A COMPARATIVE ANALYSIS ON USER INTERFACE AND USER EXPERIENCE DIFFERENCES IN BUILDING INFORMATION MODELING TOOLS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

GÖZDE BULUT DÖNMEZ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
BUILDING SCIENCE IN ARCHITECTURE

APRIL 2024

Approval of the thesis:

A COMPARATIVE ANALYSIS ON USER INTERFACE AND USER EXPERIENCE DIFFERENCES IN BUILDING INFORMATION MODELING TOOLS

submitted by **GÖZDE BULUT DÖNMEZ** in partial fulfillment of the requirements for the degree of **Master of Science** i**n Building Science in Architecture, Middle East Technical University** by,

Prof. Dr. Naci Emre Altun
Dean, **Graduate School of Natural and Applied Sciences** ________________

Assoc. Prof. Dr. A. Berrin Çakmaklı
Head of the Department, **Architecture** ________________

Assoc. Prof. Dr. M. Koray Pekeriçli
Supervisor, **Architecture, METU** ________________

Examining Committee Members:

Prof. Dr. Arzu Gönenç Sorguç
Architecture, METU ________________

Assoc. Prof. Dr. M. Koray Pekeriçli
Architecture, METU ________________

Assoc. Prof. Dr. İlker Erkan
Architecture, Süleyman Demirel University ________________

Date: 22.04.2024

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name Last name : Gözde Bulut Dönmez

Signature :

ABSTRACT

A COMPARATIVE ANALYSIS ON USER INTERFACE AND USER EXPERIENCE DIFFERENCES IN BUILDING INFORMATION MODELING TOOLS

Bulut Dönmez, Gözde
Master of Science, Building Science in Architecture
Supervisor : Assoc. Prof. Dr. M. Koray Pekeriçli

April 2024, 180 pages

Building Information Modeling (BIM) has grown in importance in the Architecture Engineering Construction (AEC) industry in recent years due to technological advancements and the increasing complexity of architectural projects. BIM offers numerous advantages across various aspects of construction projects. As Building Information Modeling gains widespread adoption, it becomes critical to explore which BIM software offers the most efficient platform for architects. Determining which software can be more easily learned and effectively streamline the architectural project production process is crucial. In this evaluation, the user interface and user experience emerge as the most significant factors to consider. This thesis presents a comparative study of two prominent BIM software in the industry by evaluating the user interface (UI) and user experience (UX), and their impact on the architectural design process across various user groups with different levels of experience. The study emphasizes that UX is as important as UI in determining the effectiveness of BIM software in architectural projects.

By examining various BIM tools and their historical development, this research provides a comprehensive understanding of the UI and UX evaluations of these software. Usability tests are conducted to gather data from architects with different levels of expertise in order to understand the effects of UI and UX on users. Additionally, interviews are conducted to gain deeper insights, ensuring a thorough analysis of each software's strengths and weaknesses. As a result, by incorporating both hands-on exercises and interviews, this research shows that different interfaces of BIM tools affect the efficiency of architects.

Keywords: Building Information Modeling, User Interface, User Experience, Human Computer Interaction

ÖZ

YAPI BİLGİ MODELLEME ARAÇLARINDA KULLANICI ARAYÜZÜ VE KULLANICI DENEYİMİ FARKLARI ÜZERİNE KARŞILAŞTIRMALI BİR ANALİZ

Bulut Dönmez, Gözde
Yüksek Lisans, Yapı Bilimleri, Mimarlık
Tez Yöneticisi: Doç. Dr. M. Koray Pekeriçli

Nisan 2024, 180 sayfa

Son yıllarda teknolojik ilerlemeler ve mimari projelerin artan karmaşıklığı nedeniyle, Yapı Bilgi Modellemesi (Building Information Modeling - BIM), Mimarlık, Mühendislik ve İnşaat (Architecture Engineering Construction - AEC) sektöründe önem kazanmıştır. BIM, inşaat projelerinin çeşitli yönlerinde birçok avantaj sunmaktadır. Yapı Bilgi Modellemesinin yaygınlaşmasıyla, hangi BIM yazılımının mimarlar için en verimli platformu sunduğunu araştırmak kritik hale gelmiştir. Hangi yazılımın daha kolay öğrenilebileceğini ve mimari proje üretim sürecini etkin bir şekilde kolaylaştırabileceğini belirlemek büyük önem taşımaktadır. Bu değerlendirme ile birlikte kullanıcı arayüzü (UI) ve kullanıcı deneyimi (UX) dikkate alınması gereken en önemli faktörler olarak öne çıkmaktadır. Bu tez, sektördeki iki önemli BIM yazılımını, kullanıcı arayüzü ve kullanıcı deneyimi açısından değerlendirerek ve bunların farklı deneyim düzeylerine sahip çeşitli kullanıcı grupları üzerindeki mimari tasarım sürecine etkilerini inceleyerek karşılaştırmalı bir çalışma sunmaktadır. Çalışma, kullanıcı deneyiminin, kullanıcı arayüzü kadar, BIM yazılımlarının mimari projelerdeki etkinliğini belirlemede önemli olduğunu vurgulamaktadır. Çeşitli BIM araçları ve tarihsel gelişimlerini

inceleyerek, bu araştırma, bu yazılımların kullanıcı arayüzü ve kullanıcı deneyimi değerlendirmelerine dair kapsamlı bir anlayış sağlamaktadır. Kullanıcı arayüzü ve kullanıcı deneyiminin kullanıcılar üzerindeki etkilerini anlamak amacıyla, farklı uzmanlık seviyelerine sahip mimarlardan veri toplamak için kullanılabilirlik testleri yapılmıştır. Ayrıca, her bir yazılımın güçlü ve zayıf yönlerini kapsamlı bir şekilde analiz etmek amacıyla mülakatlar gerçekleştirilmiştir. Sonuç olarak, hem uygulamalı alıştırmaları hem de mülakatları birleştirerek, bu araştırma, BIM araçlarının farklı arayüzlerinin mimarların verimli çalışmasını nasıl etkilediğini göstermektedir.

