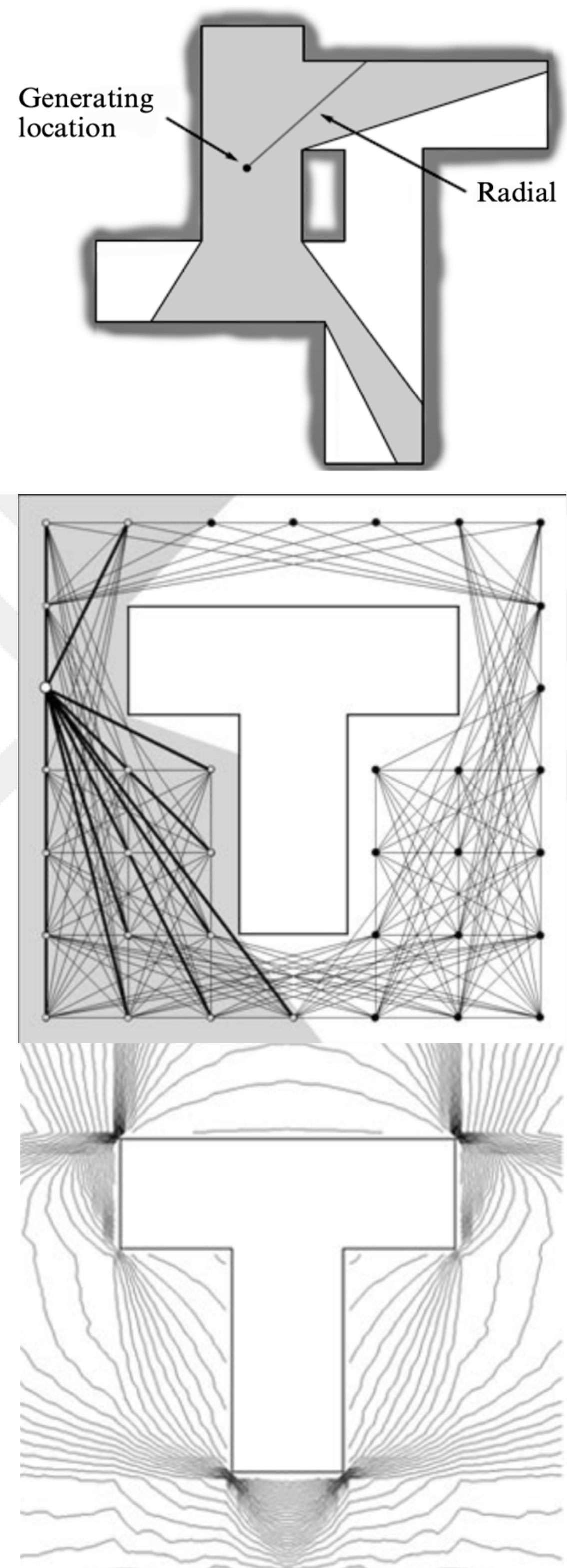


Figure 2.4: Example of an isovist polygon on top, the pattern of connections in the middle and isovist field at bottom (Turner et al., 2001).

Space syntax analysis which consists of a set of analytical techniques for the calculation of spatial inter-relationships in the built environment (Yamu et al., 2021) has been widely used in wayfinding studies to get a better understanding of the space and how people interact with it. Min et al. (2010) evaluated the layouts of commercial facilities, they discovered that the more integrated facility based on space syntax analysis, was easier for wayfinding. Hadi and Zimring (2016) analysed Intensive Care Units (ICUs) to understand the associations between design features of space layout and visibility parameters. They discovered that corridor width and shape characteristics are positively correlated with visibility. The study by Omer and Goldblatt (2016) analyses movement patterns in buildings while using space syntax analysis, and compares two shopping malls with different plan layouts, revealing how spatial configuration influences movement flow patterns. Natapov et al.(2019) emphasised three circulation types, linear, curved, and grid-based, based on geometric structure and used space syntax theory to assess their spatial performance. They found wayfinding difficult, with linear circulation being the easiest, grid-based the most difficult, and curved circulation intermediate. Pouyan et al.(2021) examined user wayfinding performance and strategies in a real hospital environment with the help of space syntax theories and found that the hospital's circulation patterns significantly affect the users' wayfinding strategies. They emphasised that the sense of direction is higher in visible destinations. Chen et al.(2021) associated space syntax analyses with outpatient behaviour in a real hospital environment thus suggesting that a symmetric tree-branch structure rather than a circular one in a hospital building has better wayfinding performance. The next two chapters outline suitable methods for analysing wayfinding behaviour.

2.3 Computation and Evaluation Methods

The assessment of wayfinding performance on a building scale has various methodologies. Observation is the key method for human wayfinding studies. It can be carried out in the form of observation of real-time data in the field or observation of scenarios designed through the experimental environment. The experimental observation process can be done in real life or VEs. The experimental scenarios can include tasks with destination points or free roaming in the space. The experimental process can be digitally video recorded and used in retrospective analysis. In addition,

task completion times, maps of the routes followed, think-aloud data and survey and interview data are among the data that can be gathered. Santa Barbara Sense of Direction Test is a self-report which assesses the navigational skills commonly utilised in wayfinding studies. It consists of 15 questions graded on a scale of 1-7 (Carbonell-Carrera et al., 2020). With this report, participants' self-reported performances and experimental results can be compared, or participants can be selected based on this test. This study doesn't evaluate individual differences therefore

The collected data can be interpreted using various analysis methods. This chapter explains two similar analysis methods, protocol analysis and BSA. Protocol analysis is commonly utilised in wayfinding studies meanwhile BSA is generally used in fields other than architecture. In the rest of this section, these two methods are explained and the reasons for choosing BSA instead of protocol analysis as the main analysis method used in the study are explained.

2.3.1 Protocol Analysis

Protocol analysis, based on observation to reveal the dynamics behind the way of thinking in various disciplines, can be considered a similar method to the BSA. It is commonly used to analyse the design thinking process and the strategies in architectural and engineering studies. It consists of a set of analyses based on verbal data, design sketches, and video recordings of the design process. Protocol analysis typically involves analysing verbal data collected from think-aloud processes or reports, as well as actions taken during the design process and collaborative behaviours (Suwa & Tversky, 1997; Gül, 2009; Prats et al., 2009; Kim & Lee, 2016; Wang et al., 2024). In protocol analysis, activities during a design task are recorded, which are subsequently transcribed, reviewed and analysed to identify recurring patterns. According to Sarkar and Chakrabarti (2013), protocol analysis consists of three stages: design task process and data collection; transcript preparation, coding and analysis. The actions are categorised based on their impact field and then coded defining the transcription process. An example of this categorisation can be seen in Figure 2.5.

Level	Content	Description
Physical	D-action	Drawing and looking at the concurrent depictions
	L-action	Looking at previous depictions
	M-action	Other physical actions
Perceptual	Emergent spaces	Perceiving the implicit spaces between depictions
	Visual features	Perceiving shapes, lengths and textures of depictions
	Spatial relationship	Perceiving proximity, alignment, intersection between depictions
Functional	F-action	Assigning non-visual information or meanings to visual depictions or perceptions
Conceptual	Setup of goals	The intention designers want to achieve
	Make decisions	Deciding the positions, arrangements and design requirements

Figure 2.5: Example of protocol analysis coding categories (Tang & Gero,2000).

Protocol analysis has also been utilised in wayfinding literature. Ahmed et al., (2020) examined the efficiency of various spatial layouts of hospital buildings through verbal data utilised in protocol analysis supported by questionnaires. Iftikhar and Luximon (2022) assessed the efficiency of the information provided by navigators in complex environments through an experiment where protocol analysis was applied. Jamshidi and Pati (2023) investigated which environmental factors affect wayfinding through protocol analysis. The next chapter presents a similar approach, BSA, and explains the reason for the choice of BSA.

2.3.2 Behavioural Sequence Analysis

BSA is a method for investigating how chains of behaviours and events are linked over time. (Marano et al., 2020). It allows the analysis of each behaviour or event not independently but in relation to each other and the context while providing insights into transitions among them. It is a method commonly used in ethology (Asher et al., 2009; Bels et al., 2022) or in criminology (Beune et al., 2010; Marano et al., 2017) but not common in architectural studies. It is important to understand the chains of behaviours and how the architectural aspects of a space affect these occurrences to design human-centred buildings.

BSA and protocol analysis are two methods that are closely related and cannot be distinguished sharply from each other. This study examines physical wayfinding behaviour rather than design processes, without analysing verbal or collaborative interactions thus BSA is incorporated into the methodology. It was used to understand

human wayfinding physical behaviour in more detail and to analyse its dependence on environmental factors.

BSA starts with observation on-site or from video recordings and can be long-term or short-term. The observation involves listing the subject's every behaviour in sequential order along with the corresponding time information. The behaviours or actions are grouped to be coded. This process is similar to protocol analysis' and is called transcription (Figure 2.6). The behaviours can be short or long-term actions. Short-term behaviours include actions like walking or sleeping, while long-term behaviours include living in a certain place or experiencing trauma. Transcription provides a series of codes representing behaviours to be analysed sequentially for each observation event. The outputs of the analysis can be listed as follows: number of unique behaviours observed, number of total behaviours observed, number of unique behavioural transitions observed, number of total behavioural transitions observed, and the frequency of each behaviour in sequences.

A flowchart that shows a network of transitions between observed behaviours and provides more details on the observed likelihood of each transition is one of the analysis's outputs (Käosaar et al., 2023). These transitions and repetitions may reveal behavioural patterns that help us understand the thought process. Existing literature on wayfinding behavior mostly approaches behavioral data from a superior perspective overlooking the details and relations between the behaviors. With the help of iVR experiments, it is possible to collect more detailed behavioural data such as turn points, pause, and eye lock time and analyse them more deeply. On the other hand, there is a gap in the literature where wayfinding gets associated with spatial characteristics more in the means of human behaviour. To understand human wayfinding better, this study examines wayfinding behaviour in detail by associating it with spatial characteristics in hospital buildings.

Behaviour	Frequency
Head-shake head	66
Eyes-looks down	58
Head-nod head	53
Face-furrow eyebrows (pull brows down)	44
Face-raised eyebrows	39
Mouth-pressing lips together	22
Head-tilts head sideways	21
Eyes-irregular blinking	20
Eyes-looks to the side	17
Head-tilt head forward; eyes-looks up	14
Mouth-full mouth smile	13
Head-tilts head down	12
Eyes-avert eyes	10
Body-half shrug; mouth-licking lips; mouth-harsh swallow	9
Face-tightening jaw; hands-clenching fists; hands-slams hands down; mouth-pouting (push lips forward and together); head-circle head	8
Eyes-pupil dilation	7
Hands-self-touch (rubs hand or fingers)	6
Body-tapping foot; hands-raises hands; mouth-half smile (from one side of the mouth); body-pointing (away); body-self-touch (face); mouth-opens mouth; head-tilts head up; eyes-look towards exit	5
Body-shrugging; hands-palms outwards	4
Face-keep a 'frozen' face; face-flair nostrils; hands-reach hand out	3
Face-self-touch (head); body-slouching; body-straightening up; body-steps backwards; body-fidget; body-stiffen shoulders; body-disconnects	2
Eyes-widen eyes; body-crossing arms; face-scratching; mouth-biting lip; hands-twitch hand; body-creating physical barrier; body-twitch leg; body-point part of body towards exit; body-tilts forwards; body-self-grooming; head-shake head; eyes-looks up	1

Figure 2.6: Example of BSA behavioural table (Marono et al., 2017).

3. EXTENDED REALITY

Extended reality (XR) is an umbrella term that covers the rapidly improving technologies that have started to be used in many fields from health to education, entertainment to architecture. It includes VR, augmented reality (AR) and mixed reality (MR). It defines all mixed real-and-virtual worlds as well as human-machine interactions produced by wearables and computer technologies (Alizadehsalehi et al., 2020). XR creates a new world simulation where real and VEs are combined at different levels of immersion through mediums such as computers, smartphones and glasses. VR technology often uses headsets or digital screens to simulate a VE with optional interaction choices while blocking out visual stimuli from the real world (Kaplan et al., 2020). AR technology overlays virtual elements on real-world vision, mostly through smartphones, tablets or glasses. MR is a very similar technology to AR where real and virtual elements are integrated with the possibility of interaction. In recent years, there has been a significant improvement in these technologies, and they have been extensively employed. XR finds application across various fields, including entertainment, education, healthcare, architecture, manufacturing, and retail. In architecture, XR has started to transform all the parts of the architectural design process: from the early design phase to the construction stage offering powerful tools to create, iterate, present and test ideas. For example, VR enables architects to immerse themselves and their clients in VEs, allowing for a deeper understanding of spatial relationships, scale, and design aesthetics. Architects can make use of VR to create a walkthrough of a building's virtual model before its physical construction. This experience helps architects make necessary refinements in their designs while providing clients with a clear understanding of the proposed project. By visualizing the spaces, clients can better comprehend how they will function and feel once constructed. VR is also used in many architectural studies such as wayfinding, energy optimization and the analysis of design processes. On the other hand, AR is often employed in architecture for on-site visualization and contextual understanding. Architects can overlay digital models onto real-world environments using AR-enabled devices like smartphones or tablets. This feature is especially useful during site visits

or construction phases. Architects can overlay proposed designs onto existing landscapes or structures, while construction workers can access application information through AR simulations on-site. Moreover, MR combining elements of both VR and AR, offers architects even more possibilities. MR enables interaction with virtual models while still being aware of and able to manipulate physical objects in the physical environment. This capability is advantageous for collaborative design sessions, where multiple stakeholders can interact with a shared virtual model in real-time, making collaborative decision-making more efficient and effective. The differences between AR, MR and VR can be seen in Figure 3.1.

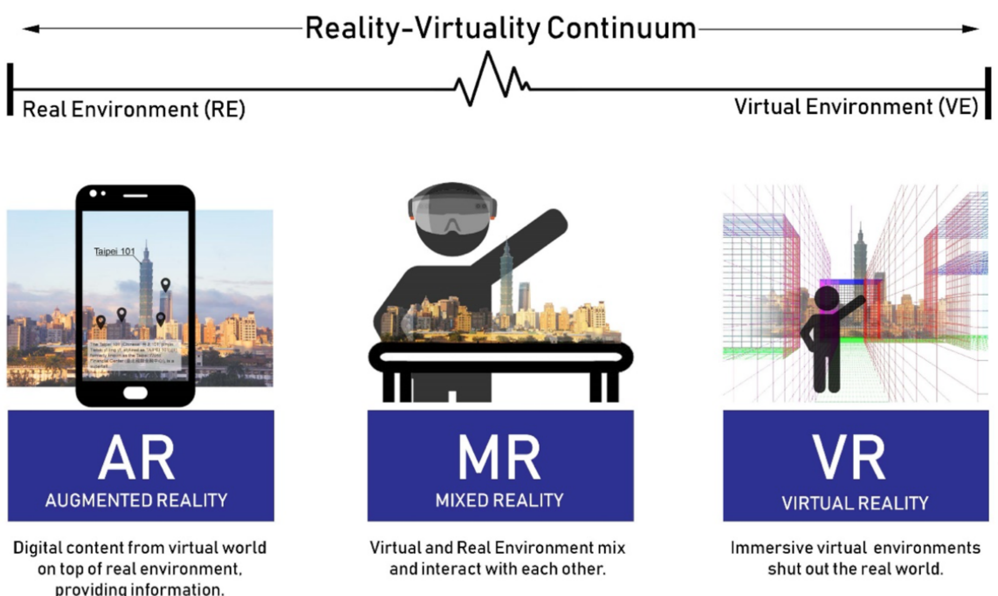


Figure 3.1: The difference between AR, MR and VR (Osorto Carrasco & Chen, 2021).

3.1 Virtual Reality

VR refers to the use of computer-generated 3D environments, also known as VEs, that users can navigate and interact with allowing for real-time simulation of one or more of the user's five senses (Guttentag, 2010). It was created to generate virtual worlds that were indistinguishable from reality while today, we consider that it is about creating “acceptable” replicas of actual objects or environments for educational, recreational, or design objectives. (Gutierrez et al., 2008). In literature, two common factors define VR: immersion and presence (Steuer, 1992; Gutierrez et al., 2008; Alizadehsalehi et al., 2020; Zhou & Camba, 2021). Presence can be defined as the sense of being in an environment (Steuer, 1992). Immersion is the user’s engagement

with a VR system that results in being in a flow state (Berkman & Akan, 2018). While presence is a subjective and psychological criterion, immersion refers to the physical setup of the user interface of the VR system.

Based on the level of immersion, VR systems are grouped under three categories: non-immersive, semi-immersive and fully immersive (iVR) (Onime et al., 2015). Fully iVR uses head-mounted displays (HMD) while semi-immersive VR can use large digital screens or HMDs and non-immersive VR uses desktop screens. Non-immersive VR doesn't allow direct interaction with the VE. Semi-immersive VR allows direct interaction with the VE while still being connected to the physical world. On the other hand, iVR creates a complete virtual experience with equipment such as sensors, detectors or gloves. iVR offers the closest experience to reality and increases the similarity of the collected data with the data obtained from the real environment.

VR technology finds applications across various industries, offering immersive and interactive experiences that can be utilised for purposes ranging from entertainment and gaming to education, training, healthcare, and architecture. It has begun to be widely used in every branch of architecture that can be sorted as follows: design exploration, post-occupancy evaluation, prototyping, collaborative design reviews, client presentations, simulation and analysis, pre-construction planning, safety training and simulation, on-site visualisation, as-built verification and documentation, remote site inspection and historical reconstruction and preservation. Design errors can be identified and fixed before implementation through experimenting with VR. On the other hand, VR is a commonly utilised tool for wayfinding studies with the possibility of multiple physical environment setups virtually. While behavioural inconsistencies between real-world and virtual settings are unavoidable, there are nevertheless significant advantages in terms of ecological validity, experimental control, and behavioural response tracking (Diersch & Wolbers, 2019).

In an early example of VR use in wayfinding, Jiang and Li (2007) assessed the wayfinding performance of the elderly using a virtual hospital environment. Kuliga et al. (2015) examined the difference in user experience in virtual and real environments. They found few statistically significant differences between the real and the virtual building while still emphasizing the high potential of VR in future studies. Through a VR experiment, Lin et al. (2019) discovered that while mental stress has a detrimental impact on navigational skills, frequent exposure to an indoor place had a positive

effect. However, repeated exposures mitigate the negative effects of stress, demonstrating a significant interaction between them. Cao et al.(2019) observed that the cognitive memory type affects the evacuation behaviour of the participants in an experiment conducted in an iVR environment. According to Zhu et al. (2020), when an alternate path with high architectural visual access was offered, participants' propensity to follow the crowd decreased thus improving architectural visual access had a beneficial effect on participants' evacuation performance. To assess the effectiveness of VR in wayfinding research, Ewart and Johnson (2021) carried out a comparative study. They found that participants who finished a wayfinding assignment in a real building and a VE model of the same structure followed remarkably similar pathways. By putting victims in a maze environment, Shi et al. (2021) investigated the navigational behaviour of firefighters in a VR experiment. A VR tool created by Feng et al.(2022) gathers behavioural data related to wayfinding, including gaze points, head motions, and walking routes. They investigated navigational behaviour through VR trials, and the findings indicate that the behaviour deviates from what is documented in the literature as complexity increases. Another study by Feng et al. (2022) looks into variations in pedestrian navigational behaviour and user experience to assess the effect of implementing different VR methods on pedestrian wayfinding studies. Al-Shaara et al. (2022) developed a 3D model of a hospital building to carry out VR experiments. They assigned participants wayfinding tasks and suggested a scheme to improve wayfinding. This scheme is based on users' wayfinding performance data, which is used to inform the process of designing signage. With a VR experiment set up, Qi et al. (2022) collected data on the sense of direction, navigational ability, and distance calculation with an emphasis on the correlation between stress and wayfinding. Results showed that participants performed better when walking in areas with more landmarks and had lower stress levels when they were in visually linked outdoor environments. Kalantari et al. (2022) investigated the impacts of various interior designs to improve wayfinding in a particular healthcare facility using VR and electroencephalogram data. They discovered that enhancements in design result in increased neuronal activation in the relevant brain regions and better wayfinding behaviour. A similar study in which iVR was used by Mao et al. proved that better navigation in a building can improve the effectiveness of evacuation performance during critical incidents (2024). VE examples from the literature can be seen in Figure 3.2.