Anahtar Kelimeler: Yapı Bilgi Modeli, Kullanıcı Arayüzü, Kullanıcı Deneyimi, İnsan Bilgisayar Etkileşimi

To my family

ACKNOWLEDGMENTS

First of all, I would like to express my gratitude to my esteemed thesis advisor, Assoc. Prof. Dr. M. Koray Pekeriçli, for his guidance throughout my undergraduate and graduate education. His expertise and insightful feedback have been instrumental in shaping this thesis.

I would like to express my sincere appreciation to all professors at METU Faculty of Architecture for their contribution to my educational and my professional life.

I also would like to acknowledge Prof. Dr. Arzu Gönenç Sorguç and Assoc. Prof. Dr. İlker Erkan for their contributions and guidance throughout the completion of this study.

I am immensely grateful to the METU Department of Architecture students and the architecture offices who participated in this research. Their contributions and dedication have been invaluable to the success of this study.

To all my friends, I am truly grateful for their support and encouragement. Each of them has played a special role in this challenging journey. I would like to give special thanks to Mustafa Eren Bük, Özge Önceler and Berk Yaşyerli for their exceptional support and friendship.

My heartfelt thanks also go out to my family, Zeliha, Ruhi and Aziz, whose love and guidance are with me in whatever I pursue. They have been a constant source of support and encouragement in my life.

Finally, I must acknowledge my dear spouse, Burak Dönmez. His profound understanding of the academic journey, insightful critiques, and unwavering support have not only helped sustain my personal commitment but have also been critical to my success. His contribution to my work extends beyond measure.

TABLE OF CONTENTS

ABSTRACT v

ÖZ vii

ACKNOWLEDGMENTS x

TABLE OF CONTENTS xi

LIST OF TABLES xiv

LIST OF FIGURES xvi

LIST OF ABBREVIATIONS xxi

CHAPTERS

1 INTRODUCTION 1

1.1 Background Information 1

1.2 Aim and Objectives 4

1.3 Contribution 6

1.4 Disposition 7

2 LITERATURE REVIEW 9

2.1 Introduction to Building Information Modeling 9

2.1.1 Concept of BIM in Architecture 11

2.1.2 Historical Development of BIM 20

2.2 BIM Tools in Architecture 32

2.2.1 Overview on Autodesk Revit 33

2.2.2 Overview on Graphisoft Archicad 40

2.2.3 Overview on Nemetschek Allplan 47

2.3 Definitions on User-Software Interaction 49

2.3.1 User Interface 50

2.3.2 User Experience 52

2.3.3 Metrics for Usability Terms 54

2.4 Critical Analysis of the Literature 57

3 MATERIAL AND METHOD 59

3.1 Material 59

3.1.1 Participants of the Research 59

3.1.2 BIM Software 62

3.1.3 Recording Software 62

3.1.4 Analysis Software 66

3.2 Method 66

3.2.1 Hands-on Modeling Exercise - Experimental Research and Data Collection 68

3.2.2 Interview with Participants - Statistical Analysis and Evaluation ... 72

4 RESULTS AND DISCUSSION 75

4.1 Results of Hands-on Modeling Exercises on the Computer 75

4.1.1 Task-1 76

4.1.2 Task-2 78

4.1.3 Task-3 80

4.1.4 Task-4 82

4.1.5 Task-5 84

4.1.6 Task-6 85

4.2 Discussion of Hands-on Modeling Exercise Results 87

4.2.1 Task-1 88

4.2.2 Task-2 92
4.2.3 Task-3 96
4.2.4 Task-4 100
4.2.5 Task-5 103
4.2.6 Task-6 106
4.2.7 All Tasks 110
4.3 Results and Discussion of Interview Results 111
4.4 Discussion of Interview Results and Modeling Exercise Results 118
5 CONCLUSIONS 121
5.1 Summary of the Research 121
5.2 Main Outcomes 122
5.3 Limitations 123
5.4 Recommendations 124
REFERENCES 127
APPENDICES 137
A. DOCUMENT PROVIDED FOR HANDS-ON COMPUTER EXERCISES 137
B. INTERVIEW QUESTIONS AND ANSWERS 139
C. RESULTS OF THE HANDS-ON EXERCISES 151
C.1 Individual Results of Tasks 151
C.2 Heat maps 163

LIST OF TABLES

TABLES

Table 2.1 The important dates and key events in the development of CAD systems 22
Table 2.2 Events which provide technological developments in the fields of graphics and computers. 26
Table 4.1 Mean values of different participant groups for Task-1 76
Table 4.2 Mean values of different participant groups for Task-2 78
Table 4.3 Mean values of different participant groups for Task-3 80
Table 4.4 Mean values of different participant groups for Task-4 82
Table 4.5 Mean values of different participant groups for Task-5 84
Table 4.6 Mean values of different participant groups for Task-6 86
Table C.1 Results of BIM tool B professionals in Task-1 151
Table C.2 Results of BIM tool A professionals in Task-1 151
Table C.3 Results of BIM tool B intermediate level students in Task-1.............. 151
Table C.4 Results of BIM tool A intermediate level students in Task-1 152
Table C.5 Results of BIM tool B beginner level students in Task-1.................... 152
Table C.6 Results of BIM tool A beginner level students in Task-1 152
Table C.7 Results of BIM tool B professionals in Task-2 153
Table C.8 Results of BIM tool A professionals in Task-2 153
Table C.9 Results of BIM tool B intermediate level students in Task-2.............. 153
Table C.10 Results of BIM tool A intermediate level students in Task-2 154
Table C.11 Results of BIM tool B beginner level students in Task-2.................. 154
Table C.12 Results of BIM tool A beginner level students in Task-2 154
Table C.13 Results of BIM tool B professionals in Task-3 155
Table C.14 Results of BIM tool A professionals in Task-3 155
Table C.15 Results of BIM tool B intermediate level students in Task-3............ 155
Table C.16 Results of BIM tool A intermediate level students in Task-3 156
Table C.17 Results of BIM tool B beginner level students in Task-3.................. 156

Table C.18 Results of BIM tool A beginner level students in Task-3 156
Table C.19 Results of BIM tool B professionals in Task-4 157
Table C.20 Results of BIM tool A professionals in Task-4 157
Table C.21 Results of BIM tool B intermediate level students in Task-4 157
Table C.22 Results of BIM tool A intermediate level students in Task-4 158
Table C.23 Results of BIM tool B beginner level students in Task-4 158
Table C.24 Results of BIM tool A beginner level students in Task-4 158
Table C.25 Results of BIM tool B professionals in Task-5 159
Table C.26 Results of BIM tool A professionals in Task-5 159
Table C.27 Results of BIM tool B intermediate level students in Task-5 159
Table C.28 Results of BIM tool A intermediate level students in Task-5 160
Table C.29 Results of BIM tool B beginner level students in Task-5 160
Table C.30 Results of BIM tool A beginner level students in Task-5 160
Table C.31 Results of BIM tool B professionals in Task-6 161
Table C.32 Results of BIM tool A professionals in Task-6 161
Table C.33 Results of BIM tool B intermediate level students in Task-6 161
Table C.34 Results of BIM tool A intermediate level students in Task-6 162
Table C.35 Results of BIM tool B beginner level students in Task-6 162
Table C.36 Results of BIM tool A beginner level students in Task-6 162

LIST OF FIGURES

FIGURES

Figure 2.1. CAD-based and BIM-based workflows illustrated by Krygiel and Vandezande (2014)....13
Figure 2.2. BIM concept represented by Kymmell (2008). 13
Figure 2.3. Dimensions of CAD and BIM projects (Maina, 2018)....14
Figure 2.4. Traditional project (left) and BIM project (right) processes (Azhar et. al, 2012)....15
Figure 2.5. Opportunities and potentials in the AEC sector provided by BIM (Krygiel & Vandezande, 2014). 18
Figure 2.6. The relationship between the position of the window and the dimension change of the wall (Luciani et. al, 2012)....20
Figure 2.7. Timeline of the technological developments related to CAD technology (Eastman, 2018)....24
Figure 2.8. Perspective view from HARNESS (Gero, 1976)....28
Figure 2.9. Plan and elevation drawings in RUCAPS (Ingram, 2020)....30
Figure 2.10. The most preferred design and drawing tool (Bain, 2020). 32
Figure 2.11. Usage rate of BIM tools according to the research in Vietnam (Toan et.al, 2022)....33
Figure 2.12. Revit export options....35
Figure 2.13. Interface of Revit 6.0 (Shaan, 2019)....37
Figure 2.14. Interface of Revit 2019 (Autodesk, n.d.) 38
Figure 2.15. Interface of Revit 2022 (Autodesk, n.d.) 39
Figure 2.16. Interface of Radar CH 1984....41
Figure 2.17. User Interface of Archicad 10 (Sperber, 2007)....43
Figure 2.18. File formats supported by Archicad....46
Figure 2.19. User Interface of Allplan 2022 (Allplan, n.d.)....48
Figure 2.20. Usability and user experience factors for software usability (Park et. al, 2022)....53

Figure 3.1. Participants numbers and types for BIM tool A and BIM tool B......... 60
Figure 3.2. Most popular language extension for coding. 63
Figure 3.3. Interface of Visual Studio Code. 64
Figure 3.4. Interface of OBS Studio 66
Figure 3.5. Main structure of the methodology 68
Figure 4.1. Heatmaps of users for Task-1. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f) 77
Figure 4.2. Heatmaps of users for Task-2. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f) 79
Figure 4.3. Heatmaps of users for Task-3. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f) 81
Figure 4.4. Heatmaps of users for Task-4. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f) 83
Figure 4.5. Heatmaps of users for Task-5. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f) 85
Figure 4.6. Heatmaps of users for Task-6. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f) 87
Figure 4.7. Data showing the mean values in different metrics of participant groups for Task-1. 88
Figure 4.8. Superimposed heat map of BIM tool A professionals for Task-1........ 90
Figure 4.9. Superimposed heat map of BIM tool B professionals for Task-1. 91
Figure 4.10. Data showing the mean values in different metrics of participant groups for Task-2. 93
Figure 4.11. Superimposed heat map of BIM tool A professionals for Task-2...... 94
Figure 4.12. Superimposed heat map of BIM tool B professionals for Task-2...... 95
Figure 4.13. Data showing the mean values in different metrics of participant groups for Task-3. 97
Figure 4.14. Superimposed heat map of BIM tool A professionals for Task-3...... 98
Figure 4.15. Superimposed heat map of BIM tool B professionals for Task-3...... 99