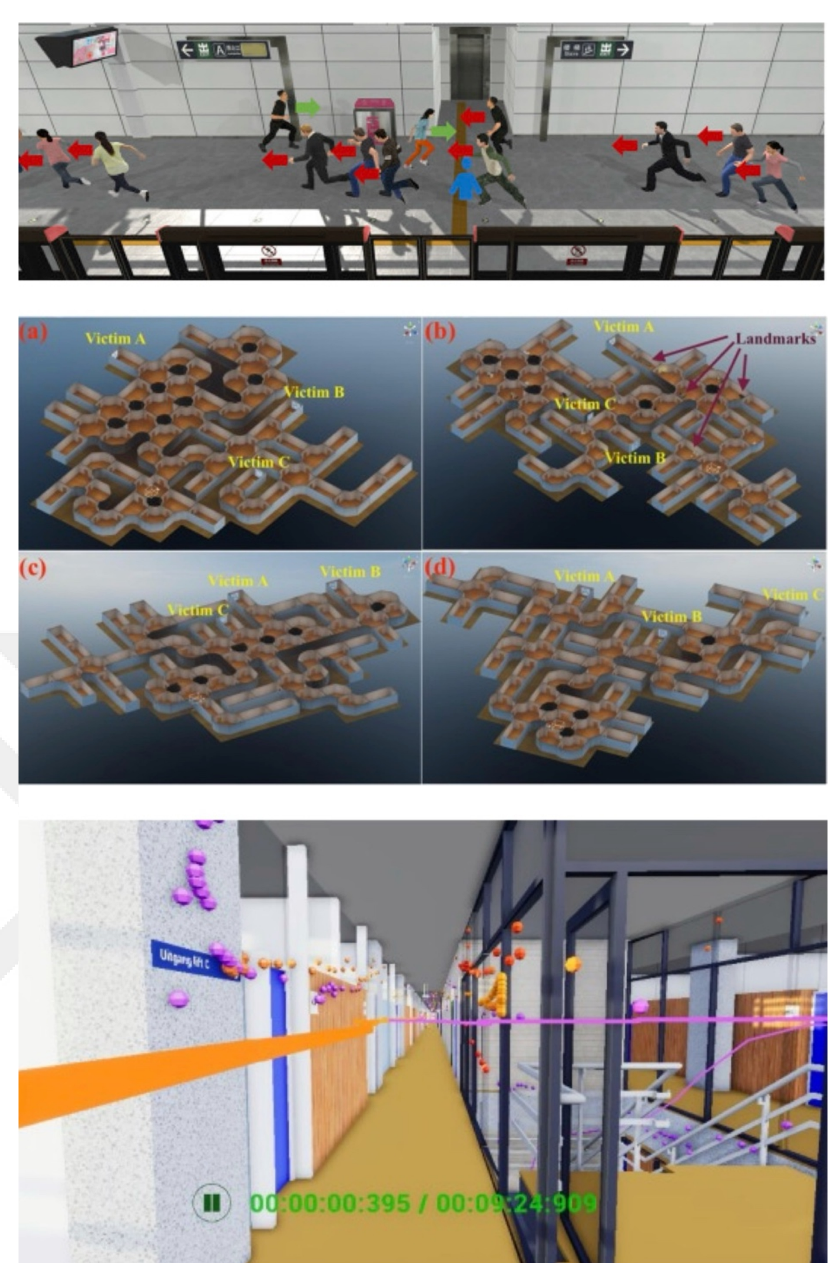


Figure 3.2: Examples from VEs (Zhu et al., 2020; Shi et al., 2021; Feng et al., 2022).

In the next chapters, the types of VR based on immersion level under three groups in more detail are examined and information on their use in architecture is explained.

3.1.1 Non-immersive VR

Non-immersive VR, unlike the other types of VR, doesn't completely transform one's environment. Users navigate and interact within this virtual space using familiar tools like keyboards, mice, or controllers. This interaction enhances presence in VEs while maintaining awareness of physical surroundings. The significance of non-immersive VR lies in its ability to make virtual experiences accessible to a wider audience by

being affordable compared to other types of VR. By eliminating the need for expensive headsets, it provides an accessible way to experience VR technology. This wider accessibility allows for a broader range of applications including educational simulations, virtual prototyping, remote collaboration and entertainment. Although non-immersive VR does not provide complete sensory immersion like fully immersive VR, it is still a powerful and versatile tool for interacting with and exploring VEs. For example, computer games are a great example of how non-immersive VR is affordable and accessible. Similarly, the field of architecture employs non-immersive VR for architectural modelling. Designers use virtual 3D models to visualize and collaborate on building and interior design with seamless workflow with CAD software. Also, it is useful for client presentations by providing fast solutions to transfer the design ideas. In summary, non-immersive VR is essential to modern architecture design because it provides an accessible and cost-effective platform for 3D visualisation, collaboration, and design iteration, enabling architects to produce more functional, efficient, and visually stimulating places. Also, in wayfinding studies, it was commonly used to experiment with different VEs and assess wayfinding behaviours. While it is still being used today, other types of VR are becoming more popular and offer more valid experiences, thus it is not as common as it once was for wayfinding studies. An example of a non-immersive VR setup can be seen in Figure 3.3.

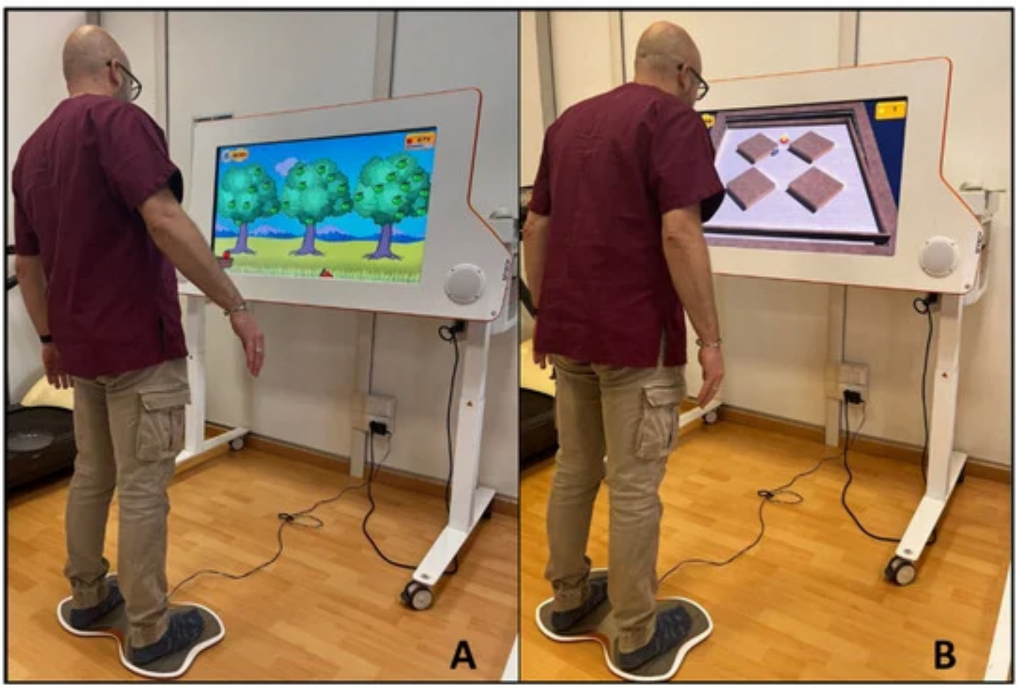


Figure 3.3 : Example of a non-immersive VR setup (Maranesi et al., 2022).

3.1.2 Semi-immersive VR

Semi-immersive VR offers a degree of immersion in a partial VE with a connection to the real world. The mediums used for semi-immersive VR can be large digital screens, projections or specialized room-sized projection setups (CAVE). This type of VR allows interaction with the VE optionally, but still one feels the presence of their physical surroundings. It has a level of immersion between non-immersive and fully immersive VR. We can see the use of semi-immersive VR commonly in training simulations for educational purposes. In the field of architecture, like non-immersive VR, it can used for the early design phase, client presentations, and collaborative design processes with a better feeling of presence than non-immersive VR. Semi-immersive VR is known as an expensive technology as it requires special and high-resolution displays. On the other hand, fully immersive VR also requires expensive hardware such as HMDs and controllers. The experiences they offer may be different from each other based on the setup regardless of immersion degree. Affordability in both types of VR is still a problem, but as the systems develop and become widespread, we see that this problem is gradually decreasing and the use of VR is increasing rapidly. An example of a semi-immersive VR setup can be seen in Figure 3.4.

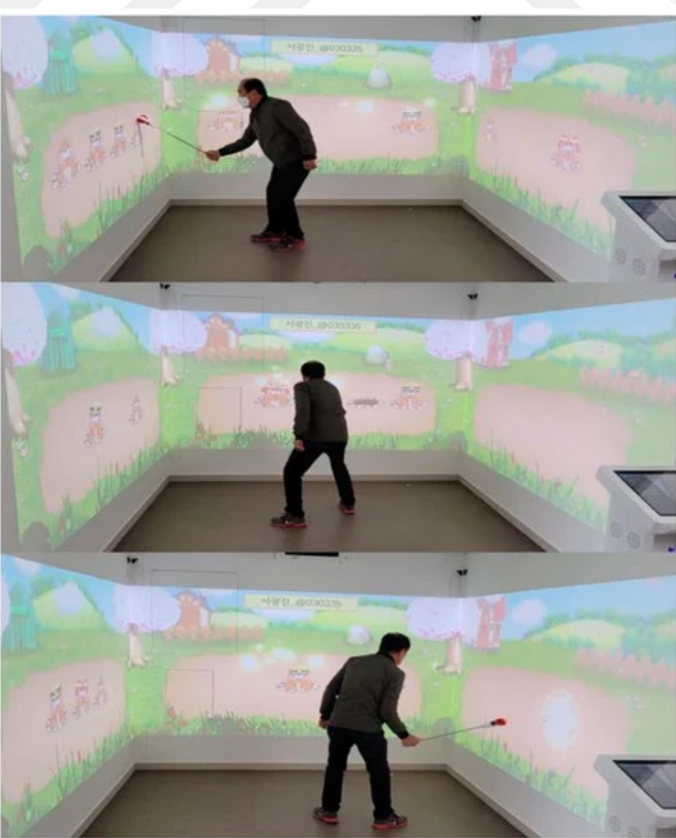


Figure 3.4 : Example of a semi-immersive VR setup (Hwang et al., 2021).

3.1.3 Immersive VR

iVR allows for complete immersion and interactivity with HMDs, controllers, and wristbands eliminating boundaries with one's physical surroundings. It transfers the user to a complete virtual experience with high-resolution displays and also the sounds of the VE. iVR HMDs track the motion of the user's hand or body and reflect it to the virtual world. Depending on the specifications of the VR setup, users can perform activities such as walking, looking around or running, just like in the real world. When the setup is insufficient for performing the physical activity as in the real world, the user can perform these activities with head movements or through controllers. A common setup for iVR with an HMD and controllers can be seen in Figure 3.5 while a more enhanced setup can be seen in Figure 3.6 with the possibility to perform physical activities such as running and walking as in the real world.

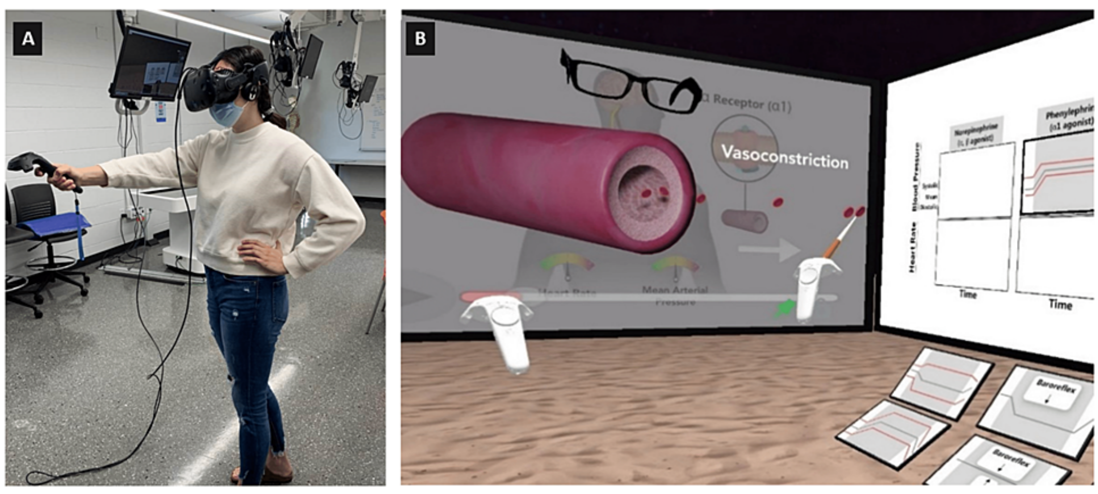


Figure 3.5: iVR setup with an HMD and controllers, and the vision of the user on the right (Hamdi et al., 2022).

This type of VR is commonly used in the gaming industry by offering a complete immersive gaming experience. From training and education to design and healthcare, its applications are vast and ever-evolving. For example, soldiers and pilots utilise it for training while doctors may use it for rehabilitation purposes. For designers, iVR creates a virtual meeting space allowing collaborative design and review processes. On the other hand in architecture, it offers an immersive preview for clients and stakeholders to better perceive the specifications of the design fostering richer communication with them. For architects, it creates VEs where design errors can be identified and spatial performance can be measured in pre and post-occupancy scenarios. It is frequently preferred in wayfinding experiments since it offers the

closest experience to real life ensuring minimum deviation from real-life experimental data.

Figure 3.6: iVR setup with an HMD, controllers and the equipment that provides physical movement (URL 2).

On the other hand, iVR has some significant disadvantages in terms of affordability and cybersickness. The cost of HMD setups, specialised equipment and the hardware required for running VR-related software can be quite high. As this technology becomes more widespread, prices become more affordable but are not yet accessible for everyone. Motion sickness-like symptoms that occur in VR are known as "cybersickness" (Kim et al., 2005). Conflicts between visual and sensory cues are one of the most common causes of cybersickness (Howarth & Costello, 1997). A conflict arises because the person perceives movement, but no physical movement occurs. The closeness of the HMD to the eye is another cause of discomfort. The symptoms of cybersickness are nausea, dizziness, vertigo, headache, eye strain, and fatigue which can last up to 5 hours (Kim et al., 2005). Wearing HMDs for long periods can be challenging due to their weight, which is considered a significant disadvantage of this technology.

3.2 Augmented Reality

AR technology overlays virtual elements onto the real world, creating a combination of real and VEs. It recognizes the user's surroundings and, by evaluating them adjusts the positions and the scales of virtual elements thus is a dynamic interactive system, unlike VR. It can combine sounds and haptics with virtual visuals, thereby providing a more realistic experience. Its use through smartphones makes it more accessible and affordable than iVR while the AR use with smart glasses is a new developing technology. In education, AR is an alternative to traditional learning methods by providing interactive and immersive content that engages students. It is often used as a marketing method that spreads rapidly for retail and changes shopping habits, offering realistic presentations of the product in question. In healthcare, it is used for surgical risk-free simulations or diagnosis of disease and treatment by making visualisation easier. In architecture, it is useful by acting as a manual for on-site applications. In historical sites, visitors can use their smartphones to get a complete understanding of the place. In architecture, AR offers new methods and experiences to both architects and other stakeholders. Architects can visualize the impact of their design choices by overlaying design elements onto a physical space or existing model. This type of visualisation is also useful for client presentations or coordination with other branches.

Figure 3.7: An example of the use of AR through a tablet in a construction site (*URL 3*).

During the construction phase, the workers can access information more accurately and precisely by directly overlaying architectural drawings and visuals on site. In

wayfinding studies, AR is mostly utilised as way-showing systems through smartphones in complex buildings such as hospital buildings. It provides dynamic and real-time navigational data, adapting to the user's surroundings and facilitating wayfinding perception.

3.3 Mixed Reality

According to some sources, MR is accepted as a term used instead of AR (Gsaxner et al., 2021) or a class of XR (Aloqaily et al., 2023). This study accepts MR as a branch of XR thus being very similar to AR. MR systems bring the virtual and real environments together and provide interaction among them, unlike AR which only overlays elements onto the real world. MR can also be defined as the combination of AR and VR. It is commonly utilized with smart glasses, enabling the user to see their surroundings. The unique feature of MR is the ability to interact with and modify even the physical components in real time. The MR systems track the user's surroundings and allow precisely placing virtual items through the use of sensors, cameras, and spatial mapping. MR has implications in various fields such as healthcare, education, entertainment and manufacturing. Although MR is rapidly developing, it is not as widespread as other XR technologies due to the need for more specialized equipment and its cost. In architecture, it is used similarly to AR but in an enhanced way. With MR technology, the designers can interact with their design models and also the physical surroundings of the design. This allows for designs that are compatible with their surroundings and nurtures the decision-making process. The clients are better able to understand the design and offer more comprehensible and precise design feedback through the utilisation of MR as well as conduct collaborative real-time feedback sessions with the architects.

Figure 3.8: A demonstration of a designer using MR through smart glasses to take the measurements of the existing stairs (URL 4).

4. METHODOLOGY

This study examines wayfinding behaviour by associating it with spatial characteristics in healthcare buildings through iVR to better understand human wayfinding. The thesis study questions the effects of spatial plan configuration on wayfinding behaviour and the relationship between re-occurring behaviours during the wayfinding process depending on spatial characteristics. The methodology has been developed to respond to this issue and is based on experimentation and observation. It quantitatively correlates human wayfinding behaviours with spatial characteristics through space syntax analysis and examines the interrelations among the behaviours of the users.

The flowchart of the methodology can be seen in Figure 4.1. An iVR experiment is designed to observe wayfinding behaviour and collect behavioural data. Various hospital buildings are selected based on their plan layout typology and VEs of these hospitals are created by 3D models. Participants completed wayfinding tasks in each building and the experiment process was recorded. The experiment provided various types of data which were then arranged to meet the requirements of four distinct analyses. The methodology consists of three stages, including (1) hospital building selection, (2) implementing space syntax analysis, (3) preparation of VEs, (4) determining wayfinding tasks, and (5) preparing the experimental setup. The details of the methodology are further explained in this chapter.

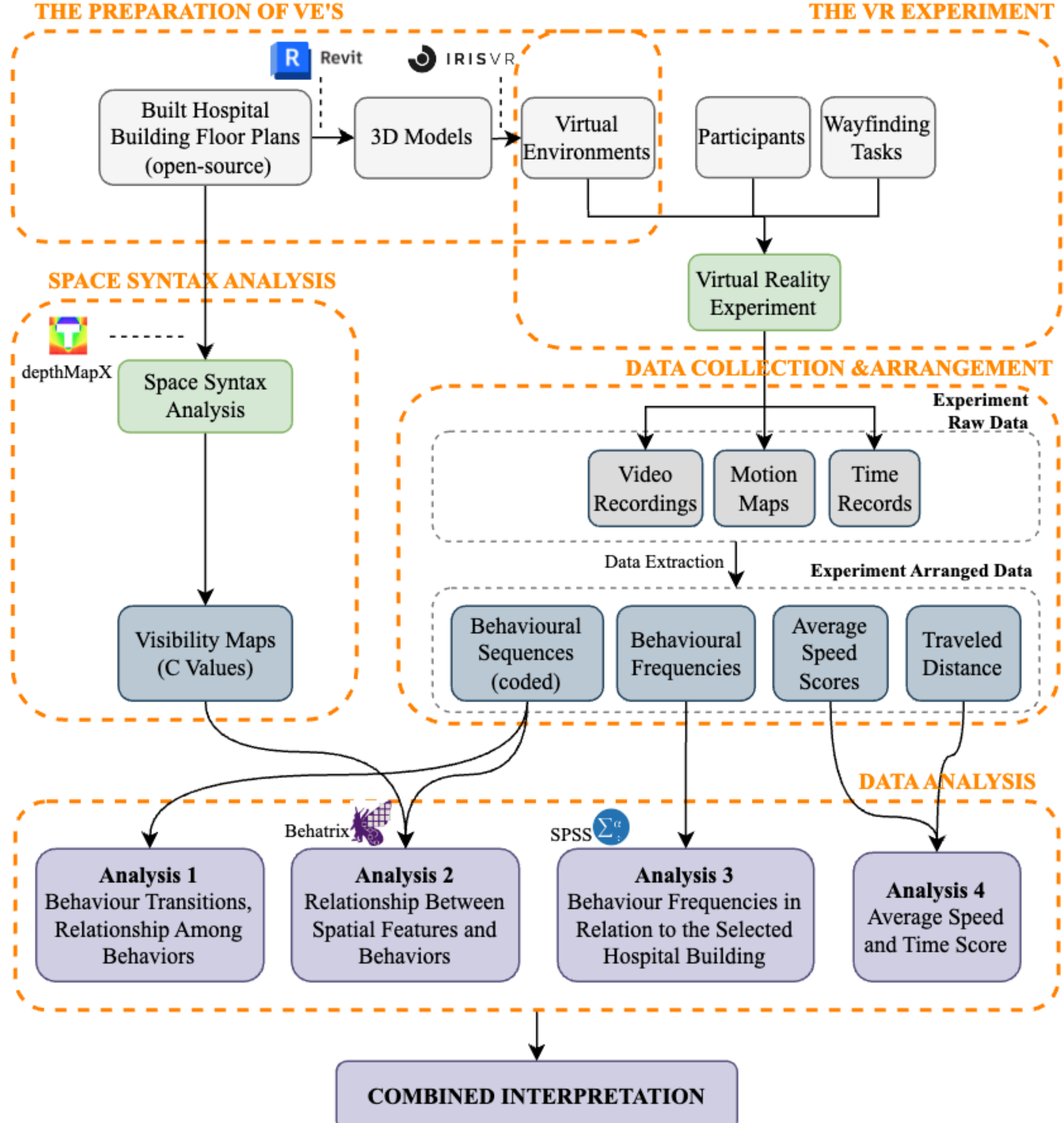


Figure 4.1: The methodology of the study.

4.1 Hospital Building Selection

3 built hospital buildings are selected to test common space layouts for hospitals, based on specific selection criteria. The architectural data collected is to be transformed into 3D models to later use as VEs. The main selection criteria is the spatial layout typology which is based on common classification derived from literature. Another significant selection criterion is the accessibility and the use authorization of the architectural data. The selection criteria in detail are explained below:

- **Floor plan layout typology**: The floor plan layout categorisation as explained in Chapter 2.1 is utilised for this study. Based on this classification, three

hospital buildings from each plan layout typology including decentralised, semi-centralised and centralised layouts, are chosen to examine the effects of spatial layout on wayfinding behaviour. The selected hospital buildings as seen in Table 4.1, are Pars Hospital with a decentralised plan layout, Radboudumc Hospital with a centralised plan layout and Rocio's Hospital with a semi-centralised plan layout.