Figure 4.16. Data showing the mean values in different metrics of participant groups for Task-4. 101
Figure 4.17. Superimposed heat map of BIM tool A professionals for Task-4. ... 102
Figure 4.18. Superimposed heat map of BIM tool B professionals for Task-4..... 102
Figure 4.19. Data showing the mean values in different metrics of participant groups for Task-5. 103
Figure 4.20. Superimposed heat map of BIM tool A professionals for Task-5. ... 105
Figure 4.21. Superimposed heat map of BIM tool B professionals for Task-5..... 105
Figure 4.22. Data showing the mean values in different metrics of participant groups for Task-6. 107
Figure 4.23. Superimposed heat map of BIM tool A professionals for Task-6. ... 108
Figure 4.24. Superimposed heat map of BIM tool B professionals for Task-6..... 109
Figure 4.25. Data showing the total mean values in different metrics of participant groups for all tasks....... 110
Figure 4.26. Work of experiences of the participants 112
Figure 4.27. Software experiences of the participants 112
Figure 4.28. The required time for participants to learn software....... 113
Figure 4.29. Level of users....... 114
Figure 4.30. Modeling flexibility of the software 115
Figure 4.31. Tool accessibility and customization features of the software 116
Figure 4.32. Custom script and extension feature of the software 116
Figure 4.33. Performance and responsiveness of the software 117
Figure 4.34. Error handling and feedback of the software 117
Figure C.1. Superimposed heat map of BIM tool A professionals for Task-1...... 163
Figure C.2. Superimposed heat map of BIM tool A intermediate level students for Task-1....... 163
Figure C.3. Superimposed heat map of BIM tool A beginner level students for Task-1....... 164
Figure C.4. Superimposed heat map of BIM tool B professionals for Task-1...... 164

Figure C.5. Superimposed heat map of BIM tool B intermediate level students for Task-1 165
Figure C.6. Superimposed heat map of BIM tool B beginner level students for Task-1 165
Figure C.7. Superimposed heat map of BIM tool A professionals for Task-2 166
Figure C.8. Superimposed heat map of BIM tool A intermediate level students for Task-2 166
Figure C.9. Superimposed heat map of BIM tool A beginner level students for Task-2 167
Figure C.10. Superimposed heat map of BIM tool B professionals for Task-2 ... 167
Figure C.11. Superimposed heat map of BIM tool B intermediate level students for Task-2 168
Figure C.12. Superimposed heat map of BIM tool B beginner level students for Task-2 168
Figure C.13. Superimposed heat map of BIM tool A professionals for Task-3 ... 169
Figure C.14. Superimposed heat map of BIM tool A intermediate level students for Task-3 169
Figure C.15. Superimposed heat map of BIM tool A beginner level students for Task-3 170
Figure C.16. Superimposed heat map of BIM tool B professionals for Task-3 ... 170
Figure C.17. Superimposed heat map of BIM tool B intermediate level students for Task-3 171
Figure C.18. Superimposed heat map of BIM tool B beginner level students for Task-3 171
Figure C.19. Superimposed heat map of BIM tool A professionals for Task-4 ... 172
Figure C.20. Superimposed heat map of BIM tool A intermediate level students for Task-4 172
Figure C.21. Superimposed heat map of BIM tool A beginner level students for Task-4 173
Figure C.22. Superimposed heat map of BIM tool B professionals for Task-4 ... 173

Figure C.23. Superimposed heat map of BIM tool B intermediate level students for Task-4 174
Figure C.24. Superimposed heat map of BIM tool B beginner level students for Task-4 174
Figure C.25. Superimposed heat map of BIM tool A professionals for Task-5 175
Figure C.26. Superimposed heat map of BIM tool A intermediate level students for Task-5 175
Figure C.27. Superimposed heat map of BIM tool A beginner level students for Task-5 176
Figure C.28. Superimposed heat map of BIM tool B professionals for Task-5 176
Figure C.29. Superimposed heat map of BIM tool B intermediate level students for Task-5 177
Figure C.30. Superimposed heat map of BIM tool B beginner level students for Task-5 177
Figure C.31. Superimposed heat map of BIM tool A professionals for Task-6 178
Figure C.32. Superimposed heat map of BIM tool A intermediate level students for Task-6 178
Figure C.33. Superimposed heat map of BIM tool A beginner level students for Task-6 179
Figure C.34. Superimposed heat map of BIM tool B professionals for Task-6 179
Figure C.35. Superimposed heat map of BIM tool B intermediate level students for Task-6 180
Figure C.36. Superimposed heat map of BIM tool B beginner level students for Task-6 180

LIST OF ABBREVIATIONS

ABBREVIATIONS	
2D	Two-dimensional
3D	Three-dimensional
AEC	Architecture Engineering Construction
ARC	Applied Research of Cambridge
BCF	BIM Collaboration Format
BDS	Building Design System
BIM	Building Information Modeling
CAAD	Computer-aided Architectural Design
CAD	Computer-aided Design
CIFE	Center for Integrated Facilities Engineering
COBie	Construction Operations Building Information Exchange
CPU	Central Processing Unit
CRT	Cathode-ray Tube
GUI	Graphical User Interface
HCI	Human Computer Interaction
IDS	Integrated Design System
IFC	Industry Foundation Classes
OBS	Open Broadcaster Software
QUIM	Quality in Use Integrated Map

SE	Software Engineering
SPie	Specifiers' Properties Information Exchange
SSHA	Scottish Special Housing Association
STEP	Standard for the Exchange of Product Data
UI	User Interface
UX	User Experience
VS Code	Visual Studio Code

CHAPTER 1

INTRODUCTION

In this chapter, background information about the study is given, followed by explanations of the research aim and objectives. The chapter also defines the study's contributions to the field of research. Finally, the disposition of the thesis is clarified at the end of this chapter.

1.1 Background Information

In the Architecture, Engineering, and Construction (AEC) industry, the limitations of two-dimensional Computer-Aided Design (2D CAD) software in addressing critical challenges throughout the project lifecycle have necessitated the evolution and adoption of Building Information Modeling (BIM). According to National BIM Standards United States (n.d.) BIM can be defined as a process that models the physical and functional features of a building in a digital environment. The origins of this process date back to the late 1970s, when it emerged as a more effective and efficient solution to replace traditional drawing and design methods. It offers more detailed, three-dimensional design and management capabilities.

The beginning of BIM stemmed from the need to record and manage information about structures more comprehensively. This approach has allowed for better coordination and collaboration between architects, engineers, and builders, resulting in more accurate and faster completion of projects (Czmoch & Pekala, 2014). While the first BIM systems provided simple models containing only geometric data, over time they began to integrate more complex structural and functional information. This integration enabled more detailed planning and management of projects.

Throughout the history of BIM, there have been many important developments that have radically changed the direction and use of BIM. There is an evolution extending from the BIM concept itself to the technologies, methodologies and processes used in the field of construction, and even the holistic approach of BIM (Borkowski, 2023).

By the late 1980s, BIM technology had further advanced and gained three-dimensional (3D) modeling capabilities (Eastman, 2018). During this period, 3D modeling played an important role in visualizing and analyzing the project, allowing earlier detection of problems that may arise during the design phase of the structure. Maina (2018) states that BIM has also become a more comprehensive project management and planning tool by adding time (4D) and cost (5D) dimensions to projects. These innovations have contributed greatly to the completion of projects on time and within budget.

By the 2000s, BIM began to focus on issues such as sustainability, energy efficiency and structural soundness (Azhar & Richter, 2009). This evolution of BIM has radically changed the project development process, increasing efficiency, collaboration, and quality in the AEC sector. Today, industry professionals have adopted BIM all over the world and it has become an indispensable part of the design and construction processes.

Numerous BIM software developed by various companies over the years contribute significantly to the development of BIM methodologies. There is many important BIM software in the industry such as Revit from Autodesk, Archicad from Graphisoft, MicroStation from Bentley Systems, Vectorworks and Allplan from Nemetschek. They allow designers and engineers to analyze in detail various aspects of buildings, such as energy performance, material selection and structural integrity (Luciani et al., 2012). They enable an effective collaboration platform between architects, engineers, and construction professionals by offering a particularly multidisciplinary design environment with their improved interfaces and advanced visualization capabilities. Each BIM software addresses specific needs and preferences with its different features and specialized tools. This diversity gives industry professionals the opportunity to choose the most appropriate BIM tool according to the specific needs of their projects. Thus, the capabilities of each software enable projects to be planned more effectively, developed faster, and completed with higher quality. Moreover, the continuous development of these software contributes to the continuous evolution of the BIM methodology and plays an important role in shaping the future of the AEC industry.

Two important concepts play a critical role in the effective use of BIM tools: user interface (UI) and user experience (UX). While user interface determines how users interact with software and hardware, enter commands, and retrieve information, user experience refers to the overall effectiveness, comfort, and whether that interaction is satisfactory (Miraz, 2021). A well-designed UI helps users learn the software faster, navigate easier, and use it more efficiently. For example, in BIM software, toolbars, menus and hotkeys enable users to work quickly and effectively. Additionally, a positive UX increases users' loyalty to the software, reduces errors, and promotes efficiency and project success in the long run.

The user interface of BIM software is designed to provide easy access to often complex design and analysis tools. These interfaces allow users to work on projects faster, more effectively, and without errors. Features of projects such as 3D modeling, energy analysis and structural simulation have become more accessible thanks to user-friendly interfaces. Additionally, the user experience of the software facilitates the learning process, increasing efficiency and innovation in the industry. The intuitiveness and accessibility of the software for users contributes to faster completion of projects and lower costs. A well-designed UX allows users to learn the software with less training, detect errors more easily and create solutions.

As a result, the user interface (UI) and user experience (UX) of BIM software significantly impact the workflows and project management of professionals in the architecture, engineering, and construction (AEC) industry. The UI and UX designs of this software provide users with access to complex modeling, design and analysis tools in a more accessible and understandable way. While a well-designed UI helps users quickly learn the software and use it efficiently, an effective UX increases user satisfaction and loyalty to the software. These features contribute to completing projects faster, reducing errors and increasing overall efficiency.

The evaluation and improvement processes of UI and UX designs of BIM software include user interface and experience metrics and methods. Metrics such as usability tests, surveys, interviews, heat maps, eye tracking, task completion rates, error rates, and user satisfaction measure various aspects of user experience and provide feedback to designers. This feedback guides the development and updating of software to better adapt to user needs and expectations.

As a result, the development of BIM technology and related architectural tools represents a major transformation in the AEC industry. The impact of user interface and experience on the adoption and effective use of these technologies cannot be ignored. A user-centered approach enables professionals in the AEC sector to work more efficiently, effectively, and satisfactorily, accelerating the digital transformation in the sector and contributing to the successful completion of projects. This approach also stands out as a key factor driving the future development of BIM technologies and innovations in the sector.

This study aims to examine the role and future potential of BIM in the industry by providing an overall assessment of this interaction. Therefore, it will be used to reveal how BIM technologies bring innovation and efficiency in the AEC sector, the role of user interface and experience in this innovation process, and future trends in the industry.