- **Floor plan area:** The selected hospital buildings have similar construction areas as seen in Table 4.1. However, the circulation areas show significant differences based on the floor number. This research is constrained by incorporating only the ground and 1st floors of the buildings due to the intent of reducing the duration of the iVR experiments and computational costs.

Table 4.1 : Information about selected hospital buildings adapted from URL 1.

Name	Total Area (sqm)	Total Area in the Study (Ground + 1st Floor) (sqm)	Circulation Area in the Study(m^2)	Plan Layout Typology
Pars Hospital	30.000	10.566	1546	Decentralised
Radboudumc Hospital	45.000	10.658	2336	Cenralised
Rocios Hospital	55.300	33.300	8063	Semi-centralised

Circulation Units

This way, Pars and Radboudumc hospitals have nearly the same floor area (10.000 sqm) used in the study meanwhile Rocio's Hospital has a significantly larger area. The larger floor area (about 33.000 sqm) is utilised in 1 of the 3 hospital buildings to

measure the impact of building area on wayfinding performance. Circulation areas also change in direct proportion to the floor areas. For this reason, while Pars and Radboudumc hospitals have similar areas, Rocio's Hospital has a larger circulation area.

On the other hand, having readable and scaled data for modelling buildings in the digital environment is very important. The models that make up the VEs should reflect the actual scales of the spaces exactly to observe wayfinding behaviours that are closest to the behaviours observed in real life. The hospital buildings that are accessible online are inspected using the previously mentioned criteria, and those that have floor plans that are readable, scaled, and coherent are chosen. On the other hand, due to privacy and authorisation concerns, the data available open-source is chosen.

Only the ground floor and first floor of the buildings are considered for the experiment to minimise participant fatigue and prevent unnecessary time consumption. Each unit required for wayfinding tasks in buildings is located on these two floors. The next step in the selection process is to convert floor plan images to 2D dwg format so that they can subsequently be used in space syntax analysis and 3D modelling software.

4.2 Implementing Space Syntax Analysis

UCL DepthMapX is used which is an open-source software for space syntax analysis. It is aimed to find patterns in behaviours during wayfinding and relate them with the spatial features of the space. To express spatial features as numerical values, visibility graph analysis, which is one of the space syntax analyses measuring the degree to which the spaces see each other, is performed. The degree to which one may view other building components from a specific place is determined by visibility analysis (O'neil, 1991; Pinelo and Turner, 2010). *Visibility* is an important aspect to use in wayfinding studies since wayfinding is primarily connected with the sense of sight. Visibility is used as a representation of spatial layout as spatial layout directly shapes the visibility of space and affects wayfinding performance. Visibility graph analysis gives *Visibility (V) values* as output. For visibility graph analysis, floor plans should be given as input to DepthMapX in dwg format. The floor plan images previously collected are modelled as 2D linework in AutoCad in dwg format. These dwg files for each floor in each building are given as input to DepthMapX. The dimensions of the grid system to be laid on the drawings for the mapping process are selected as 500

pixels for the detection of V values pointwise. A smaller grid size facilitates more detailed results, but it could be more challenging to collect V values for participant locations thus a 500-pixel grid size is the optimum size for this study. The visibility maps and the V values are later utilised in the analysis section with other data to be collected from the experiment.

4.3 Preparation of Virtual Environments

The floor plan images of the selected hospital buildings retrieved from the web as online images are drawn as 2D linework in dwg format. These 2D drawings are the base of the 3D models to later use as VEs and the input for Space Syntax Analysis. The selected buildings are large-scale buildings with approximate square metres and consisting of 4-8 storeys. It is not possible to model and use the entire structures in the iVR experiment since doing so will exhaust the participants and exceed the file load capacity of the VR software due to hardware limitations. To prevent these outcomes, only the first two floors including the ground and first floor which has all the necessary units to use in wayfinding tasks are modelled. Some modelling principles on signage and interior characteristics are decided during the 3D modelling process to avoid differences that would affect wayfinding other than spatial features in the buildings. The next two chapters explain these principles in detail.

4.3.1 3D modeling principles

Based on the 2D floor plans, 3D models of the buildings were produced using a BIM-based platform Revit. The main structure of the buildings including load-bearing elements such as columns, curtain walls, floors and stairs are primarily modelled. After the main structure is completed, the inner walls, doors, windows, elevators and facade systems of the buildings are modelled. In all three buildings, the same types of components are used for the same functions such as the same door type, same painting colour and same ceiling. Since modelling all of the decorative items and furniture makes the models too heavy and prevents them from being displayed in VR, only a portion of the furniture is modelled to give the participants a sense of reality. The modelled furniture includes information desks, the seating items in waiting and circulation areas, signage and lighting components. The details of the signage system common to all models are described in the next section. Images of the 3D models can

be seen in Figure 4.2. Although not all spatial features can be reflected in exact 3D models, important criteria that strongly affect wayfinding performance, such as space dimensions, plan scheme, and opacity-transparency ratio, are processed exactly into the models. Features that are not exactly compatible with reality include component types, colours, signage elements, and furniture designs. This is sometimes due to hardware constraints, and sometimes to prevent the formation of other strong features that would affect wayfinding performance between buildings.

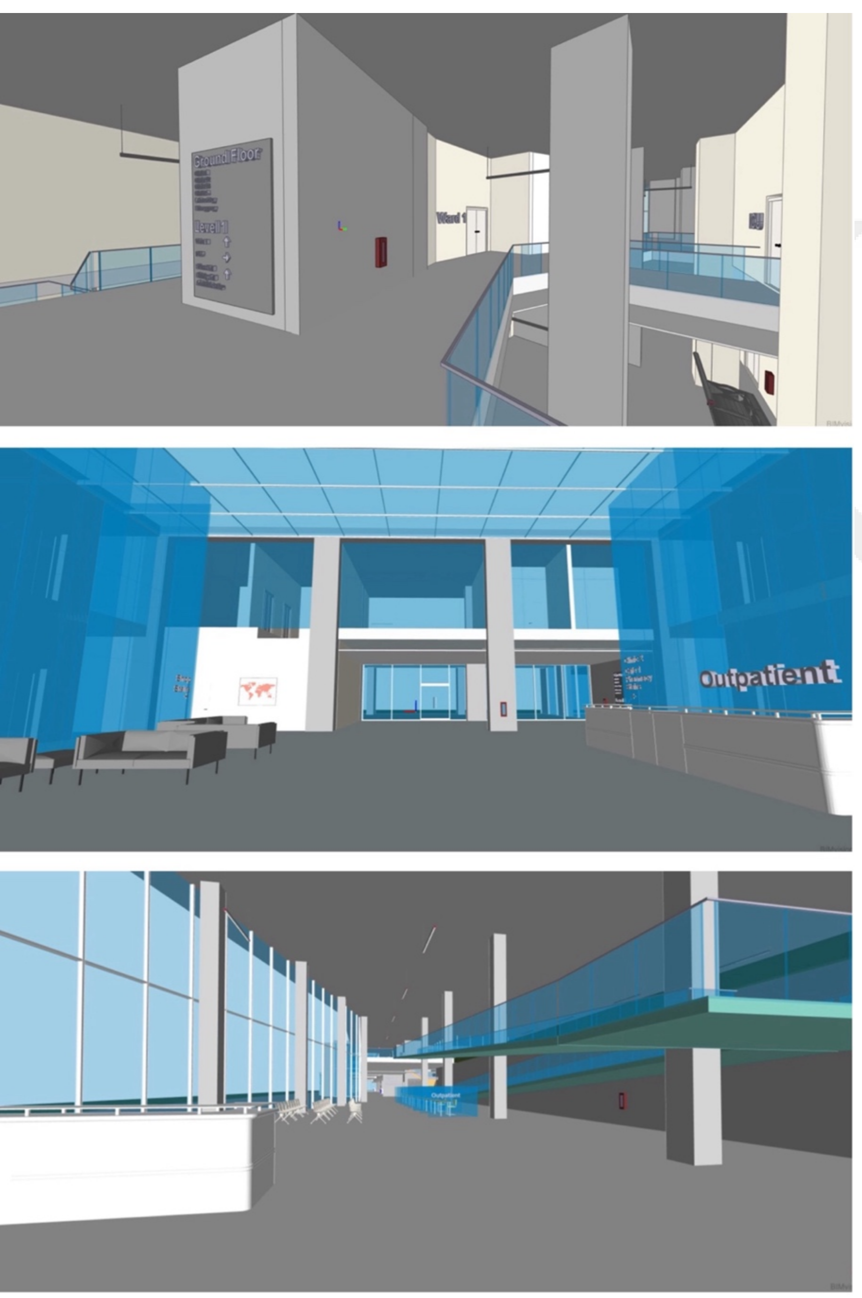


Figure 4.2 : Images from 3D models of the buildings. At the top: 1st floor of Pars Hospital. In the middle: Ground floor of Radboudumc Hospital. At the bottom: Ground floor of Rocio's Hospital.

4.3.2 Signage system

The same signage tables are used in all 3D models to avoid signage variances affecting participants' wayfinding. These signs are designed in the simplest way to be easily understood and to guide the user quickly. There are two types of signage placed in the 3D models which are main signage tables and intermediate pointers as seen in Figure 4.3.

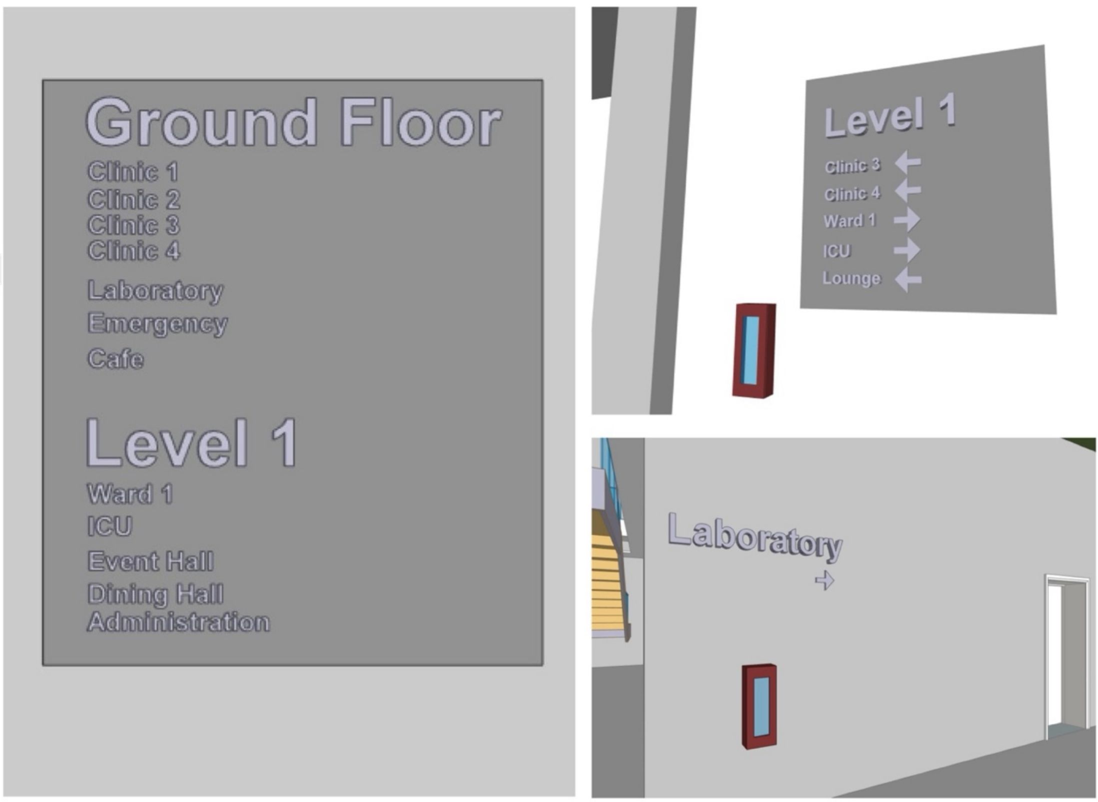
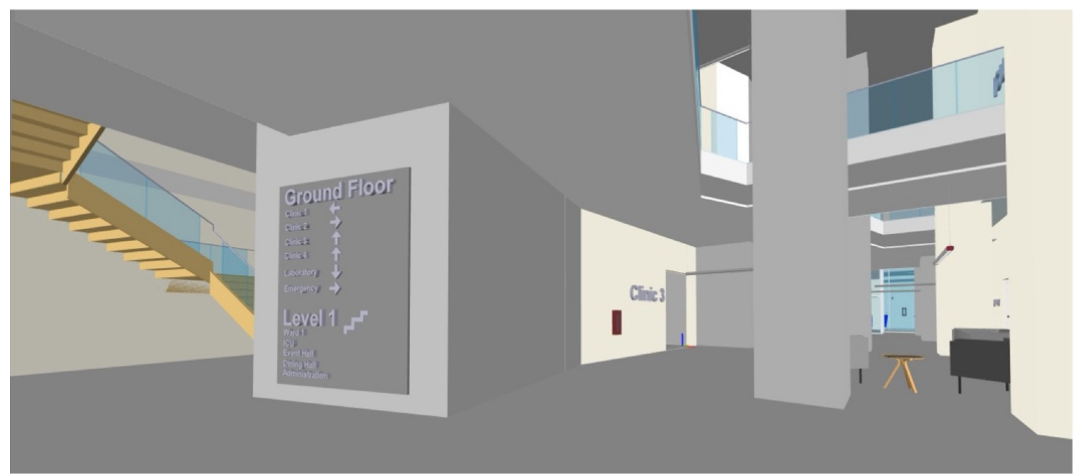


Figure 4.3: Two types of signage from the 3D models: main signage tables(on the left) and intermediate pointers(on the right).

The main signage tables are in dark grey with light grey coloured text on them to provide readability mounted on the wall at the entrances and next to circulation elements which are stairs and elevators where they can be seen directly. The ones at the entrances have only the names of the units on each floor while the ones next to the circulation elements have icons pointing in the directions of the units. Intermediate pointers consist of wall-mounted elements with the names and directions of the units close to the point where they are located and the names of the units at that location. The colour of the intermediate pointers is light grey which is the same as the colour of the text on the main signage tables. The signage integrated with their surroundings in

each building model can be seen in Figure 4.4. The circulation elements, entrances and locations of the main signage tables in each building model can be seen in Figure 4.5.



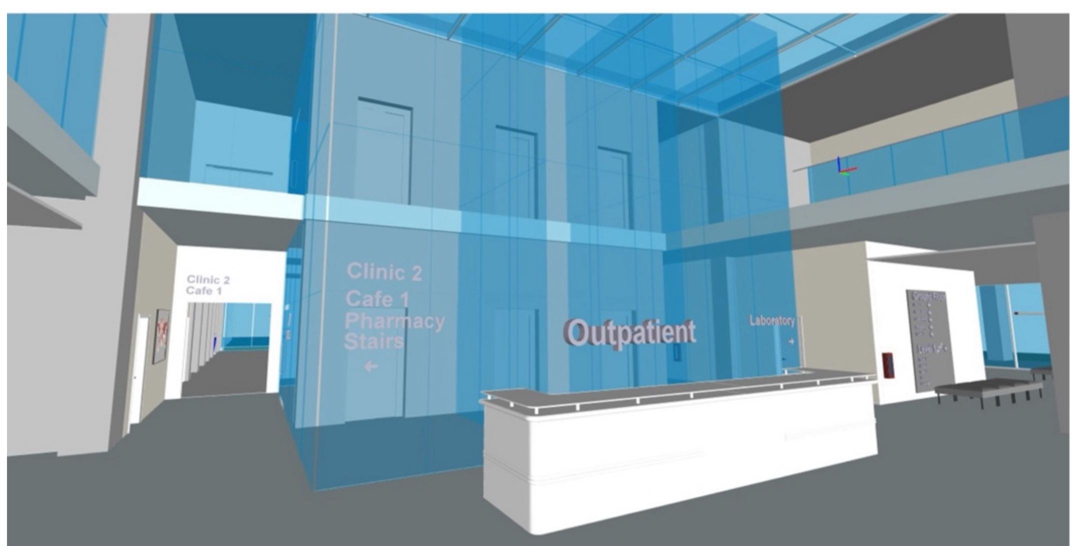


Figure 4.4 : Examples of various signage elements in all three buildings' 3D models. From top to bottom: Pars Hospital, Radboudumc Hospital, Rocio's Hospital.

Ground Floor | Level 1

Pars Hospital

Radboudumc Hospital

Rocio's Hospital

Primary Circulation
Secondary Circulation
Units

stairs
main entrance
main signage tables

Figure 4.5 : Locations of main signage tables in each building.

4.4 Wayfinding Tasks

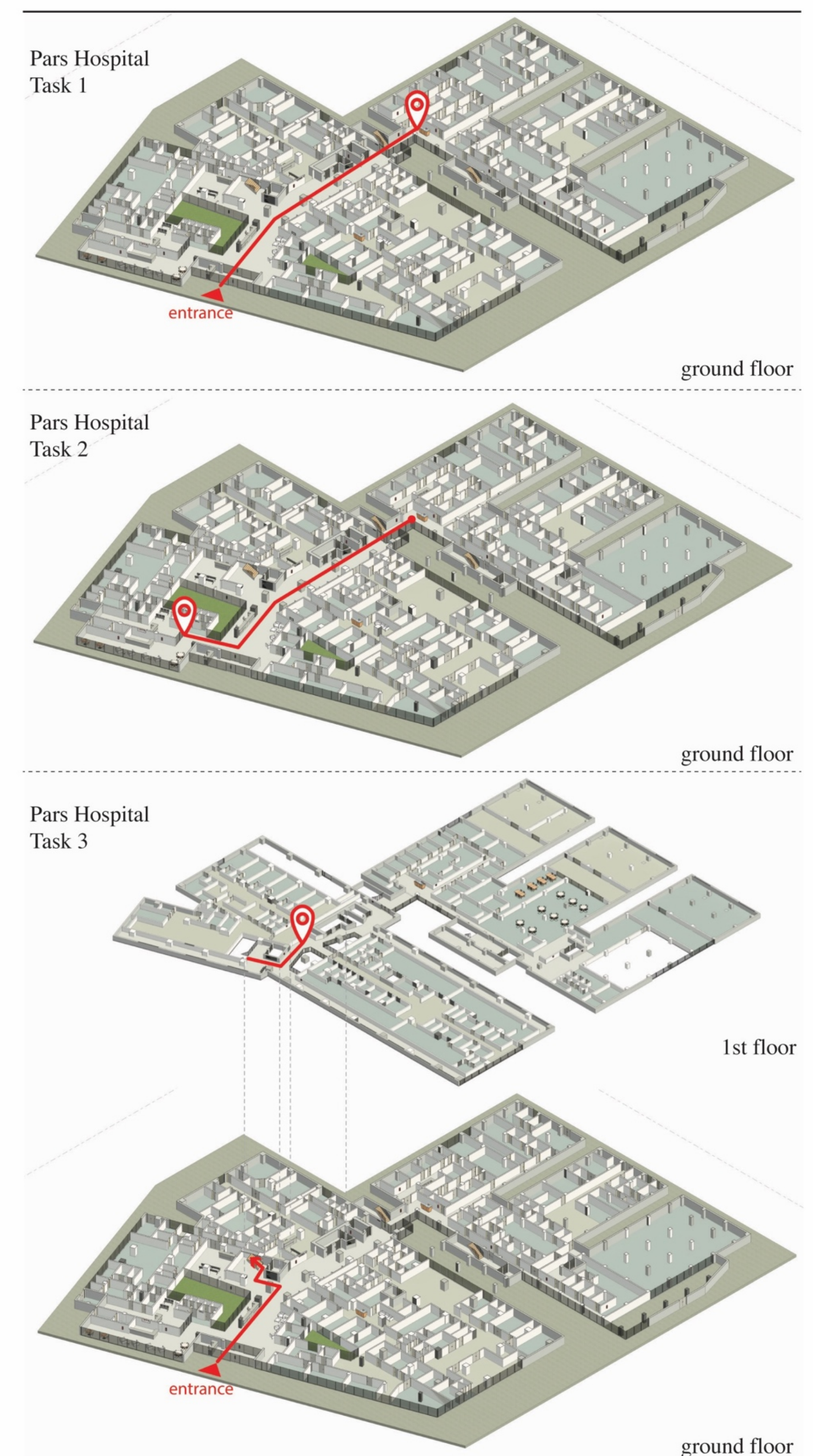
The iVR experiment consists of giving participants wayfinding tasks in three buildings and recording their wayfinding process. To utilise different parts of the buildings included in the experiment, three wayfinding tasks with target locations have been developed. In this way, the spatial experience constraint of a single scenario is eliminated. Task 1 requires circulation entirely on the ground floor, while tasks 2 and

3 provide circulation between floors. The routes of each task can be seen in Figure 4.**6**. The start and target locations of the tasks can be listed as follows:

- **Task 1, Entrance (Ground Floor) - Clinic (Ground Floor):** The participant enters the building and heads to the clinic located on the ground floor. The clinic located furthest from the entrance is selected in each building to make wider use of the ground floor primary circulation area.
- **Task 2, Clinic (Ground Floor) - Laboratory (Ground Floor or 1st Floor):** The participant starts this task from the clinic selected in the previous task and heads to the laboratory. In each building, laboratories have unique locations. In Pars Hospital, the laboratory is located close to the entrance which directs the participant to go back the way they came for the previous task. In Radboudumc Hospital, the laboratory is located directly across the clinic from Task 1which is easy to see at first sight. In Rocio's Hospital, the laboratory is located on the first floor which requires the use of circulation elements. Observing the contribution of the arrangement of functions to the wayfinding experience is made possible by these differences in placement.
- **Task 3, Entrance (Ground Floor) - Ward (2nd Floor):** The participant starts from the entrance as in Task 1, and heads to the ward on the first floor. The closest ward on the first floor in each building is selected to make the task less tiring for the participants. The choice of circulation unit is left to the user. Figure 4.**6** shows the circulation unit suitable for the shortest route in each building for Task 3.

As Figure 4.6 demonstrates, the circulation areas based on the unit functions and publicity are shown in different colours. Orange colour represents the primary circulation areas while purple represents the secondary. The secondary circulation areas can be counted as semi-private areas between units. The blue areas show the inner space of the units which can be counted as private allowing controlled access such as clinic rooms and laboratories. The wayfinding tasks mainly utilise the primary circulation areas since the participants are assigned a patient's tasks in the experiment which makes them use common areas. There are multiple circulation elements in each building such as multiple stairs or ramps. The choice of the circulation element is left

to the participant, and the routes of the tasks are shown in Figure 4.6 as the shortest paths to the target



.

Figure 4.6 : 3 wayfinding tasks in each building.

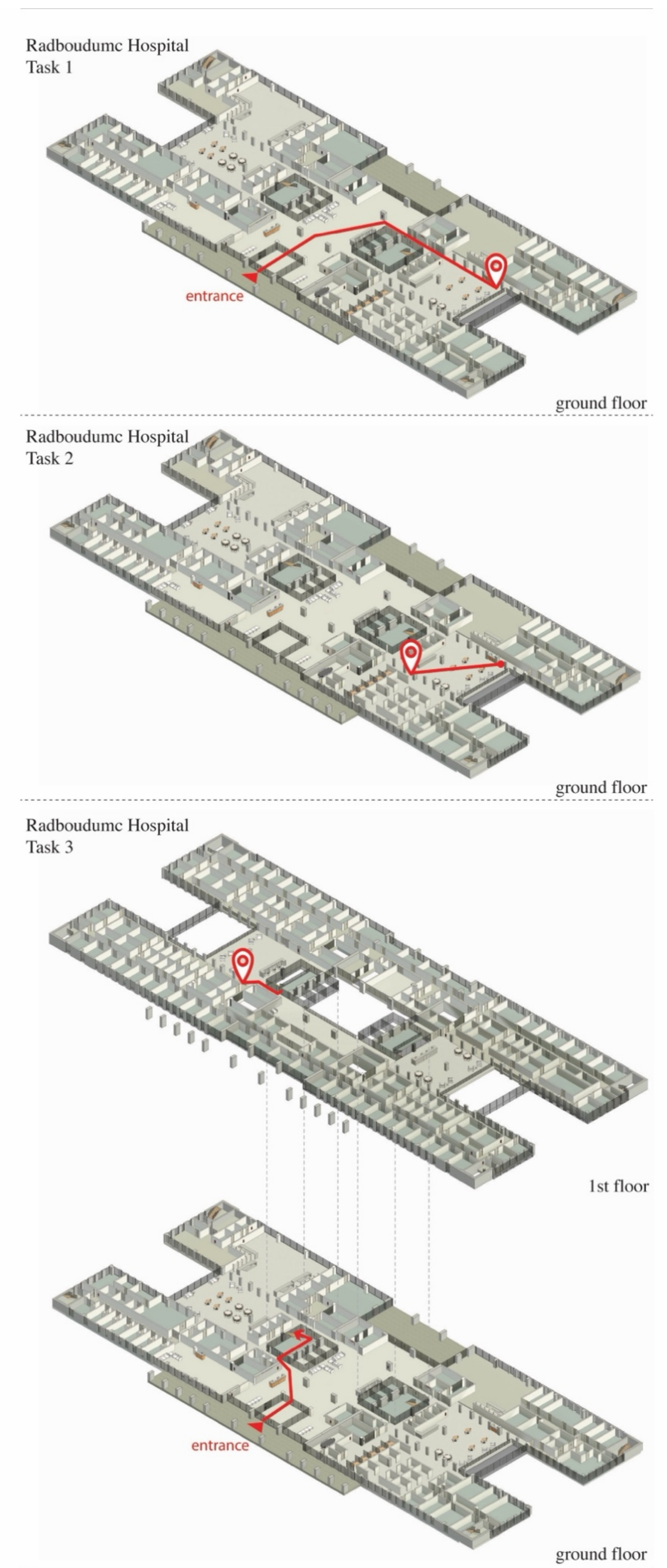


Figure 4.6 (continued): 3 wayfinding tasks in each building.

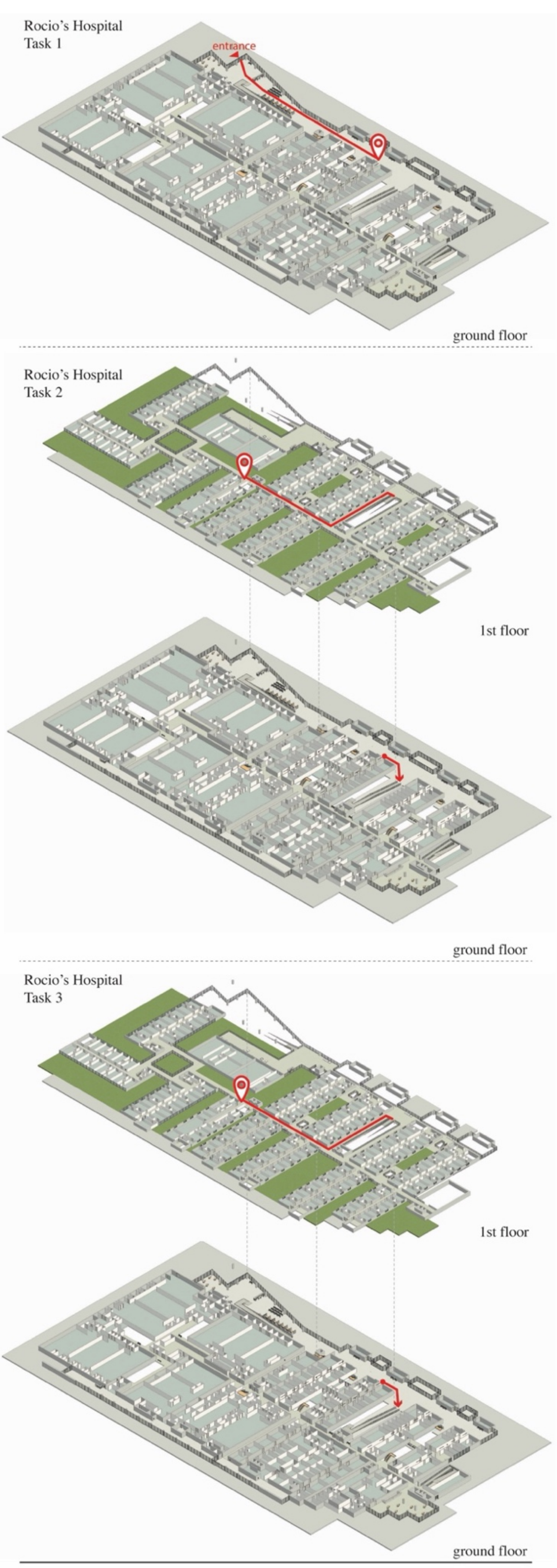


Figure 4.6 (continued): 3 wayfinding tasks in each building.

4.5 Experimental Setup

The iVR experiment consists of assigning 3 wayfinding tasks to 3 participants in VEs of the 3 selected hospital buildings. These VEs are produced by converting the architectural drawings of the buildings into 2D digital drawings and then into 3D models. iVR is utilised for the experiment using Oculus Quest 2 HMD with controllers as shown in Figure 4.7. The HMD provides a 360-degree VE view, completely blocking vision from the real world. The controllers provide interaction with the VE by reflecting the location and position of its user's hand in the real world to the virtual world. The controllers also control one's virtual reflection allowing its relocation in VE. Through these features, Oculus Quest 2 offers a fully immersive VR experience.

Figure 4.7 : Oculus Quest 2 VR set including an HMD and two controllers.

On the other hand, the 3D models which are created in Revit cannot be directly viewed in a VR environment since Revit doesn't have direct integration with a VR system. Because of this, the models are transferred to the VR environment using a third-party programme, Iris VR. The 3D models uploaded to the Iris VR's online system can be experienced as VEs through the software installed on the VR set. The views from the VEs can be seen in Figure 4.8. During the experiment, the real-time display of the headset is recorded for later use for the analyses. This real-time view is also reflected onto a computer to know the position of the participant simultaneously, to control the

disruptions that may occur during the experiment and to answer the info desk questions correctly during the experiment.

The functions of the buttons on the controllers vary depending on the program used. The functions assigned to the 2 buttons on the controllers used during the experiment in Iris VR are shown in Figure 4.9. During the experiment, two buttons on the right controller are used for movement. The right thumbstick controls the walking movement and the right trigger provides teleportation while using doors or the circulation elements. Due to software constraints, the doors and the stairs can only be used by teleportation. Since the way of teleportation differs each time, the duration of teleportation is not included in the experiment time. The participant does not need to walk in real life, the only physical movement necessary in real life is to turn around at the point where they are providing orientation. Head movements are transferred to the VE one-to-one enabling the participants to see their surroundings 360 degrees.

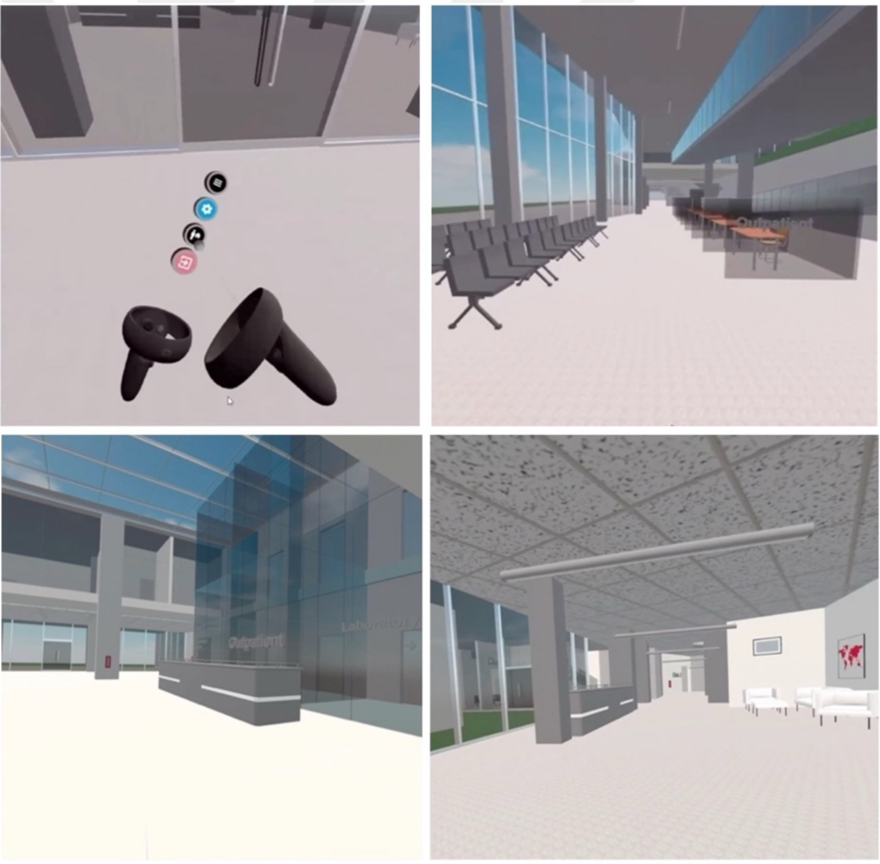


Figure 4.8 : The views from VEs. From top left to bottom right: The controllers in VE, the entrances of Rocio's Hospital, Radboudumc Hospital and Pars Hospital.

Figure 4.9 : The functions of the buttons used during the experiment on the controllers.

The participants are asked to complete 3 wayfinding tasks successively. At the beginning of the experiment, a brief explanation about the experiment and the instructions about the controllers are given to the participants. For them to get used to the VE and the use of controllers, they are allowed to move freely in an empty environment for a short time. After this short training, the experiment starts with Task 1. The virtual image is set to be the entrance of the building and put the HMD to the participant. The subjects are only told of the target location and do not receive any directions. There are signage tables placed around the building as well as information desks. The participants can use information desks to ask for any directions if they feel lost or find the signage insufficient. Their questions are answered by the experimenter by tracking their location on the real-time projected display on the computer. To prevent and detect cybersickness, the participants are asked after each task if they feel well and 10-minute breaks are provided. Likewise, they are asked to report any symptoms such as headache, nausea, and dizziness during the tasks. If these symptoms are observed, the subject does not continue the experiment. The details of the experiment process and experiment data are explained in the next chapter.

5. THE VR EXPERIMENT

The experiment was conducted by three participants, by assigning three wayfinding tasks in three different hospital buildings modelled for the VE. Each participant completed a total of nine wayfinding tasks for three buildings. The experiment was limited to three participants, to constrain the amount of data collected that could be further analysed. As explained previously, BSA focuses on each behaviour of the participants during the experiment. Therefore, the amount of data that needs to be collected and organised even for one person is quite large. Throughout the experiment, the process is recorded and these recordings are then used as data. The first subheading of this topic, (1) participant selection, explains how the participants were selected and gives information about them. The second part, (2) data collection, explains the raw data collection methods from the experiment and the last part, (3) data arrangement, explains how these raw data have been extracted and organised to meet the requirements of various analyses. Data arrangement is one of the most important aspects of this study, as a detailed and large data pool has been created specifically for BSA and its organisation is critical to the accuracy of the analysis results. 937 behaviours with their corresponding V values are prepared for a total of 27 sequents from three tasks completed by three participants in three hospitals.

5.1 Participant Selection

Participants took part in the experiment to collect data for BSA. Behavioural sequences containing a large number of actions are obtained even from a single participant. The number of participants is limited to three and the size of the data set to be analysed is kept under control. The details about the participants can be seen in Table 5.1. Participants were selected from the same age range to prevent physical or cognitive differences that may arise from age differences during the experiment, and this age range was determined as 25-30. Two participants were architects and one of them was a publisher. For the iVR experiment, no prior VR experience was needed. One of the three participants had knowledge of VR and how to use the VR set. Each participant

was given a short training on how to move and orient in the VE, and how to use the controllers before the experiment, regardless of their experience since the controlling mechanism is dependent on the software used. The participant's experiment would be cancelled if cybersickness were observed. Since cybersickness was not observed, all the experiments were implemented fully.

Table 5.1 : Participant information.

Participant(P)	Age	Occupation	Previous VR Experience	Cybersickness
P1	27	Architect	Yes	No
P2	28	Architect	No	No
P3	29	Publisher	No	No

5.2 Data Collection

The whole experiment process was recorded to use for the analyses. The screen that the subjects saw in the VR glasses and the sounds were recorded during the experiment. Simultaneously, the image in the VR environment was projected on a computer screen to control the process. On the other hand, the routes followed by the subjects during the tasks were digitally mapped as 2D linework on the floor plans. An example of one participant's motion maps belonging to Pars Hospital can be seen in Figure 5.1. These are used for the calculation of the travelled distance and also overlaid with visibility maps to obtain point V value data by location from space syntax analysis. It is aimed to examine the relationship between behaviour and visibility by taking the V value of the current position according to time.

At the end of the experiments, a total of 9 video recordings from 3 participants were obtained with durations varying between 10 and 15 minutes. Each video recording includes 3 tasks in one hospital building. The raw videos required editing since the periods covering the use of circulation units such as stairs or ramps, and freezing when teleporting through the doors were cut out of the videos. These are factors that do not depend on the participant but may affect the participant's wayfinding performance overall. The edited videos were then arranged again so that each video contained a single task in a hospital for one participant thus increasing the number of videos to 27 (9 tasks for each participant x 3 participants). The video durations vary between 14 sec to 2 mins 35 sec. These videos provided the completion time of each scenario. This

time data is then used in the analysis section to calculate average speeds and identify the hospital where each participant is fastest or slowest.

Figure 5.1: Selected Example : The motion maps of 3 wayfinding tasks of P3 in Pars Hospital.

Since the experiment was undertaken in the VR environment, walking activity was provided through the thumbstick on the controller. The walking speed in the VR environment is independent of the actual walking speed and varies depending on the VR software used. In this study, walking speed is calculated by dividing the distance travelled by the task completion time and does not reflect the actual speed, only used for comparative analyses. The travelled distance is calculated through the motion maps. To sum up, the data collected from the experiment can be listed as (1) video recordings which are the source of sequential behaviour data and time data, and (2) motion maps as the source of travelled distance data and the current location data. These collected data were extracted and arranged according to certain rules for various analyses. This process is explained in detail in the next section.

5.3 Data Arrangement

The collected data from the experiment were organised according to specific rules based on the type of analysis to be performed. As seen in Figure 5.2, there are four types of analyses and additionally Space Syntax Analysis, and the input data required for them is explained in this chapter. The Space Syntax Analysis provide visibility maps of each hospital building to later utilise in Analysis 2. Analysis 1 examines the relations among wayfinding behaviours while Analysis 2 associates these behaviours with the spatial characteristics of the buildings. Analysis 3 further examines the durations of the behaviours and Analysis 4 simply evaluates the average speeds for each hospital building.

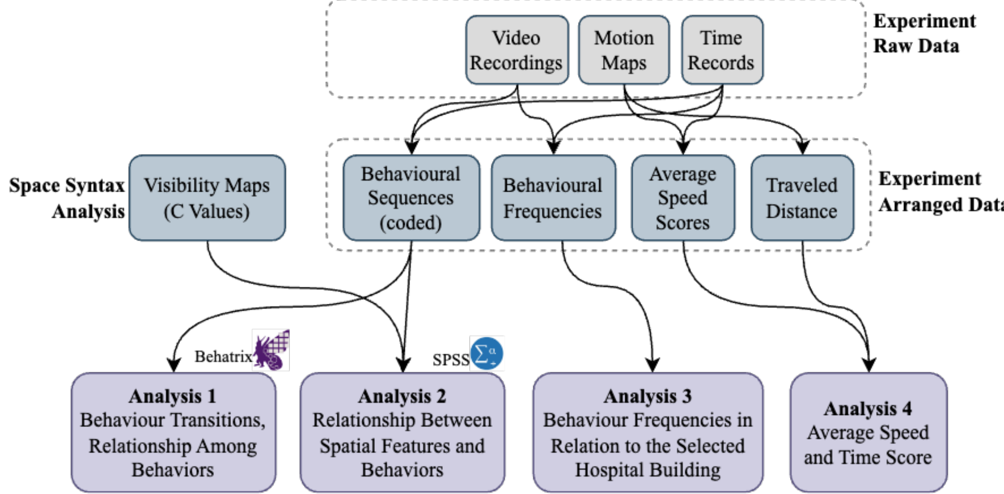


Figure 5.2: The collected raw data, the arranged data and the analyses they were used in.

- Analysis 1 - BSA: Video recordings and time records were utilised for BSA, Analysis 1. The behaviours according to time are arranged as behavioural sequents. A total of 937 behaviours and 31 minutes 52 seconds are analysed in this study. The BSA requires a series of sequential behaviours along with their corresponding codes. The behaviours observed during the experiment were listed under 5 main groups and each was assigned a unique letter code as seen in Table 5.2 with their description.

Table 5.2 : Behavioural Codes Table.

Behavioural Group	Behaviour	Code	Description
walking	walk forward	a	walking forward
	slight walk leftward	b	walking slightly leftward without stopping
	walk leftward (180 degrees)	c	turning back from left side and walking forward without stopping
	slight walk rightward	d	walking slightly rightward without stopping
	walk rightward (180 degrees)	e	turning back from right side and walking forward without stopping
using circulation units	pass through door	f	
	use stairs	g	
	use ramp	h	
pause	pause (orientation change)	i	pause to change orientation
	pause (search)	j	pause to look around and search for way
	pause (lock eye to signage)	k	pause to look at the signage
	pause	l	pause for a short while without changing orientation, looking around or at a signage.
orientation	slight leftward orientation	m	orienting slightly to the left while stopping
	leftward orientation (90 degrees)	n	orienting to the left while stopping
	turn back from left side	o	turning back from left side while stopping
	slight rightward orientation	p	orienting slightly to right while stopping
	rigtward orientation (90 degrees)	q	orienting to the right while stopping
	turn back from right side	r	turning back from right side while stopping
interaction	info desk interaction	s	stopping in front of info desk and asking questions

The videos were analysed to extract behavioural information based on time. Listing behaviours without breaking their order is critical for BSA. The behavioural table for task 2 of Participant 3 in Pars Hospital can be seen in Table 5.3 as an example. This task includes 40 behaviours with a 55-second duration. The corresponding codes of the behaviours are also listed across them for later use in BSA.

Table 5.3 : Selected Example : The behavioural table representing task 2 of P3 in Pars Hospital.

Time(sec)		Behaviour	Code
Start	End		
0	4	walk forward	a
4	5	pause	l
5	6	pass through door	f
6	9	walk forward	a
9	10	pause (orientation change)	i
10	11	slight walk leftward	b
11	13	slight walk rightward	d
13	15	slight walk leftward	b
15	16	walk forward	a
16	17	pause (orientation change)	i
17	18	rightward orientation (90 degrees)	q
18	19	leftward orientation (90 degrees)	n
19	25	walk forward	a
25	27	slight walk rightward	d
27	28	pause (orientation change)	i
28	29	leftward orientation (90 degrees)	n
29	30	pause (search)	j
30	31	walk forward	a
31	32	slight walk leftward	b
32	33	slight walk rightward	d
33	33	pause (orientation change)	i
33	34	rightward orientation (90 degrees)	q
34	35	leftward orientation (90 degrees)	n
35	37	walk forward	a
37	38	slight leftward orientation	m
38	39	slight leftward orientation	m
39	40	rightward orientation (90 degrees)	q
40	41	walk forward	a
41	42	slight leftward orientation	m
42	43	slight walk rightward	d

Table 5.3 (continued): Selected Example : The behavioural table representing task 2 of P3 in Pars Hospital.