1.2 Aim and Objectives

The main aim of this study is to compare the differences in user interface and user experience in Building Information Modeling tools and to guide architects by analyzing the results.

Research objectives are listed as:

- Examining the effect of different BIM tools on the processing speed of user interfaces in architectural projects by comparing the processing speeds of experienced and inexperienced users and analyzing how these speeds vary in both BIM tools.
- Analyzing the users' mouse movement numbers and keyboard usage frequency to reveal behavioral differences between different user groups and understand how these behaviors relate to the user interfaces of BIM tools.
- Visualizing the user interactions through heat maps will help show the areas of the interface where users spend the most time and the tools they use most often.
- Collecting users' evaluations of the interfaces through interviews with participants to get important information about users' preferences, difficulties, and overall experience.
- Comparing the transaction quantities in architectural projects using different BIM tools, which is crucial to understanding the effectiveness of the tools used in the different phases of projects.
- Providing guiding information to architects about user interface of the BIM tools by analyzing the research results.

While these objectives are being investigated, it is intended to basically answer the following questions: “What is the impact of user interfaces of different BIM tools on processing speed in architectural projects?”, “What is the difference between the amount of processing in the project planning phase of different BIM tools?”, “Is there a relationship between professional experience and mouse movement when using the same software?

1.3 Contribution

With the development of technology and therefore the introduction of personal computers into human life, the computer-human relationship has become important. This relationship has begun to be taken into consideration in the development process of computer technologies and software. Therefore, the concepts of interface and experience have become worth evaluating and examining. The interface, which is an environment where the user and the software meet, is directly related to the usability of the software. Since the time personal computers have become widespread, research has been done on this subject and there is a continuous development and improvement process. These developments are made possible by evaluating the user interface and user experience. There are methods and studies in literature that will improve this subject. But these studies are not in the field of architecture. Therefore, a methodology has been applied in this thesis that will shed light on future studies in this field.

In this thesis, the place and importance of this subject in the discipline of architecture has been investigated by using this research and inferences in literature. BIM software, which has a very important place in the construction industry, is discussed in this context. With the data obtained as a result of the research, two actively used BIM software in the industry are the materials for the research in the thesis. In this regard, an evaluation was made on the usability of these two software in terms of user interface and user experience for architects. This test, performed on experienced users, intermediate level students and beginner students, was conducted on six different tasks. Interface usage in these tasks was evaluated in detail based on time, mouse movement and keyboard usage. These evaluations include both analysis of the numerical data produced as the result of the hands-on modeling exercise and interviews with volunteer users who participated in these exercises. That is, quantitative and qualitative evaluations were made in this thesis.

1.4 Disposition

This study is composed of five chapters. The first one is the Introduction Chapter. Which provides background information about the study, motivations of the research field and the aim and objectives of the study.

The second chapter consists of literature review on Building Information Modeling (BIM), BIM tools in architecture, and user-software interactions. In this context, historical developments of BIM and some commonly used architectural software are investigated. Additionally, the concepts of user interface and user experience and their representations in architectural software are also examined. A critical analysis of literature is conducted at the end of this chapter.

In the third chapter, materials and methods of the study are defined. Firstly, selection of materials and reasons for their election are explained. Then, different phases of research method are presented. The expected results of experiments related to hands-on exercises and interviews are explained in the fourth chapter.

Finally, conclusion of the targeted experiments and interviews, along with the contributions to literature are included with a summary of the study in the fifth chapter.

CHAPTER 2

LITERATURE REVIEW

In this chapter, a literature review has been carried out on Building Information modeling, user interface and user experience. The critical analysis of the literature has been added at the end of this study.

2.1 Introduction to Building Information Modeling

Implementation of BIM into construction industry is accepted as one of the major technological innovations in the field (Liu et al., 2015). After the implementation up until today, BIM has been used in the design and construction of some of the largest buildings around the world with an estimation of $1 trillion annual savings by the total cost reduction in the world-wide design and construction industry by the year 2025 (Boston Consulting Group, 2016). Later on, it was adopted in many related fields other than design and construction, which can be exemplified with mechanical, electrical and plumbing engineering, infrastructure design and management, and energy engineering. These adoptions have resulted in operational changes for all these fields and legislative arrangements for governments to include BIM solutions in their related mechanisms and economic systems (Guan et al., 2005). Sharing intelligent models that are created using BIM tools across different actors in a multidisciplinary work reduces time and cost spent in the progress, offers more control over the task, and enables better coordination between the actors throughout the life cycle of assets (Allen Consulting Group, 2010).

The terminological evolution of BIM has continued for decades. The term “Building Information Model” was first coined by Van Nederveen and Tolman (1992) in their studies under the title of “Modelling Multiple Views of Buildings”. Even though “Building Modelling” has been used since 1960s, these systems were distinct from the BIM concept and included modelled buildings with the purpose of extracting specified information from them (Ingram, 2020). The term, Building Information Model, was suggested as an alternative name in their search for a model that would form a common ground for different participants of building practice as designer, structural engineer, and mechanical engineer. In 2002, a white paper was published by Autodesk Building Solutions Industry that introduced their strategies on BIM stating the term as a collaborative and database centric modeling approach for application of information technologies to the building industry by emphasizing its three main capabilities: creating digital databases for collaboration, managing changes using the databases and preserving information for reuse in later applications (Autodesk, 2002). Ingram (2020) states that, popularization of the term is credited to Jerry Laiserin because of the face-to-face debate he organized in 2003 with the two leading design software companies, Autodesk and Bentley Systems, about their respective approaches to BIM which concretized the term as the way of referring to this concept.