Time(sec)		Behaviour	Code
Start	End		
43	44	walk forward	a
44	45	pause (search)	j
45	46	slight walk leftward	b
46	47	rightward orientation (90 degrees)	q
47	49	walk forward	a
49	50	pause (orientation change)	i
50	51	leftward orientation (90 degrees)	n
51	52	rightward orientation (90 degrees)	q
52	53	pause	l
53	55	walk forward	a

- **Analysis 2 - Visibility and Behavioural Relationship:** The behavioural tables, visibility maps and motion maps are the inputs for this analysis. The overlaid motion and visibility maps provide point V value data by location to relate behaviours with the visibility of the location. An overlaid example of a visibility and a motion map can be seen in Figure 5.3.

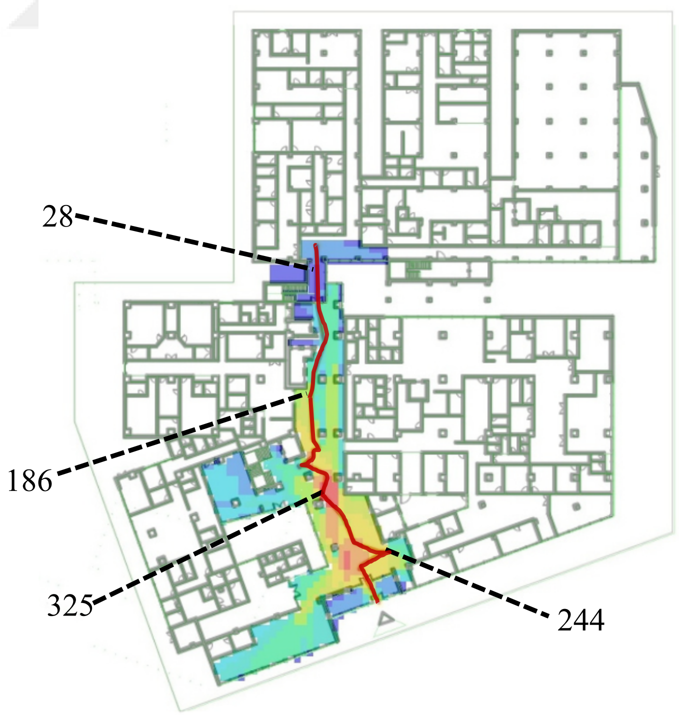


Figure 5.3 : Selected Example: The motion map of Task 1 of P3 and the visibility map of Pars Hospital ground floor overlaid. Examples of the point V values on the route are shown.

The behaviours and their corresponding V values were gathered together in tables for each task by tracking the location of the participants through the videos and utilising overlaid maps. An example of this table can be seen in Table 5.4. This table shows that the route followed for this task has visibility values ranging between 30 and 303.

Table 5.4 : Selected Example : Behavioural table including V values for Task 2 of P3 in Pars Hospital.

Time(sec)		**Code**	**V value**
Start	End		
0	4	a	55
4	5	l	37
5	6	f	30
6	9	a	110
9	10	i	140
10	11	b	130
11	13	d	128
13	15	b	145
15	16	a	141
16	17	i	142
17	18	q	178
18	19	n	160
19	25	a	177
25	27	d	277
27	28	i	281
28	29	n	281
29	30	j	275
30	31	a	260
31	32	b	276
32	33	d	291
33	33	i	291
33	34	q	291
34	35	n	292
35	37	a	280
37	38	m	269
38	39	m	235
39	40	q	231
40	41	a	259
41	42	m	233
42	43	d	245
43	44	a	276
44	45	j	303

Table 5.4 (continued): Selected Example : Behavioural table including V values for Task 2 of P3 in Pars Hospital.

Time(sec)		Code	V value
Start	End		
44	45	j	303
45	46	b	286
46	47	q	262
47	49	a	214
49	50	i	194
50	51	n	174
51	52	q	151
52	53	l	151
53	55	a	143

- **Analysis 3 - Behavioural Frequencies:** The behavioural tables have been reorganised for this analysis, and the duration of each behaviour has been calculated as seen in Table 5.4. This has been applied for all tasks to calculate later the total durations of each behaviour in each building.

Table 5.5 : Selected Example: Behavioural frequency table for Task 2 of P3 in Pars Hospital.

Duration (sec)	Code
4	a
1	l
1	f
3	a
1	i
1	b
2	d
2	b
1	a
1	i
1	q
1	n
6	a
2	d
1	i
1	n
1	j
1	a
1	b

Table 5.5 (continued): Selected Example: Behavioural frequency table for Task 2 of P3 in Pars Hospital.

Duration (sec)	Code
1	d
0	i
1	q
1	n
2	a
1	m
1	m
1	q
1	a
1	m
1	d
1	a
1	j
1	b
1	q
2	a
1	i
1	n
1	q
1	l
2	a

- **Analysis 4 - Average Speed and Time Score:** The travelled distance from the motion maps and the time data are used to calculate average speed scores for each task. The travelled distance, time and average speeds of Participant 3 in each task can be seen in Table 5.6 as an example. The building, where each participant was the slowest and fastest, can be also seen on these tables.

This chapter explained the arrangement of the data for four different analyses. These analyses are described in detail in the next section along with their results.

Table 5.6 : Selected Example: The average speed table of P3.

Building	Task 1			Task 2			Task 3			
	Time (sec)	Dist. (m)	Average Speed (m/s)	Time (sec)	Dist. (m)	Average Speed (m/s)	Time (sec)	Dist. (m)	Average Speed (m/s)	TotalAv. Speed (m/s)
Pars Hospital	88	73,9	0,84	51	61,5	1,21	42	47,7	1,14	1,06
Radboudumc Hospital	129	99,4	0,77	14	19,5	1,39	46	57,9	1,26	1,14
Rocios Hospital	90	122,5	1,36	155	164,3	1,06	96	114,2	1,19	1,20

YK

6. DATA ANALYSIS AND DISCUSSIONS

This study mainly focuses on behaviours during wayfinding through BSA while conducting other analyses. It is aimed to make more accurate inferences by integrating BSA with the results of other analyses. The collected and arranged data was used for Space Syntax Analysis and then 4 types of analyses were conducted which include the output of Space Syntax Analysis. These four types were explained separately and then comprehensively with the results in this chapter. These analyses can be listed as follows:

- **Analysis 1- BSA:** Focusing on the behaviours and the relations between them during the wayfinding process, associating them with the building.
- **Analysis 2- Visibility and Behavioural Relationship:** Focusing on the behaviours and the visibility of the current location where the behaviours occur to associate spatial characteristics of a space with wayfinding performance.
- **Analysis 3- Behavioural Frequencies:** Measuring the total durations of the behaviours and interpreting them within the building context.
- **Analysis 4- Average Speed:** Calculating the average speed of the participants in each building to comprehend the relationship between spatial characteristics and wayfinding performance.

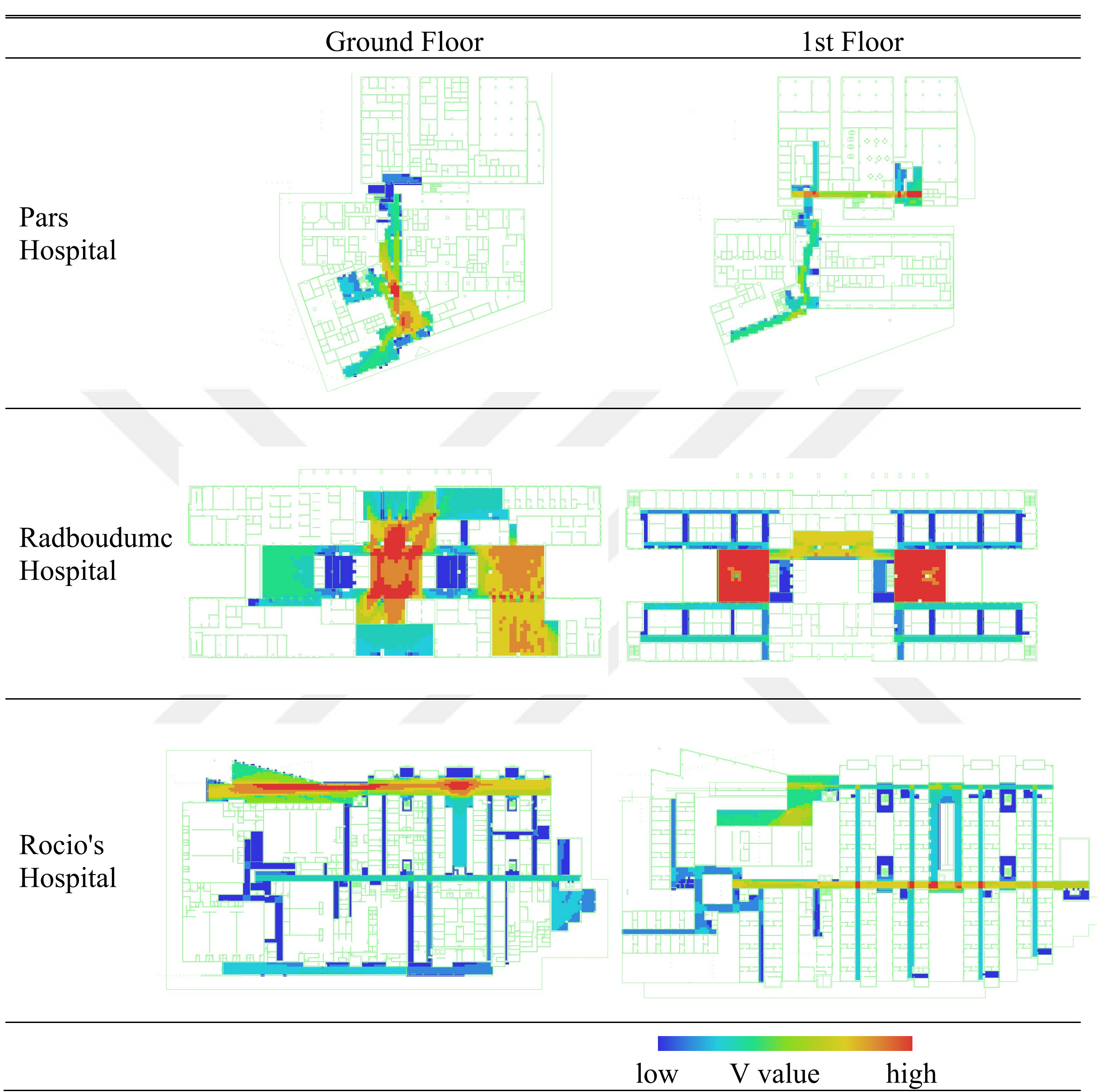
The details and results of these analyses are explained extensively in the following chapters.

6.1 Space Syntax Analysis

The visibility graph analysis of each building was conducted using DepthMapX software and the visibility maps of the buildings can be seen in Table 6.1. Because of its bigger space, Rocio's Hospital has far higher V values than the other two buildings, as Table 6.2 demonstrates. However, visibility decreases in all three buildings on the first level as a result of large entrance areas on the ground floors and a higher number

of corridors on the first floors. V values on the ground floors can be quite different from each other, whereas V values on the 1st floors are quite close to each other.

Table 6.1 : Visibility maps of each floor of buildings.



Radboudumc Hospital which has a centralised space layout has a visibility map where higher V values are more common in terms of the distribution, especially at the centres. The semi-centralised type, Rocio's Hospital also has areas with high V values where the semi-centres and the connecting corridors meet.

Higher visibility provides better visual access which defines the accessibility of one's vision (Li & Huang, 2020), improving wayfinding performance. However, this is a general discourse that is measured on a single variable and ignores other spatial characteristics.

Table 6.2 : V values for each building.

	V values			
	Ground Floor		1st Floor	
	min	max	min	max
Pars Hospital	2	336	8	135
Radboudumc Hospital	17	591	8	219
Rocio's Hospital	0	1536	1	229

Many environmental factors affect one's spatial experience and wayfinding performance in a building. Since it is almost impossible to calculate all spatial factors and make an inference, direct observation of human behaviour will provide the closest results to the evaluation obtained by calculating all factors. In this study, whether visibility and wayfinding performance progress in direct proportion is evaluated by observing human behaviour in VEs.

6.2 Analysis 1- BSA

BSA inspects the behaviours and the transitions among them to reveal the influence of behaviours on each other and the patterns observed in transitions. Wayfinding behaviours and transitions were examined associated with the space using BSA. Behatrix was used as the BSA software since it is an easy-to-use open-source software developed at Torino University. Behatrix takes a sequence of behavioural codes such as "afbpaiqnainaiqadinqjajfa". Each letter describes a behavioural code and the observed sequence of behaviours is preserved. The BSA gives the number of unique behaviours, total number of behaviours, number of unique transitions, total number of transitions and the transition matrix table which shows the count of the transitions for each behavioural pair. The transition matrices are the important outputs for this study to examine how spatial characteristics affect the occurrence of certain transitions. Transition matrices seen in Table 6.3 were created by looking at the total behavioural data from all participants for each hospital by BSA. These matrices comprise the behavioural codes previously explained in Chapter 5, Table 5.3 and the transitions count for each pair. Each matrix contains the code of the behaviours observed during the wayfinding tasks in the building to which it belongs. The codes on the vertical axis of the tables are the first behaviours in behaviour pairs and the codes on the horizontal axis are the second. For example, the a-b transition has a count of ten while b-a has 4 in Pars Hospital. The behaviours c and h were not observed at Pars Hospital and are

therefore not present in the matrix table. The transition matrices show that the most observed behavioural pairs are a-i for Pars Hospital (count 15), Rocio's Hospital (count 24), and n-a for Radboudumc Hospital (count 13).

Table 6.3 : The transition matrices of three hospital buildings.

Pars Hospital Transition Matrix

	a	b	d	e	f	g	i	j	k	l	m	n	o	p	q	r	s
a	4	10	8	0	10	2	15	10	8	7	4	3	0	3	1	0	0
b	4	1	9	1	0	0	1	1	1	1	0	0	0	1	4	0	0
d	6	4	0	0	1	1	7	1	2	2	0	1	0	0	0	0	0
e	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f	10	2	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0
g	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
i	0	1	0	0	0	0	0	0	0	0	5	6	1	2	8	0	0
j	12	3	1	0	1	0	0	0	0	0	1	1	0	1	3	1	0
k	6	1	1	0	0	0	0	0	0	0	0	2	1	0	3	0	0
l	7	1	3	0	2	0	0	0	1	0	0	0	0	0	0	0	0
m	8	0	2	0	0	0	0	0	0	0	1	0	0	1	2	0	0
n	9	0	0	0	1	0	0	5	0	2	0	0	0	0	3	0	0
o	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
p	3	0	0	0	0	0	0	1	0	1	2	1	0	0	0	0	0
q	10	2	1	0	0	0	0	2	2	1	1	5	0	0	0	0	1
r	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
s	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Radboudumc Hospital Transition Matrix

	a	b	d	f	g	i	j	k	l	m	n	o	p	q	r	s
a	3	12	12	8	0	4	8	3	5	3	6	2	2	6	1	0
b	6	2	6	3	0	4	2	1	0	0	2	0	0	4	0	0
d	10	6	0	2	0	3	1	0	0	0	0	1	0	1	0	1
f	2	2	0	0	1	2	3	3	1	1	2	0	1	1	0	0
g	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
i	0	0	0	0	0	0	0	0	0	2	7	2	1	5	0	0
j	9	2	4	0	0	1	0	0	0	0	1	1	5	0	0	0
k	4	2	0	0	0	1	0	0	0	0	1	0	0	5	0	0
l	5	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
m	1	0	0	0	0	0	0	1	1	0	0	0	2	1	0	0
n	13	1	1	2	1	0	1	3	0	0	0	0	2	1	2	0
o	3	2	0	0	0	0	2	0	0	0	1	0	1	0	0	0
p	5	0	0	2	0	0	4	0	0	0	3	0	0	0	0	0
q	11	2	1	1	1	0	1	2	0	0	4	2	0	0	0	0
r	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
s	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Table 6.3 (continued): The transition matrices of three hospital buildings.

Rocio's Hospital Transition Matrix

	a	b	d	f	g	h	i	j	k	l	m	n	o	p	q	r
a	1	15	15	3	2	2	24	6	4	7	0	1	0	2	7	1
b	8	0	9	1	0	0	4	1	2	0	0	0	0	1	1	1
d	11	9	1	1	0	1	5	0	1	0	1	0	0	0	1	1
f	2	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1
g	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0
h	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
i	0	0	0	0	0	0	0	0	0	0	3	10	3	4	13	3
j	3	2	1	0	0	0	0	0	0	0	0	0	0	0	1	2
k	0	0	0	0	0	0	0	0	0	0	0	4	1	0	2	2
l	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
m	5	0	1	0	0	0	0	0	0	0	0	0	0	3	0	0
n	21	1	1	0	0	0	1	1	0	0	0	0	0	0	8	3
o	5	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0
p	3	0	2	0	1	0	0	0	0	0	4	0	0	0	0	0
q	20	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0
r	5	0	0	0	0	0	0	0	1	0	1	4	3	0	0	2

The most observed transitions are listed in Table 6.4. On the other hand, the most observed transitions with the expected and observed route maps can be found in Appendix A to better understand the relationship between routes and behaviours. The transition a-i is common for both Pars and Rocio's Hospital. The participants often paused to change their orientation while walking forward, indicating that they were unsure of the direction they were following. The second common observation at Pars Hospital is the j-a pair, where participants walked forward following a searching pause, suggesting that their search behaviour influenced their path forward. The a-i and j-a combined prove that the participants were unsure of their route but a pause for search made them sure of it. Other commonly observed pairs like a-b and a-j, which signify pausing and orienting movements following walking, also support this indecisiveness. This indecision may lead to stress or a waste of time.

The n-a is the most observed pair in Radboudumc Hospital while a similar pair q-a is another common one. These pairs represent 90 degrees of orientation while walking indicating sharp moves and decision changes without stopping. On the other hand, a-b, a-d and d-a pairs support these quick decision changes. The participants often changed their route without stopping. This may imply rapid decisions made under stress or without careful consideration. The a-i is the most observed pair in Rocio's Hospital like in Pars Hospital. The participants often paused to search and then oriented 90 degrees. They were unsure of their route, stopped to consider, searched

around and took sharp turns indicating a slow decision process. The q-n pair is remarkable as it signals to give up the decision by turning in the opposite direction after a 90-degree turn. The a-b and a-d reveal the indecisiveness with slight orientations while walking without pausing.

Table 6.4: The most observed transitions of three hospital buildings. From top to bottom: most observed to least observed.

Pars Hospital		Radboudumc Hospital		Rocio's Hospital	
a-i	walk forward- pause (orientation change)	n-a	leftward orientation (90 d.)- walk forward	a-i	walk forward - pause (orientation change)
j-a	pause(search)- walk forward	a-b	walk forward - slight walk leftward	n-a	leftward orientation (90 d.)- walk forward
a-b	walk forward- slight walk leftward	a-d	walk forward - slight walk rightward	q-a	rigtward orientation (90 d.)- walk forward
a-f	walk forward- pass through door	q-a	rigtward orientation (90 d.)- walk forward	q-n	rigtward orientation (90 d.)- leftward orientation (90 d.)
a-j	walk forward- pause (search)	d-a	slight walk rightward- walk forward	a-b	walk forward slight walk leftward
f-a	pass through door- walk forward	j-a	pause (search)- walk forward	a-d	walk forward- slight walk rightward
q-a	rigtward orientation (90 d.)- walk forward	a-f	walk forward- pass through door	i-q	pause (orientation change)- rigtward orientation (90 d.)
		a-j	walk forward- pause (search)		

The results of BSA are summed up below:

- Pars Hospital with the decentralised plan layout directed the users to pause frequently to check the validity of their routes even though they were mostly on the right path leading to unnecessary pauses and loss of time.
- Radboudumc Hospital having a centralised plan layout with two symmetrical halves connecting at the centre led the users to make quick decisions that were not always correct.
- At Rocio’s Hospital, users made slow and thoughtful decisions, even if sometimes wrong ones creating a less stressful wayfinding experience.

The next chapters analyse the other data such as visibility, behavioural frequencies and average speed to validate the results from BSA.

6.3 Analysis 2- Visibility and Behavioural Relationship

Analysis 2, examines the relationship between behaviour and building visibility by using cross-tabulation between behaviours and V values. The purpose of this analysis is not to compare hospitals but rather to assess the effect of visibility on behaviour so no distinction was made according to hospitals. The 937 behaviours observed throughout the entire experiment were analysed with their respective V values to have valid results. SPSS, a statistical analysis software was utilised for cross-tabulation. The cross-tabulation table shows the percentage of each behaviour at certain V values and the total count of unique behaviours observed at each visibility level. The V values were rounded to the nearest 50 to facilitate the interpretation of the analysis. The behaviour row is divided with borders into behavioural groups as shown previously in Table 5.2, again listed below:

- walking: a, b, d, e (The behaviour "c" hasn't been observed throughout the experiment)
- using circulation units: f, g, h
- pause: i, j, k, l
- orientation: m, n, o, p, q, r
- interaction: s

For example, looking at the V value 1000 in Table 6.5, the behaviour coded "a" is observed at a rate of 0.5, followed by "n" with a rate of 0.3. As expected, walking behaviour with the code "a" has the highest rate at almost every C level. Overall, the walking group(a, b, c) was more common at high visibility levels (>800) indicating participants tended to walk more and make slight orientation changes during walking. The pause group (i, j, k, l) was observed more at low visibility levels. This proves that the participants tend to pause in low visibility and walk in high visibility. The pause was mainly for orientation change(i) or no reason(l) in high visibility levels. The pause observed at low visibility levels was for orientation change(i), search(j) or looking at the signage(k) at low visibility levels. This indicates that the participants often paused

to search for their way through analysing their surroundings or the signage at low visibility levels. The orientation group(m, n, o, p, q, r) was also observed more in low visibility.