Even though there are a great number of applications and studies on BIM, there is not a consistent definition yet. The National Building Information Model Standard Project Committee (n.d.). defines BIM as “digital representation of physical and functional characteristics of a facility and shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle”. Another definition was made by British Standard Institute as “the process of generating and managing information about a building during its entire life” (Fu, 2018).

BIM in the broader scale, consists of virtual modeling concepts together with information database on many different subjects as construction details, building geometry, spatial relations, material property and quantity, and building site characteristics in computer environment that architects, engineers and constructors as main actors of AEC industry use in design and construction to enable better information sharing and collaborative work (Kubba, 2012). Each member of the project team creates and maintains their sub-model as parts of a central model which allows project teams to detect collisions in design and construction simulation phases in virtual environments and response before, they reflect on the real-world situations. It can be said that the overall model gains more intelligence as it is fed by the content brought by sub-models with each interaction between the actors since each actor keep adding their knowledge and related information on the documents and operational actions. Moreover, all the information embedded in the model might be extracted and used throughout the lifecycle of the project. Even though parameters of a model are changed, the model keeps the information within it coordinated while adapting to that change, and that characteristic enables the information to remain consistent and accurate.

A well accepted characterization of building information models states four main characteristics as; intelligent digital representations of building components which can be associated with parametric rules and computable data, behavioral information of components to be used for analyses and simulation, consistent and nonredundant data enabling reflections of any change to the related components, coordination of data of models (Eastman et al., 2011).

It might be said that BIM is not only a way of creating digital representations but a complete process including the representational models which are in mutual relation with the process itself. The process includes comprehensive models that are used to make project decisions and inform all actors of the process through better communication. In BIM, comprehensive models offer coordinated information, and they are the main tools used in design, visualization, simulation and documentation phases (Ingram, 2020).

2.1.1 Concept of BIM in Architecture

3D CAD, one of the traditional architectural drawing tools, is widely used in the preparation of architectural expressions such as plans, sections, elevations, etc.

However, this drawing method allows these different expressions to be prepared independently. Because of that, the relationship between these drawings is created manually. Therefore, when establishing relationships between unconnected and independent drawings during the architectural drawing process, deficiencies or errors may occur. In other words, conventional 3D CAD systems depict buildings through separate, independent views like plans, sections, and elevations. Any modification in one view necessitates a manual check and update of all others, leading to potential errors and documentation issues (Azhar and Richter, 2009). Because all architectural elements and expressions in these drawings are represented by graphic and geometric objects such as line, polyline, arc, and circle. On the contrary, BIM operates with intelligent, context-aware models where building elements are not only graphical shapes but are defined as functional parts of the structure, like walls, beams, and columns. These elements in BIM, termed "smart objects," carry comprehensive data about the building, encompassing both physical and functional aspects as well as lifecycle information. That is, in architectural drawings prepared using BIM, building elements and systems such as walls, columns and beams are defined. They represent different features of the buildings, and provide the connection between different drawings and also disciplines (Azhar et.al, 2008). For instance, an air conditioning unit in a BIM model would include specifics about its manufacturer, operational procedures, and even spatial requirements (CRC Construction Innovation, 2007). In short, it can be said that one of the main differences between the BIM and traditional 3D CAD is in their approach to building representation.

BIM also affects all phases of a project. Unlike traditional drawing methods, different design and documentation methods are needed throughout the entire process, from concept to use. All elements of architecture and other disciplines are represented by using a three-dimensional model. This methodology enables the preparation of architectural drawings through a parametric model. All drawings and smart elements are related to each other through this model. Thus, the coordination of different architectural representations can be made without error. In the CAD-based workflow, since all drawings are prepared separately and individually, this coordination can only be done manually (Krygiel & Vandezande, 2014). In short, the BIM project provides a centralized workflow, while the CAD project is created by manually bringing together different drawings (Figure 2.1).

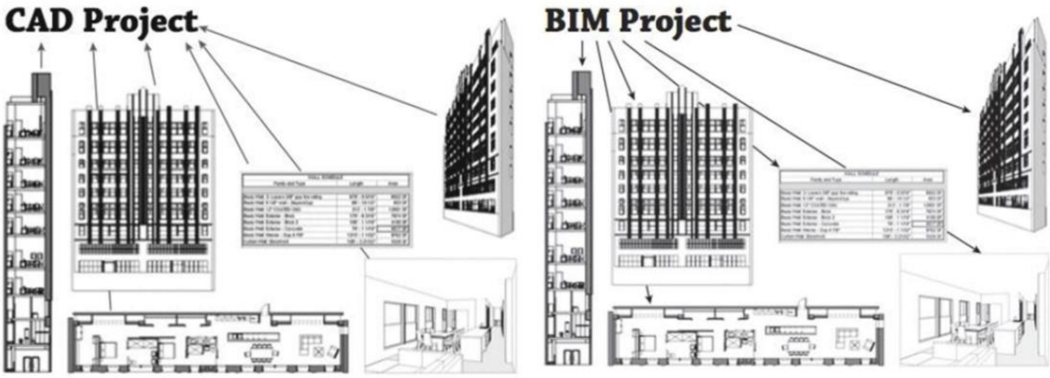

Figure 2.1. CAD-based and BIM-based workflows illustrated by Krygiel and Vandezande (2014).

Kymmell (2008) states that BIM, as a technology, encapsulates the concept of a digital project simulation. This simulation integrates 3D models of various project components, linking them with essential details needed for the project's planning, design, construction, and operation phases (Figure 2.2).