Table 6.5 : The cross-tabulation table implies the percentage of behaviours within each V value (0 percentage represents the values between 0-0.05).

	Behaviour																				**Count of Unique Behaviours**
	walking				**using c.u.**			**pause**				**orientation**						**int.**		
Visibility	**a**	**b**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**		
0	0,2	-	-	-	-	0,4	-	-	0,2	-	-	-	0,2	-	-	-	-	-		4
50	0,3	-	-	-	0,1	0	-	0	0,1	0,1	0,1	0	0,2	0	0,1	0,1	0	-		13
100	0,3	0	0,1	-	-	0,2	-	-	0,1	0,1	-	0	0	-	-	0	-	-		9
150	0,3	0,1	0	-	0	-	0	0,1	0	0,1	0,1	0	0,1	0	0	0,1	0	-		14
200	0,2	0,1	0,1	-	0,1	0	-	0,1	0	0,1	0	0	0,1	0	0	0,1	-	-		14
250	0,3	0,1	0,1	0	0	-	-	0,1	0,1	0	0	0	0,1	0	0	0,1	-	0		15
300	0,3	0,1	0,1	-	-	-	-	0,1	0,1	-	0	0	0,1	0	0	0,1	0	-		12
350	0,3	-	0,1	-	-	-	-	0,1	0,1	-	-	0,1	0,1	-	-	0,2	0	-		8
400	0,1	-	0,1	-	-	-	-	0,3	-	-	-	0,2	0,2	-	-	0,2	-	-		6
450	0,2	0,1	0,1	-	0,2	-	-	0	0	0,1	0	-	0,2	-	-	0,1	0	-		11
500	0,3	0,1	0	-	-	0	0	0,1	0,1	0	0	-	0,1	0	0	0,1	-	0		14
550	0,3	0,1	0,1	-	0	-	-	0	0,1	0	-	0	0,1	0	0,1	0,1	0	-		13
600	0,1	0,1	0,1	-	-	-	-	0,2	-	-	-	-	0,1	0,1	-	0,1	-	-		7
650	-	0,1	-	-	0,3	-	-	0,2	0,2	-	-	0,1	-	-	0,2	-	-	-		6
700	0,2	0,2	0,1	-	-	-	-	0,1	0,1	-	-	-	0,1	0,1	-	0,1	0,1	-		9
750	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-		1
800	0,3	-	0,3	-	-	-	0,1	-	-	0,1	-	-	0,1	-	-	-	-	-		5
850	-	0,4	0,2	-	-	-	-	0,2	-	-	-	0,1	-	-	0,1	0,1	-	-		6
900	0,1	0,1	0,1	-	-	-	-	0,1	-	0,1	-	0,1	0,2	-	-	0,1	0,2	-		9
950	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		1
1000	0,5	-	0,1	-	-	-	-	-	-	-	-	-	0,3	-	-	0,1	-	-		4
1050	0,3	0,3	0,4	-	-	-	-	-	-	-	-	-	-	-	-	0,1	-	-		4
1100	0,4	-	-	-	-	-	-	-	0,1	-	0,3	-	0,1	-	-	0,1	-	-		5
1150	0,4	0,3	0,3	-	-	-	-	-	-	-	-	0,1	-	-	-	-	-	-		4
1200	0,4	-	0,3	-	-	-	-	0,1	-	-	-	-	-	0,1	-	-	-	-		4
1250	0,3	0,5	-	-	-	-	-	-	-	0,3	-	-	-	-	-	-	-	-		3
1300	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		1
1350	0,3	0,1	-	-	-	-	-	0,2	-	-	-	-	0,1	0,2	-	0,1	0,2	-		7
1400	0,3	0,1	0	-	-	-	-	0,2	-	-	-	0	0,1	-	0	0,1	0	-		9
1450	0,3	0	0	-	-	-	-	0,1	-	-	0	0,1	0,1	-	0,1	0,1	0,1	-		10
1500	0,4	-	-	-	-	-	-	0,2	-	-	0,2	-	-	-	0,2	-	-	-		4

The participants changed their orientation often in low visibility than in high visibility. The count of unique behaviours at each visibility level is a significant result showing the participants' determination during the wayfinding process. More behavioural shifts were detected during low visibility, but fewer during high visibility. It can be assumed that the participants were more stable at high visibility levels overall.

The results of this analysis can be summed up as follows:

- At high visibility levels the wayfinders:
    - walk more with slight orientation changes.
    - pause more for no reason showing momentary indecision.
    - are more decisive.
- At low visibility levels the wayfinders:
    - pause more to search around and utilise the signage.
    - change their orientation more.
    - are more indecisive.

6.4 Analysis 3- Behavioural Frequencies

Analysis 3, assesses the behavioural frequencies by examining the durations for behaviours in each hospital. This analysis aims to check the validity of the results of the previous analyses. Table 6.6 shows the frequencies and the percentages of the behaviours for each building. Walking forward (a) was the most frequent behaviour in all three buildings as expected and had the highest percentage at Rocio's Hospital. Also, the walking group as seen in Table 6.7, has a significantly higher percentage (80,1) at Rocio's Hospital. This suggests that the participants were more decisive and were able to find the way without frequently changing the direction or pausing. In Pars Hospital, the participants often looked at the signage (k), paused for searching (j) and slightly changed their orientation during walking (b, d). This indicates that the space itself was not very informative and the participants often looked for signage and clues by altering orientation during walking. Compared to the other two hospitals, the Radboudumc Hospital was the hospital in which the orientation movement during walking (b, d) was observed the most. In Radboudumc Hospital, the participants often altered their orientation during walking (b, d), more than in the other two buildings.

They also checked the signage (k) but not as much as in Pars Hospital. The most frequent behaviour after walking in Rocio's Hospital is slightly changing the orientation during walking (b, d). The participants didn't need to check the signage (k) as often as the other two buildings.

Table 6.6: The durations of the behaviours in each hospital (0 seconds represents the seconds between 0-0.5).

	Pars Hospital			**Radboudumc Hospital**			**Rocio's Hospital**	
Behaviour	**Duration(sec)**	**%**	**Behaviour**	**Duration(sec)**	**%**	**Behaviour**	**Duration(sec)**	**%**
a	222	46,1	**a**	249	45,6	**a**	574	67,5
k	44	9,1	**b**	64	11,7	**d**	70	8,2
b	40	8,3	**j**	52	9,5	**b**	37	4,4
d	36	7,5	**d**	37	6,8	**q**	36	4,2
j	30	6,2	**n**	30	5,5	**n**	28	3,3
q	27	5,6	**k**	29	5,3	**j**	23	2,7
n	20	4,1	**q**	25	4,6	**r**	23	2,7
i	16	3,3	**o**	15	2,7	**k**	16	1,9
l	15	3,1	**p**	12	2,2	**i**	13	1,5
m	10	2,1	**i**	9	1,6	**o**	12	1,4
s	8	1,7	**s**	9	1,6	**p**	10	1,2
p	6	1,2	**l**	5	0,9	**m**	5	0,6
o	4	0,8	**m**	5	0,9	**l**	3	0,4
r	3	0,6	**r**	5	0,9			
e	1	0,2						
Total	482	100	**Total**	546	100	**Total**	850	100

The overall percentages as seen in Table 6.7 show that Rocio's Hospital had the best scores among all three buildings with the least pause and orientation percentages. Pars Hospital was the worst-performing building with the highest pause and orientation percentage close to the highest. It can be assumed that Radboudumc didn't have a significant performance with high pause and orientation percentages.

Table 6.7: The percentages of frequencies of behavioural groups (%).

Behavioural Group	Pars H.	Radboudumc H.	Rocio's H.
Walking	62,0	64,1	80,1
Pause	21,8	17,4	6,5
Orientation	14,5	16,8	13,4

6.5 Analysis 4- Average Speed

Analysis 4 focuses on the virtual average speeds of the participants. The virtual average speed is calculated by dividing the travelled distance of each participant by task completion time. As mentioned in previous chapters, this speed doesn't reflect the real walking speed but is associated with the virtual walking speed based on the VR software used. Table 6.8 shows each participant's average speed in each hospital building. Red color indicates the participant's slowest speed and green the fastest. All three participants had the highest average speed in Rocio's Hospital where the visibility was the highest and the floor area was the largest. Two of the three participants scored the slowest in Pars Hospital where the visibility was the lowest and the floor area was the smallest. In Radboudumc Hospital, one participant scored the slowest. The results show that Rocio's Hospital performed the best while Pars Hospital performed worst according to the average speed analysis.

Table 6.8 : The average speed of participants (P) based on the building.

	Average Speed (m/s)			
	P1	P2	P3	Total
Pars Hospital	1,16	1,27	1,06	1,16
Radboudumc Hospital	1,25	1,15	1,14	1,18
Rocio's Hospital	1,26	1,33	1,20	1,26

Furthermore, with task-based average speed data, the fastest completed task overall can be analysed without associating with the building. Table 6.9 shows the fastest completed task is Task 2. Task 2 consists of a route only on the ground floor in two of three hospitals, while in one hospital it consists of a route that requires changing the floors. The slowest completed task is Task 3 which consists of a route requiring changing from the ground floor to the first floor in all hospitals. The search for the circulation element might be the cause of this speed drop. On the other hand, the tasks were assigned to the subjects in the order indicated by their numbers during the experiment. In Task 1, the subjects tried to navigate in a completely unknown space, while in Tasks 2 and 3, they tried to navigate in a space they had previously experienced partly. Considering learned memory, the average speed was expected to be Task 3>2>1, whereas the actual results were Task 2>3>1. While the speed increased in Task 2 after Task 1, Task 3 was the slowest completed task. This indicates that factors such as spatial and task characteristics may override the advantage of learnt data.

Table 6.9: The average speed based on the tasks.

Task	Average Speed (m/s)
Task 1	1,20
Task 2	1,27
Task 3	1,14

6.6 Comparison of the Outputs

Four analyses were conducted and explained separately in the previous chapters. This section attempts to select the best-performing plan layout among the three hospitals by interpreting the four analyses holistically. The results' accuracy will be assessed by examining them together through questioning. The result of each analysis is summed up in Table 6.10.

Table 6.10 : The hospital buildings' plan layout characteristics, floor areas and the results of each analysis.

	Analysis 1 BSA	**Analysis 2** Visibility x Behaviour	**Analysis 3** Behavioural Frequency	**Analysis 4** Average Speed
Pars Hospital decentralised ~10.500 m^2	• frequent and unnecessary pauses for search • orientation after pause	lowest overall visibility: • frequent pause for search • frequent utilisation of signage • overall more indecisive wayfinders	• highest utilisation of signage • highest pause	• lowest average speed
Radboudumc Hospital centralised ~10.700 m^2	• quick moves and decision changes while walking • wrong decisions	average visibility close to the lowest overall visibility, no significant results	• frequent orientation change during walking • high pause	• average speed close to the slowest
Rocio's Hospital semi-centralsied ~33.300 m^2	• slow decision process • decision abandonment evident	highest overall visibility: • aimless pauses as a result of momentary indecision • overall more decisive wayfinders	• lowest pause and orientation change	• highest average speed

Table 6.10 shows the results of each analysis separately. Pars Hospital has the smallest floor area, lowest visibility, and a decentralised plan layout. The BSA analysis

suggests that the users take frequent and mostly unnecessary pauses even though their route is right indicating indecisiveness. The second analysis shows that based on the experiment, the wayfinders spend significant time searching surroundings, utilising signage, and are more indecisive in low visibility which is compatible with Pars Hospital. The first two analyses are in line with each other. The third analysis for Pars Hospital suggests that the users often pause and utilise signage. The results show that the first three analyses for Pars Hospital are consistent with each other. It can be assumed that it provides a poor-quality wayfinding experience, causing users to take frequent and sometimes unnecessary pauses. The slowest average speed score from Analysis 4 also supports this result. On the other hand, the users frequently utilise signage since the space itself is not informative enough despite its small floor area.

Radboudumc Hospital has a centralised floor plan with two symmetrical halves and a floor area close to the smallest. BSA suggests that users make quick decisions while in motion, resulting in occasional errors. Analysis 2 doesn't show a significant compatible result for Radboudumc Hospital since its visibility values are average close to the lowest levels. The results of Analysis 3 support Analysis 1, emphasising the frequency of orientation change while walking. Analysis 3 also indicates the high pause frequency. The result of Analysis 4 indicating slow speed, supports the results of Analyses 1 and 3. The reason for the slow speed is frequent orientation changes and pauses. Overall, the analyses for Radboudumc Hospital are consistent with each other and point to a poor quality wayfinding experience. This may be because two symmetrical halves united at the centre are very similar to each other, which can be confusing.

Rocio's Hospital has a semi-centralised floor plan with the largest floor area and highest visibility levels. According to the BSA, it offers its users a calmer and slower navigation experience although a trend of decision abandonment is evident. Analysis 2 suggests the users are more decisive although pauses due to momentary indecision are observed. While there are instances where the users waver in their decisions and abandon them for brief moments, they typically exhibit a more decisive front in general. The low orientation change and pause rate obtained from Analysis 3 support the decisive profile of Rocio's Hospital's users. The last result from Analysis 4, the highest average speed data also points to a more stable and quick wayfinding process

in general. The overall results show that Rocio's Hospital offers its users a more comfortable wayfinding experience than the other two hospital buildings.

Rocio's Hospital despite its large floor area was the easiest building to navigate among three hospital buildings. Rocio's Hospital which has a semi-centralised floor plan resulting in high visibility provided a wayfinding experience where the participants did not need to use frequent signage and proceeded calmly. The space consisting of three main parallel corridors connected by perpendicular intermediate corridors was informative enough and not confusing. Considering all the spatial features brought by the plan scheme holistically, the integrated result based on the experiment shows that high visibility provides the most efficient wayfinding performance. Pars Hospital was the hardest building to navigate even though it had a small floor area. The decentralised floor plan led to irregularity in the spatial arrangement and low visibility values which were not informative enough. Radboudumc Hospital with a centralised floor plan performed close to, if not the worst. The regular spatial arrangement with two symmetrical halves connecting at a centre was confusing for the participants.

6.7 Discussion

Although the experiment was conducted with only three participants, each behaviour was recorded separately resulting in a total of 937 behavioural data and their corresponding visibility values by using BSA. With BSA, the wayfinding processes of the participants were not interrupted while collecting this data. Raw and instantaneous data could be obtained instead of ones that would pass through the filter of the person's interpretation, free from personal influences. Thinking processes that even the participants were not aware of were extracted by analysing transitions of behaviours. On the other hand, VR provided a controllable experimental environment, in which only the plan layout was variable and other environmental factors such as lightning, heat and crowd remained constant as much as possible. Thus, it can be assumed that the floor plan layout shaped the results predominantly from the spatial features. The detail level of the data collected in VR was also higher than it would be in reality through the ability to see the participant's head movements and point of view.

Four different analyses were evaluated individually and then holistically. The accuracy of the results of Analysis 3 could be questioned when interpreted alone due to the small amount of data. All four analyses pointed to the same results for each hospital building

proving that the interpretation of the behaviours provides valuable information about the spatial performance and wayfinding experience of the users. This provided a methodology for the assessment of wayfinding performance while the results are not final judgements.

As explained in the previous chapter, the findings indicate that the semi-centralised floor plan layout as seen in Rocio's Hospital offers the most efficient and comfortable wayfinding performance. Meanwhile, the centralised and decentralised floor plan layouts offer a relatively lower quality experience in terms of wayfinding. Each type of plan layout directs the users to engage in different behavioural groups such as pausing frequently, shifting orientation, or walking more. The redirection determines the comfort, speed, and ease of the wayfinding process. On the other hand, the recurring connections between these behaviours revealed the dynamics of wayfinding thinking for each plan layout. The centralised floor layout directs the users to a fast-paced decision-making process, whereas the semi-centralised leads to a slow and efficient one. Lastly, the visibility of the space shaped by the floor plan layout significantly impacts the behaviours. There is a directly proportional relationship between visibility and wayfinding performance. Spaces with high visibility offer a more comfortable wayfinding experience to the wayfinders based on our experiment.

Non-environmental factors such as the participant profile and prior VR experience were two important factors that might have influenced the wayfinding performance of the participants. Two of the three participants who are architects performed a better average speed score than the only participant who is a publisher. The participant's slow speed in comparison to other participants only affected the comparison between participants; the comparison of the average hospital speeds remained unaffected. Thus the participant profile didn't have an impact on overall results. On the other hand, the participants were given the same training before the experiment and the time needed in a VE to get used to the system to prevent previous VR experiences from affecting the results. The overall results derived from data revealed which behaviours each floor plan layout type led people to and how this affected wayfinding performance. These results are of great importance, especially in the early design phase of human-centred hospital building design.

7. CONCLUSIONS

This study examined the wayfinding behaviour in detail by associating it with spatial characteristics in hospital buildings through iVR and BSA. The research questioned (1) the effects of spatial plan configuration on wayfinding behaviour, (2) the relationship between re-occurring behaviours during the wayfinding process depending on spatial characteristics, and (3) the extent and level of detail in behavioural data that can be gathered about human wayfinding through VR. A VR experiment in which three participants were assigned three wayfinding tasks in three hospital buildings was conducted to answer these questions. The hospital buildings were selected based on three different plan typologies from the built projects for the experiment. The buildings' visibility maps were constructed using space syntax analysis and subsequently utilised to analyse the relationship between spatial characteristics and behaviours. The buildings were designed in 3D and then transferred to a VR headset, which generated the VEs. Both the experiment process and the participants' motion maps were recorded. Several data types were taken out and organised from these records to satisfy the requirements for four distinct analyses. The results of the iVR wayfinding experiment provided valuable insights into human wayfinding behaviour and thinking based on spatial characteristics of hospital buildings.

The results answered the questions as follows, although they are not definitive:

1. Different floor plan layouts have directed people to different behavioural groups during the wayfinding process. The analysis of the transitions between behaviours revealed the participants' thought processes, and this analysis was associated with the plan layout. The decentralised floor plan layout led participants to frequent pauses and signage use. The centralised floor plan layout led participants to make quick decisions while in motion and to frequent pauses. The semi-centralised floor plan layout directed participants to walk more and to a slow decision process.

2. The reoccurring behaviours observed at certain visibility values revealed the relationship between spatial features and human wayfinding behaviour. The results showed that at high visibility levels, the wayfinders walk more, take momentary pauses and are more decisive. Meanwhile, at low visibility levels, the wayfinders pause more to search around, utilise the signage, change their orientation, and are more indecisive.
3. The ability to track the participant's head movements and points of view through the utilisation of VR provided detailed data about the participants' behaviours throughout the experiment. This detailed behavioural data was free from personal interpretation and the examination of the transitions among this data revealed the embedded thought process during wayfinding. VE provided a platform to track human behaviour in wayfinding. However, this research excluded the role of VR in the assessment of wayfinding. Future studies may focus on this task by extending the current scope of the thesis.

The original contribution of this research is driven by its methodology that integrates space syntax analysis, iVR and BSA. The results can be used to base a method to create human-centred structures by employing the plan layout typology that provides the most effective wayfinding outcomes, particularly in the early design stages. Moreover, accurate inferences can be drawn by analysing the user behaviour in the existing buildings to improve the user experience by using the methodology of this study. Apart from utilising the most optimal plan scheme in the early design stage, the spatial-behavioural connections detailed in this research can be used as a guide depending on the building typology and the desired user experience. This expands the range of applications for the study beyond the confines of hospital buildings.

In this study, the methodology was mainly developed to measure wayfinding performance, but it can be considered as a methodology that can contribute to the early design phase in future studies. It can create an environment where design ideas are tested in the schematic design phase by professional designers or architecture students. In architecture education where schematic design is considered the base, experiencing design ideas and assessing their performance may contribute to the design thinking process of the students.

The most significant limitation of the study was the capability mismatch between the software and hardware of VR. The VR experiment aimed to imitate the reality as much as possible with real like 3D models of the hospital buildings. The furniture, decorative items and plants inside and outside the buildings were placed in the 3D models to provide a sense of reality. The experiment could not be completed because of the massive 3D models causing frequent freezing of the VR glasses' display. Therefore, the majority of the furniture, plants, and decorative items were removed from the 3D models to make them simpler, decreasing the models' sense of reality. Another limitation was the lack of architectural data on hospital buildings, which influenced the hospital building selection process. Hospitals with accessible open-source, detailed, readable and scaled data, highly affected the selection process. An additional limitation was the time needed to prepare the experimental setup and arrange the data. The converting process of architectural information from images in jpeg format into 3D models was time-consuming. 3D modelling of one hospital building took up to three weeks. The data extraction from the recordings and arrangement were also long processes. The analysis and arrangement of one video recording took up to 3 hours based on the length of the video. New artificial intelligence-based technologies for 3D modelling or video analysis may be used to overcome this limitation and speed up the process in future studies.

One limitation that may have affected the study results was that the hospitals experienced the same order in the experiment. This may have affected the results due to learned memory. According to the experimental results, while the wayfinding speed was expected to be slower in the largest building, the fastest performance was observed in the building last in the experimental order. This may again be the learned memory effect.

In this study, individual differences among the factors affecting wayfinding were not discussed, but the participants' profiles may have affected their performance. Detailed analysis of individual profiles during the selection process was not evaluated using tests such as the Santa Barbara Sense of Direction Test. Since no individual performance comparison was made, it did not affect the results of this study, but this factor can be included in future studies.

The stress factor or wayfinding strategies that describe the information type and principles that wayfinders employ during the wayfinding process weren't in the scope

of this study. Future studies may extend the scope by examining the traces of stress utilising BSA, obtaining a more comprehensive interpretation of human wayfinding. Moreover, visibility was the only spatial aspect analysed quantitatively in this study. Other spatial characteristics such as colour, transparency or ceiling height may be included to measure their effects on wayfinding. Another important factor affecting wayfinding performance is crowd interaction which highly impacts the stress level of the wayfinders. This study didn't include crowd interaction in the experiment because of hardware and time constraints. Future studies may incorporate crowd simulations within the VEs and assess the impact on the wayfinding performance of the buildings.

To sum up, this study contributes to the wayfinding literature with its unique methodology. The findings provide important contributions about the influence of the floor plan layout on wayfinding behaviour. The practical implication of the findings may reduce the loss of time due to inefficiency in the wayfinding process.

REFERENCES

Ahmed, S., Muhammad, I. B., Isa, A. A., & Sani, M. A. (2020). Influence of spatial layout on wayfinding behaviour in a hospital environment in Nigeria. *Journal of Art Architecture and Built Environment*, *3*(1), 26–44. https://doi.org/10.32350/jaabe.31.02

Aksoy, E., Aydın, D., İskifoğlu, G. (2020). Hastanelerde plan şeması ve yön bulma kararları arasındaki ilişkinin analizi. *MEGARON / Yıldız Technical University, Faculty of Architecture E-Journal*. https://doi.org/10.14744/megaron.2020.21797

Alizadehsalehi, S., Hadavi, A., & Huang, J. C. (2020). From BIM to extended reality in AEC industry. *Automation in Construction*, *116*. https://doi.org/10.1016/j.autcon.2020.103254

Aloqaily, M., Bouachir, O., & Karray, F. (2023). Digital twin for healthcare immersive services: fundamentals, architectures, and open issues. *Digital Twin for Healthcare*, 39–71. https://doi.org/10.1016/b978-0-32-399163-6.00008-1

Al-Sharaa, A., Adam, M., Amer Nordin, A. S., Alhasan, A., Mundher, R., Zaid, O. (2022). Enhancing wayfinding performance in existing healthcare facilities using virtual reality environments to revise the distribution of way-showing devices. Buildings, 12(6). https://doi.org/10.3390/buildings12060790

Asher, L., Collins, L. M., Ortiz-Pelaez, A., Drewe, J. A., Nicol, C. J., & Pfeiffer, D. U. (2009). Recent advances in the analysis of behavioural organization and interpretation as indicators of animal welfare. *Journal of the Royal Society Interface*, *6*(41), 1103–1119. https://doi.org/10.1098/rsif.2009.0221

Aydoğan, H., & Şalgamcıoğlu, M. E. (2015). Architectural morphology and user behavior relationship in shopping malls: a comparative case study on forum shopping centers in Istanbul through syntactic analysis. In *Proceedings of the 11th Space Syntax Symposium*. Portugal: Instituto Superior Técnico, Departamento de Engenharia Civil, Arquitetura e Georrecursos.

Baskaya, A., Wilson, C., & Özcan, Y. Z. (2004). Wayfinding in an unfamiliar environment. *Environment and Behavior*, *36*(6), 839–867. https://doi.org/10.1177/0013916504265445

Bels, V. L., Pallandre, J. P., Pelle, E., & Kirchhoff, F. (2022). Studies of the behavioral sequences: the neuroethological morphology concept crossing ethology and functional morphology. *Animals*, *12*(11), 1336. https://doi.org/10.3390/ani12111336

Berkman, M. I., & Akan, E. (2018). Presence and ımmersion in virtual reality. *Encyclopedia of Computer Graphics and Games*, 1–10. https://doi.org/10.1007/978-3-319-08234-9_162-1

Beune, K., Giebels, E., & Taylor, P. J. (2010). Patterns of interaction in police interviews. *Criminal Justice and Behavior*, *37*(8), 904–925. https://doi.org/10.1177/0093854810369623

Cao, L., Lin, J., & Li, N. (2019). A virtual reality based study of indoor fire evacuation after active or passive spatial exploration. *Computers in Human Behavior*, *90*, 37–45. https://doi.org/10.1016/j.chb.2018.08.041

Carbonell-Carrera, C., Gunalp, P., Saorin, J. L., & Hess-Medler, S. (2020). Think Spatially with Game Engine. *ISPRS International Journal of Geo-information, 9*(3), 159. https://doi.org/10.3390/ijgi9030159

Chen, C.-H., Chang, W.-C., & Chang, W.T. (2009). Gender differences in relation to wayfinding strategies, navigational support design, and wayfinding task difficulty. *Journal of Environmental Psychology*, *29*(2), 220–226. https://doi.org/10.1016/j.jenvp.2008.07.003

Chen, M.-S., Ko, Y.-T., & Hsieh, W.-C. (2021). Exploring the planning and configuration of the hospital wayfinding system by space syntax: A case study of Cheng Ching Hospital, Chung Kang Branch in Taiwan. *ISPRS International Journal of Geo-Information*, *10*(8), 570. https://doi.org/10.3390/ijgi10080570

Cheng, K., & Newcombe, N. S. (2005). Is there a geometric module for spatial orientation? squaring theory and evidence. *Psychonomic Bulletin & Review*, *12*(1), 1–23. https://doi.org/10.3758/bf03196346

Deng, L., & Romainoor, N. H. (2022). A bibliometric analysis of published literature on healthcare facilities' wayfinding research from 1974 to 2020. *Heliyon*, 8(9), e10723. https://doi.org/10.1016/j.heliyon.2022.e10723

Diersch, N., & Wolbers, T. (2019). The potential of virtual reality for spatial navigation research across the adult lifespan. *Journal of Experimental Biology*, *222*. https://doi.org/10.1242/jeb.187252

Dogu, U., & Erkip, F. (2000). Spatial factors affecting wayfinding and orientation. *Environment and Behavior*, *32*(6), 731–755. https://doi.org/10.1177/00139160021972775

Ewart, I. J., & Johnson, H. (2021). Virtual reality as a tool to investigate and predict occupant behaviour in the real world: the example of wayfinding.

Journal of Information Technology in Construction, *26*, 286–302. https://doi.org/10.36680/j.itcon.2021.016

Feng, Y., Duives, D. C., & Hoogendoorn, S. P. (2022). Development and evaluation of a VR research tool to study wayfinding behavior in a multi-story building. *Safety Science*, *147*, 105573. https://doi.org/10.1016/j.ssci.2021.105573

Feng, Y., Duives, D. C., & Hoogendoorn, S. P. (2022). Wayfinding behavior in a multi-level building: a comparative study of HMD VR and desktop VR. *Advanced Engineering Informatics*, *51*. https://doi.org/10.1016/j.aei.2021.101475

Gsaxner, C., Eck, U., Schmalstieg, D., Navab, N., & Egger, J. (2021). Augmented reality in oral and maxillofacial surgery. *Computer-Aided Oral and Maxillofacial Surgery*, 107–139. https://doi.org/10.1016/b978-0-12-823299-6.00005-5

Gutierrez, M., Vexo, F., & Thalmann, D. (2008). *Stepping into Virtual Reality*. Springer Science & Business Media.

Gül, L. F. (2009). Evaluating design behaviour when using emerging collaboration technologies. *Architectural Engineering and Design Management*, *5*(3), 107–123. https://doi.org/10.3763/aedm.2008.0088

Hadi, K., & Zimring, C. (2016). Design to improve visibility. *HERD: Health Environments Research & Design* Journal, 9(4), 35–49. https://doi.org/10.1177/1937586715621643

Hamdi, Y., Akouaydi, H., Boubaker, H., & Alimi, A. M. (2022). Handwriting quality analysis using online-offline models. *Multimedia Tools and Applications*, *81*(30), 43411–43439. https://doi.org/10.1007/s11042-022-13228-w

Hillier, B., & Hanson, J. (1989). *The Social Logic of Space*. Cambridge University Press.

Howarth, P., & Costello, P. (1997). The occurrence of virtual simulation sickness symptoms when an HMD was used as a personal viewing system. *Displays*, *18*(2), 107–116. https://doi.org/10.1016/s0141-9382(97)00011-5

Hwang, N. K., Choi, J. B., Choi, D. K., Park, J. M., Hong, C. W., Park, J. S., & Yoon, T. H. (2021). Effects of semi-immersive virtual reality-based cognitive training combined with locomotor activity on cognitive function and gait ability in community-dwelling older adults. *Healthcare*, *9*(7), 814. https://doi.org/10.3390/healthcare9070814

Iftikhar, H., & Luximon, Y. (2022). The syntheses of static and mobile wayfinding information: an empirical study of wayfinding preferences and

behaviour in complex environments. *Facilities*, *40*(7/8), 452–474. https://doi.org/10.1108/f-06-2021-0052

Jamshidi, S., Ensafi, M., & Pati, D. (2020). Wayfinding in interior environments: an integrative review. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.549628

Jamshidi, S., & Pati, D. (2023). Identifying environmental elements and attributes that contribute to ındoor wayfinding: an exploratory study utilizing think-aloud protocol. *Journal of Interior Design*, *49*(2), 117–138. https://doi.org/10.1177/10717641231207031

Jia, Z., Nourian, P., Luscuere, P., & Wagenaar, C. (2023). Spatial decision support systems for hospital layout design: A review. *Journal of Building Engineering*, *67*, 106042. https://doi.org/10.1016/j.jobe.2023.106042

Jiang, C.-F., & Li, Y.-S. (2007). Virtual hospital: a computer-aided platform to evaluate the sense of direction. *29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Lyon, France. https://doi.org/10.1109/iembs.2007.4352801

Jideofor Anselm, A., Mohammed, S., Tyabo, S., & Mohammed, A. (2024). Study of spatial disorientation and wayfinding challenges in buildings using axial analysis: a case of hospital buildings in nigeria. *Journal of Architectural Environment & Structural Engineering Research*, *7*(1), 20–33. https://doi.org/10.30564/jaeser.v7i1.6233

Kalantari, S., Tripathi, V., Kan, J., Rounds, J. D., Mostafavi, A., Snell, R., & Cruz-Garza, J. G. (2022). Evaluating the impacts of color, graphics, and architectural features on wayfinding in healthcare settings using EEG data and virtual response testing. *Journal of Environmental Psychology*, *79*. 101744. https://doi.org/10.1016/j.jenvp.2021.101744

Käosaar, A., Smith, D. N., Keatley, D. D. A., Ambhorkar, P., von Looz, D. M., & Konstantinidis, K. (2023). Using behavior sequence analysis to study teams during long- duration ısolation and confinement. *Journal of Human Performance in Extreme Environments*, *18*(1). https://doi.org/10.7771/2327-2937.1154

Kaplan, A. D., Cruit, J., Endsley, M., Beers, S. M., Sawyer, B. D., & Hancock, P. A. (2020). The effects of virtual reality, augmented reality, and mixed reality as training enhancement methods: a meta-analysis. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *63*(4), 706–726. https://doi.org/10.1177/0018720820904229

Kim, K., & Lee, K. P. (2016). Collaborative product design processes of industrial design and engineering design in consumer product companies. *Design Studies*, *46*, 226–260. https://doi.org/10.1016/j.destud.2016.06.003

Kim, Y. Y., Kim, H. J., Kim, E. N., Ko, H. D., & Kim, H. T. (2005). Characteristic changes in the physiological components of cybersickness. *Psychophysiology*, *42*(5), 616–625. https://doi.org/10.1111/j.1469-8986.2005.00349.x

Kuliga, S. F., Nelligan, B., Dalton, R. C., Marchette, S., Shelton, A. L., Carlson, L., & Hölscher, C. (2019). Exploring individual differences and building complexity in wayfinding: the case of the seattle central library. *Environment and Behavior*, *51*(5), 622–665. https://doi.org/10.1177/0013916519836149

Kuliga, S., Thrash, T., Dalton, R., & Hölscher, C. (2015). Virtual reality as an empirical research tool - exploring user experience in a real building and a corresponding virtual model. *Computers, Environment and Urban Systems*, *54*, 363–375. https://doi.org/10.1016/j.compenvurbsys.2015.09.006

Lacanna, G., Wagenaar, C., Avermaete, T., & Swami, V. (2018). Evaluating the psychosocial impact of indoor public spaces in complex healthcare settings. *HERD: Health Environments Research & Design Journal*, 12(3), 11–30. https://doi.org/10.1177/1937586718812439

Lee, J. H., & Ostwald, M. J. (2024). Latent dirichlet allocation (LDA) topic models for space syntax studies on spatial experience. *City, Territory and Architecture*, *11*(1). https://doi.org/10.1186/s40410-023-00223-3

Li, J., Shu, Y., Chen, N., Wang, F., & Li, H. (2020). ‘Re-socialisation’ in isolated spaces: a case study on the social organisation of Fangcang shelter hospital patients under extreme spatial conditions. *Indoor and Built Environment*, *31*(5), 1210–1223. https://doi.org/10.1177/1420326x20973745

Li, R., & Huang, H. (2020). visual access formed by architecture and its ınfluence on visitors’ spatial exploration in a museum. *Interdisciplinary Journal of Signage and Wayfinding*, *4(1).* https://doi.org/10.15763/issn.2470-9670.2020.v4.i1.a55

Li, R., & Klippel, A. (2012). Wayfinding in libraries: can problems be predicted? *Journal of Map and Geography Libraries*. 8. 21-38. 10.1080/15420353.2011.622456.

Lin, J., Cao, L., & Li, N. (2019). Assessing the influence of repeated exposures and mental stress on human wayfinding performance in indoor environments using virtual reality technology. *Advanced Engineering Informatics*, *39*, 53–61. https://doi.org/10.1016/j.aei.2018.11.007

Liou, T., Arab, Y, Hassan, AS., and Witchayangkoon, B. (2023). Space syntax analysis of Iowa State University student innovation center. *International Transaction Journal of Engineering, Management, &*

Applied Sciences & Technologies, 14(1), 1-15. https://doi.org/10.17485/IJST/v17i15.3016

Lynch, K. (1960). *The image of the city*. The M.I.T. Press.

Mao, Y., Wang, X., Bai, Q., He, W., & Pan, G. (2024). Simulated interventions based on virtual reality to improve emergency evacuation under different spatial perception models. *International Journal of Industrial Ergonomics*, *99*. https://doi.org/10.1016/j.ergon.2024.103545

Maranesi, E., Casoni, E., Baldoni, R., Barboni, I., Rinaldi, N., Tramontana, B., Amabili, G., Benadduci, M., Barbarossa, F., Luzi, R., Di Donna, V., Scendoni, P., Pelliccioni, G., Lattanzio, F., Riccardi, G., & Bevilacqua, R. (2022). The effect of non-immersive virtual reality exergames versus traditional physiotherapy in parkinson's disease older patients: preliminary results from a randomized-controlled trial. *International Journal of Environmental Research and Public Health*, *19*(22). https://doi.org/10.3390/ijerph192214818

Marono, A., Clarke, D. D., Navarro, J., & Keatley, D. A. (2017). A behaviour sequence analysis of nonverbal communication and deceit in different personality clusters. *Psychiatry, Psychology and Law*, 1–15. https://doi.org/10.1080/13218719.2017.1308783

Marono, A. J., Reid, S., Yaksic, E., & Keatley, D. A. (2020). A behaviour sequence analysis of serial killers' lives: from childhood abuse to methods of murder. *Psychiatry, Psychology and Law*, *27*(1), 126–137. https://doi.org/10.1080/13218719.2019.1695517

Min S.Y., Kim Y.O., & Kim C.J. (2010) Investigation on spatial intelligibility and spatial cognition for retail facility vitalization. In *Proceedings of Space Syntax Eighth International Symposium on Architectural Interchanges in Asia*, Kitakyushu International Conference Center, Kitakyushu, Japan, p.A-51. Architectural Institute of Japan.

Natapov, A., Kuliga, S., Dalton, R. C., & Hölscher, C. (2019). Linking building-circulation typology and wayfinding: design, spatial analysis, and anticipated wayfinding difficulty of circulation types. *Architectural Science Review*, *63*(1), 34–46. https://doi.org/10.1080/00038628.2019.1675041

Nicoletta, S., Eletta, N., Cardinali, P., & Migliorini, L. (2022). A broad study to develop maternity units design knowledge combining spatial analysis and mothers' and midwives' perception of the birth environment. *HERD: Health Environments Research & Design Journal*, *15*(4), 204-232. https://doi.org/10.1177/19375867221098987

Omer, I., & Goldblatt, R. (2016). Using space syntax and q-analysis for investigating movement patterns in buildings: the case of shopping malls.

Environment and Planning B: Urban Analytics and City Science, *44*(3), 504–530. https://doi.org/10.1177/0265813516647061

O'Neill, M. J. (1991). Effects of signage and floor plan configuration on wayfinding accuracy. *Environment and Behaviour*, *23*(5), 553-574. https://doi.org/10.1177/0013916591235002

Onime, Uhomoibhi, & Radicella. (2015). MARE: mobile augmented reality based experiments in science, technology and engineering. In *Online Experimentation: Emerging Technologies and IoT* (p. 212). International Frequency Sensor Association Publishing.

Osorto Carrasco, M. D., & Chen, P. H. (2021). Application of mixed reality for improving architectural design comprehension effectiveness. *Automation in Construction*, *126*, 103677. https://doi.org/10.1016/j.autcon.2021.103677

Peponis, J., Zimring, C., & Choi, Y. K. (1990). finding the building in wayfinding. *Environment and Behavior*, *22*(5), 555–590. https://doi.org/10.1177/0013916590225001

Pinelo, J., & Turner, A. (2010). *Introduction to UCL DepthMap 10*. depthmapX. Retrieved November 12, 2023, from https://varoudis.github.io/depthmapX/

Pouyan, A. E., Ghanbaran, A., & Shakibamanesh, A. (2021). Impact of circulation complexity on hospital wayfinding behavior. *Journal of Building Engineering*, 44, 102931. https://doi.org/10.1016/j.jobe.2021.102931

Prats, M., Lim, S., Jowers, I., Garner, S. W., & Chase, S. (2009). Transforming shape in design: observations from studies of sketching. *Design Studies*, *30*(5), 503–520. https://doi.org/10.1016/j.destud.2009.04.002

Qi, F., Lu, Z., & Chen, Y. (2022). Investigating the influences of healthcare facility features on wayfinding performance and associated stress using virtual reality. *HERD: Health Environments Research & Design Journal*, *15*(4), 131–151. https://doi.org/10.1177/19375867221108505

Qiu, X., Yang, Z., Yang, J., Wang, Q., & Wang, D. (2023). Impact of AR navigation display methods on wayfinding performance and spatial knowledge acquisition. *International Journal of Human–Computer Interaction*, 1–21. https://doi.org/10.1080/10447318.2023.2169524

Raubal, M., & Egenhofer, M. J. (1998). Comparing the complexity of wayfinding tasks in built environments. *Environment and Planning B: Planning and Design*, *25*(6), 895–913. https://doi.org/10.1068/b250895

Sarkar, P., & Chakrabarti, A. (2013). A support for protocol analysis for design research. *Design Issues*, *29*(4), 70–81. https://doi.org/10.1162/desi_a_00231

Schaumann, D., Putievsky Pilosof, N., Gath-Morad, M., & Kalay, Y. E. (2020). Simulating the impact of facility design on operations: a study in an internal medicine ward. *Facilities,* 38(7/8), 501–522. https://doi.org/10.1108/f-10-2018-0132

Shi, Y., Kang, J., Xia, P., Tyagi, O., Mehta, R. K., & Du, J. (2021). Spatial knowledge and firefighters' wayfinding performance: A virtual reality search and rescue experiment. *Safety Science*, *139*, 105231. https://doi.org/10.1016/j.ssci.2021.105231

Steuer, J. (1992). Defining Virtual Reality: Dimensions Determining Telepresence. *Journal of Communication*, *42*(4), 73–93.

Soliman, A. M. (2017). Appropriate teaching and learning strategies for the architectural design process in pedagogic design studios. *Frontiers of Architectural Research,* *6*(2), 204–217. https://doi.org/10.1016/j.foar.2017.03.002

Suwa, M., & Tversky, B. (1997, October). What do architects and students perceive in their design sketches? A protocol analysis. *Design Studies*, *18*(4), 385–403. https://doi.org/10.1016/s0142 694x(97)00008-2

Tang, H., & Gero, J.S. (2000). A Content-Oriented Coding Scheme for Protocol Analysis and Computer-Aided Architectural Design. CAADRIA *proceedings*c

Turner, A., Doxa, M., O'Sullivan, D., & Penn, A. (2001). From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space. *Environment & Planning. B, Planning & Design/Environment and Planning. B, Planning and Design, 28*(1), 103–121. https://doi.org/10.1068/b2684

Wang, P., Miller, M. R., Han, E., DeVeaux, C., & Bailenson, J. N. (2024). Understanding virtual design behaviors: a large-scale analysis of the design process in virtual reality. *Design Studies*, *90*, 101237. https://doi.org/10.1016/j.destud.2023.101237

Weisman, J. (1981). Evaluating architectural legibility. *Environment and Behavior*, *13*(2), 189–204. https://doi.org/10.1177/0013916581132004

Werner, S., & Schindler, L. E. (2004). The role of spatial reference frames in architecture. *Environment and Behavior*, *36*(4), 461–482. https://doi.org/10.1177/0013916503254829

Yamu, C., van Nes, A., & Garau, C. (2021). Bill Hillier's legacy: space syntax - a synopsis of basic concepts, measures, and empirical application. *Sustainability*, *13*(6), 3394. doi:10.3390/su13063394

Zhou, J., & Camba, J. D. (2021). Computer-aided process planning in immersive environments: a critical review. *Computers in Industry*, *133*, 103547. https://doi.org/10.1016/j.compind.2021.103547

Zhu, R., Lin, J., Becerik-Gerber, B., & Li, N. (2020). Influence of architectural visual access on emergency wayfinding: a cross-cultural study in China, United Kingdom, and United States. *Fire Safety Journal*, *113*, 102963. https://doi.org/10.1016/j.firesaf.2020.102963

Url-1 < *https://archdaily.com* >, retrieved November 3, 2023.

Url-2< *https://www.cyberith.com/entertainment* >, retrieved April 12, 2024.

Url-3< *https://www.constructionequipmentguide.com* >, retrieved April 13, 2024.

Url-4<*https://news.microsoft.com/transform/design-revolution-microsoft-hololens-mixed-reality-changing-architects-world/*>, retrieved April 13, 2024.

YÖK

APPENDICES

APPENDIX A: Route maps and the most obaerved behavioural transitions of the participants.

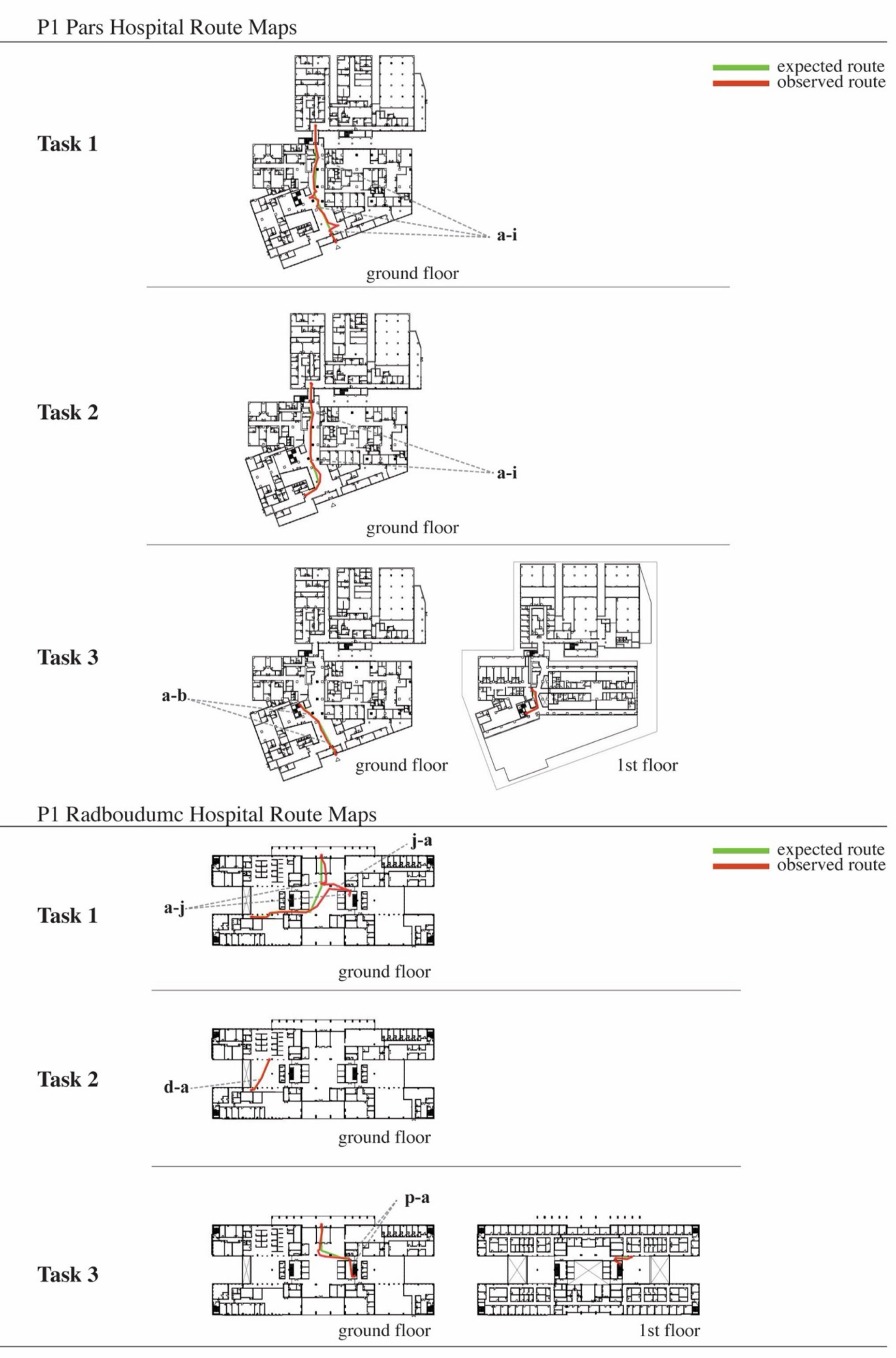


Figure A.1 : Route maps of P1.

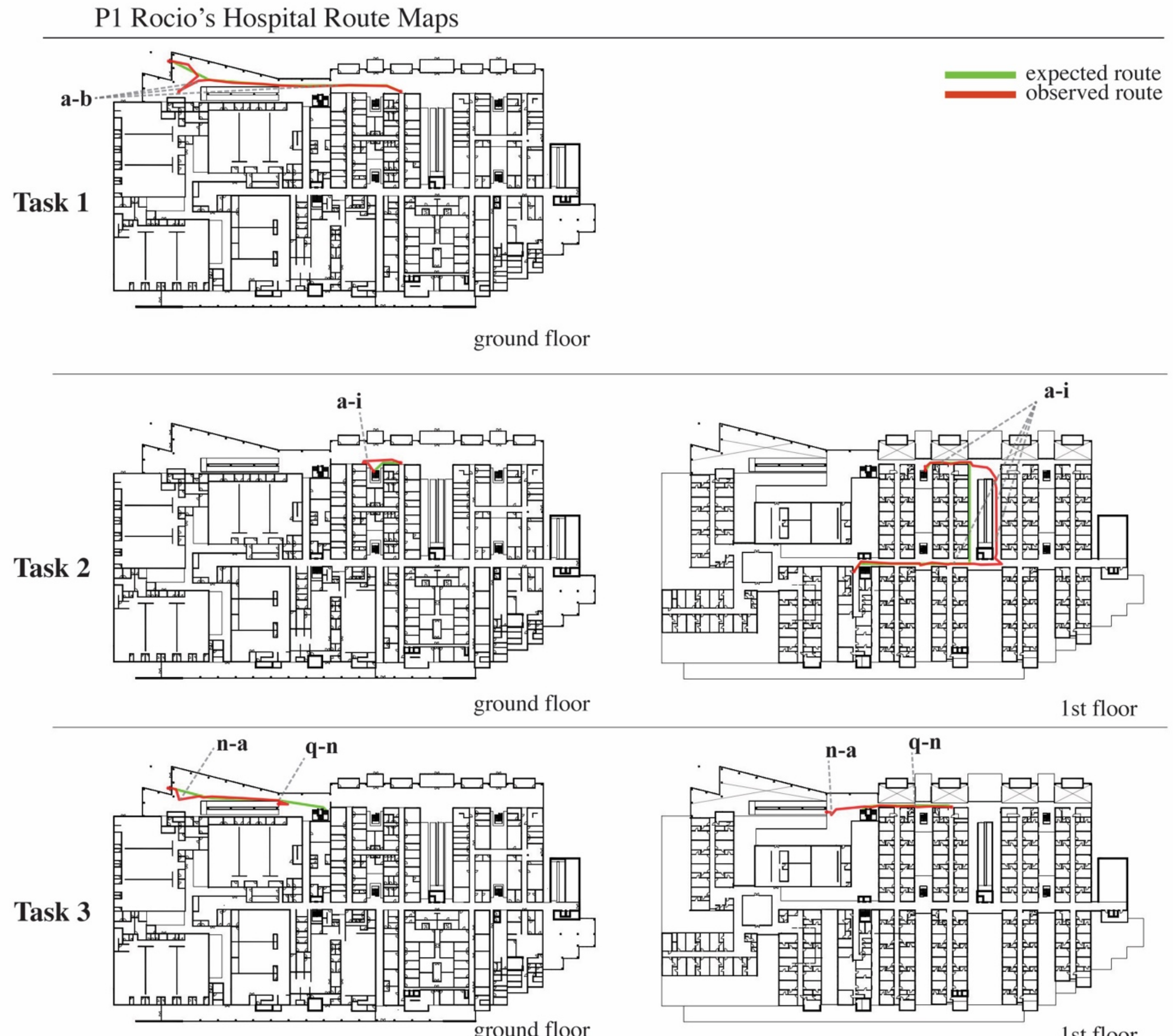


Figure A.1 (continued): Route maps of P1.

P2 Pars Hospital Route Maps

expected route
observed route

Task 1

f-a

a-f

ground floor

Task 2

b-q

ground floor

Task 3

a-j

ground floor

1st floor

P2 Radboudumc Hospital Route Maps

expected route
observed route

Task 1

a-d

a-l

ground floor

Task 2

a-j

ground floor

Task 3

k-a

k-a

ground floor

1st floor

Figure A.2 : Route maps of P2.

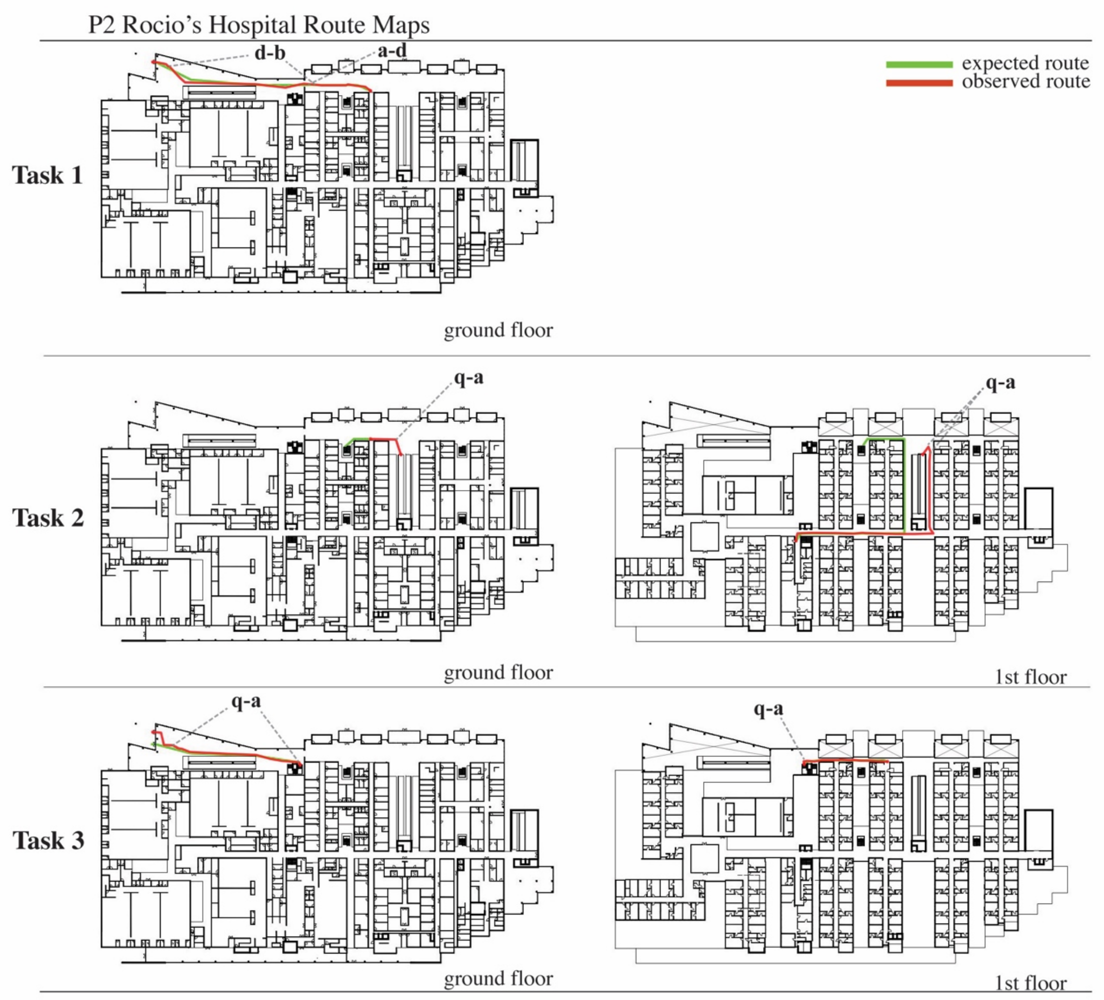


Figure A.2 (continued): Route maps of P2.

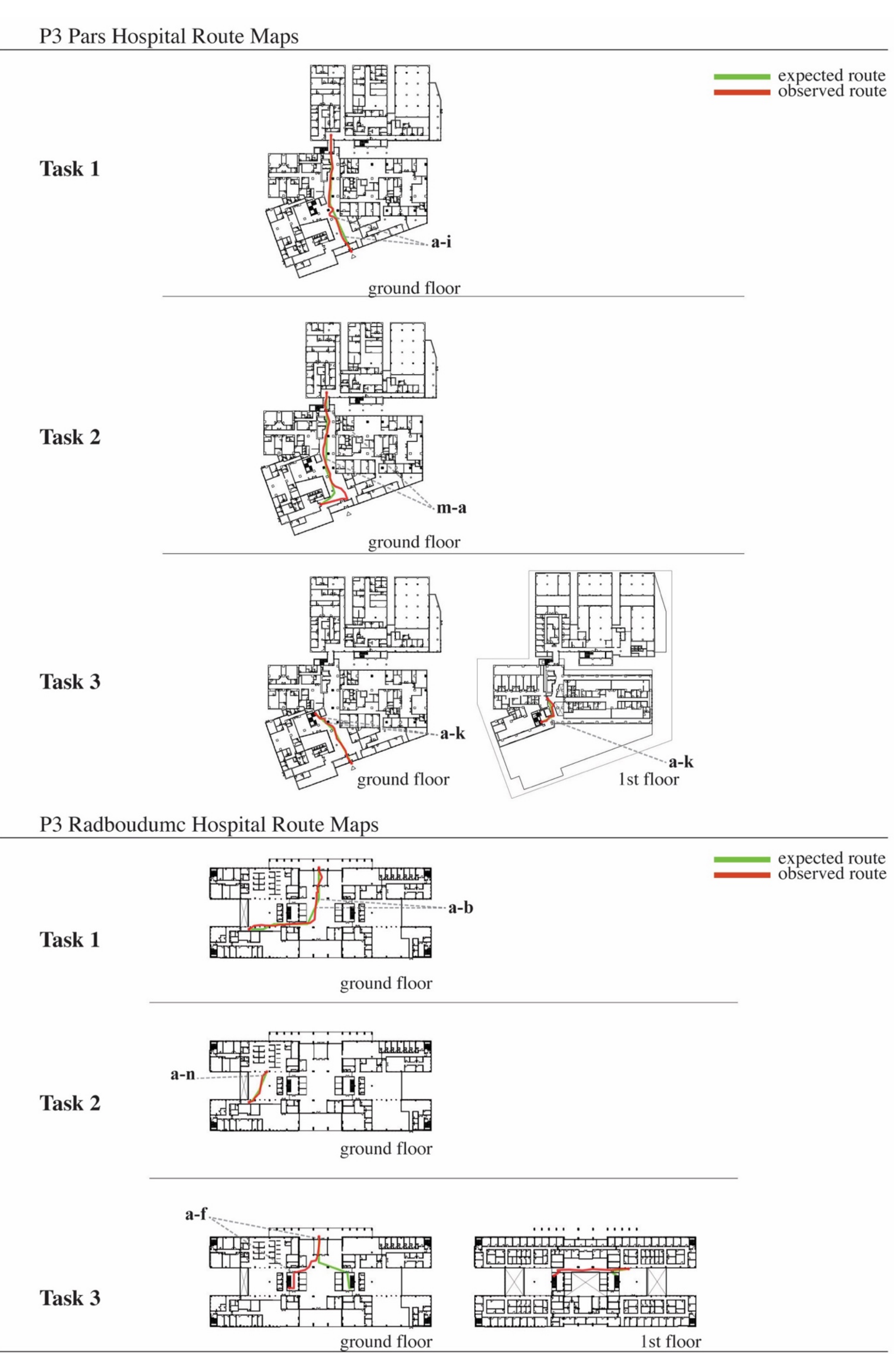


Figure A.3 : Route maps of P3.

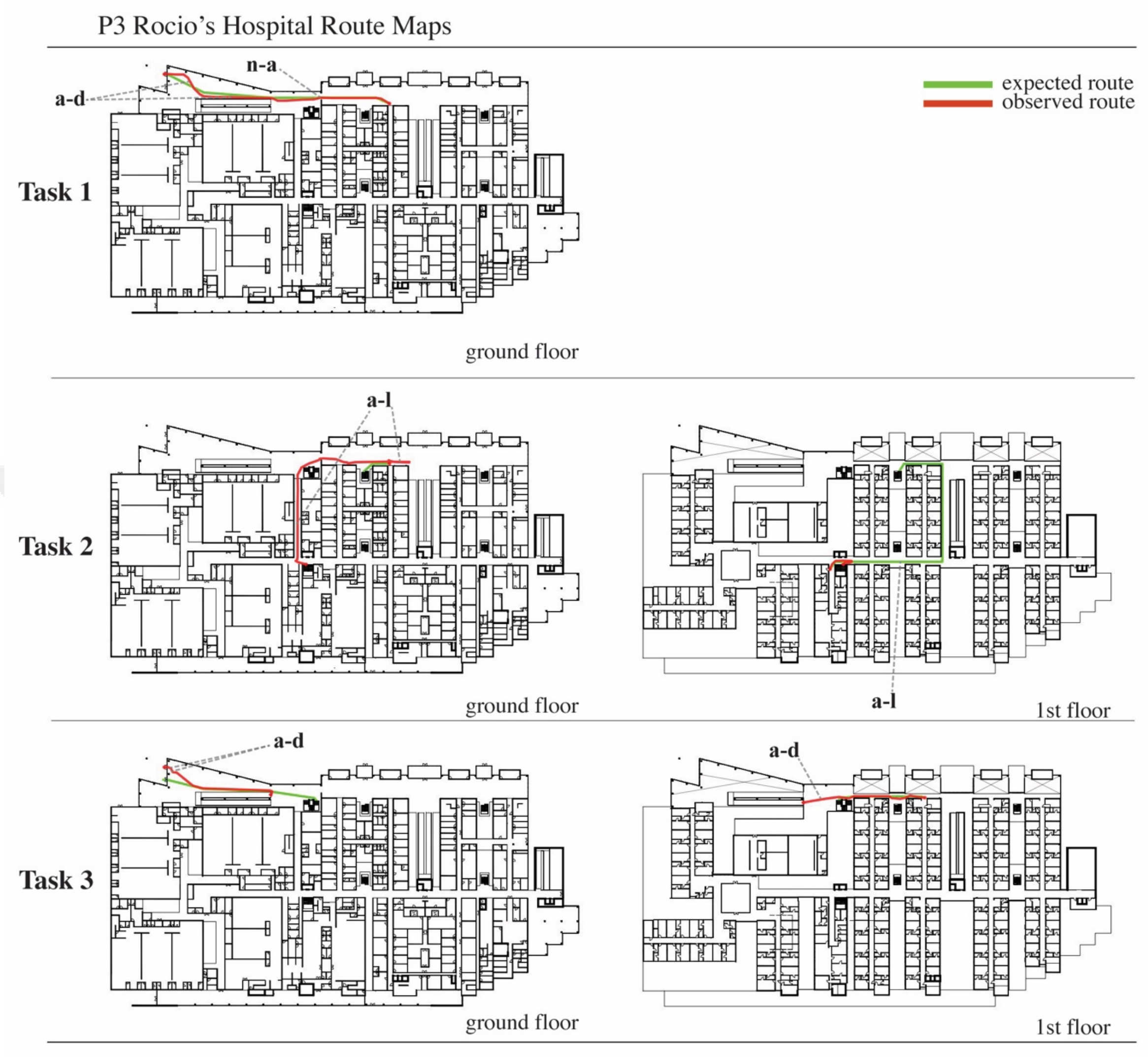


Figure A.3 (continued): Route maps of P3.

CURRICULUM VITAE

Name Surname : Elif Bahar Okuyucu

EDUCATION :

- **B.Sc.** : 2020, Istanbul Technical University, Faculty of Architecture, Department of Architecture

PROFESSIONAL EXPERIENCE AND REWARDS:

- Architect at Dome + Partners.
- 1st prize, Bursa District of Khans Urban Design Competition.

PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

- **Okuyucu, B., Yazıcı, S.** (2021). Evaluation of the relationship between user behavior and spatial performance. *Proceedings of International Graduate Research Symposium 23'.* Istanbul, Turkey: Istanbul Technical University

- **Okuyucu, B., & Yazıcı, S.** (2024). A Comparative Study driven by Spatial Performance and VR toward Wayfinding in Architectural Space: Healthcare Buildings as a Case Study. *ESTOA*, 26 (In publication process).