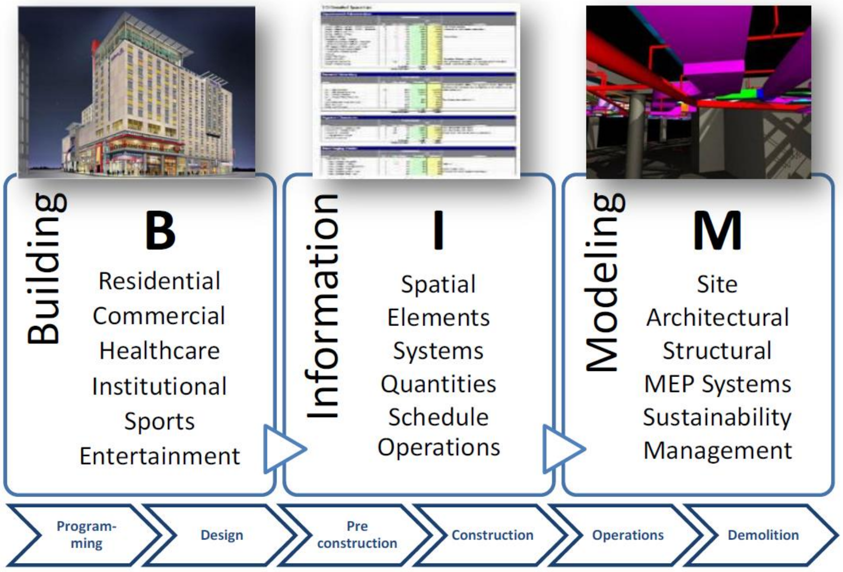

Figure 2.2. BIM concept represented by Kymmell (2008).

In addition to that, BIM originated from object-oriented parametric modeling, a technique characterized by its interconnected and responsive design elements. For instance, modifying an element like a door automatically adjusts related components like the adjacent wall, thus maintaining a consistent design relationship (Stine, 2023).

Design and drawing tools that can produce only two-dimensional or only three-dimensional drawings are unsuccessful in the integration between two dimensions and three dimensions. In other words, it is not possible for changing design decisions to affect the overall workflow. Reflecting the change of an object to all drawings is only possible by manually editing all drawings one by one. In contrast, BIM offers a more integrated, dynamic, and information-rich architectural modeling approach (Eastman et. al, 2011).

Ramilo & Embi (2014) mentioned that CAD tools are used as manual drafting and exercised for preparation of the project documents such as drawings, visuals etc. In other words, while building elements prepared in CAD software are represented by non-parametric and manual drafting, BIM software provides parametric 3D models. Moreover, BIM provides the integration of all building elements by creating a central system with the help of a 3D model of all information about the building (Czmoch & Pękala, 2014). This system, where the information of the entire design and construction process can be managed, can progress from 3D to nD according to need and usage (Figure 2.3). In short, the dimension of the BIM model increases according to the information and management parameters.

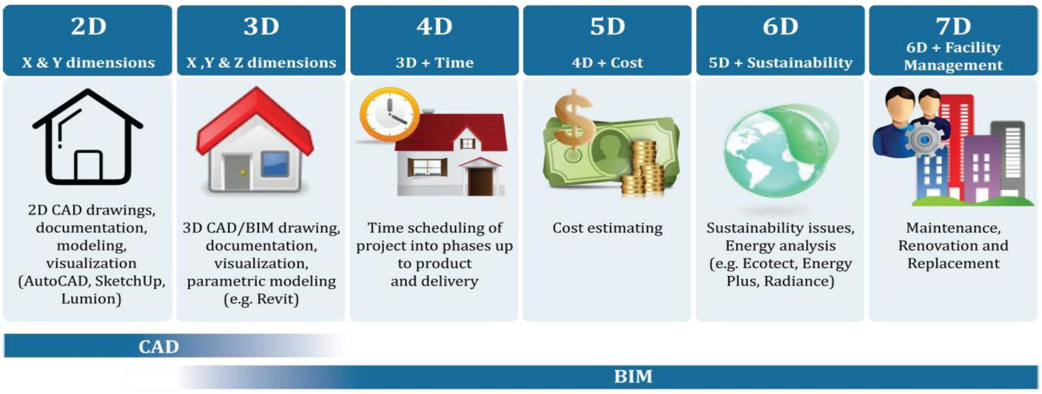

Figure 2.3. Dimensions of CAD and BIM projects (Maina, 2018).

Maine (2018) explained the content and differences of these dimensions. The 3D representation tool was basically created by adding the 'z' plane to the tool that allows two-dimensional drawing. When the 'time' parameter is added to the three-dimensional tool, a 4D representation is obtained, and when 'cost' is added, a 5D representation is obtained. In addition to that, when parameters about simulation in the contexts of sustainability and energy are added, the project is called 6D, and finally when the 'management' parameter that can affect all phases of the design and construction process is added, the project is called 7D.

BIM can be considered as a virtual model that allows all employees in the project team to collaborate more efficiently and accurately than traditional methods. Thus, it enables establishing a central control and communication mechanism for different disciplines and systems such as architects, engineers, contractors, subcontractors, and material suppliers. All team members can see the full impact of their intervention and project decisions on the project. In other words, all disciplines are involved in the project before the construction process begins, and the entire process is designed by creating an accurate model (Carmona and Irwin, 2007).

BIM projects are based on a system focused on communication and collaboration. Therefore, everyone from different disciplines who will work in the project process must be actively involved in the system at the beginning of the project process (Azhar et. al, 2012). Thus, the BIM process differs from the traditional project process (Figure 2.4).

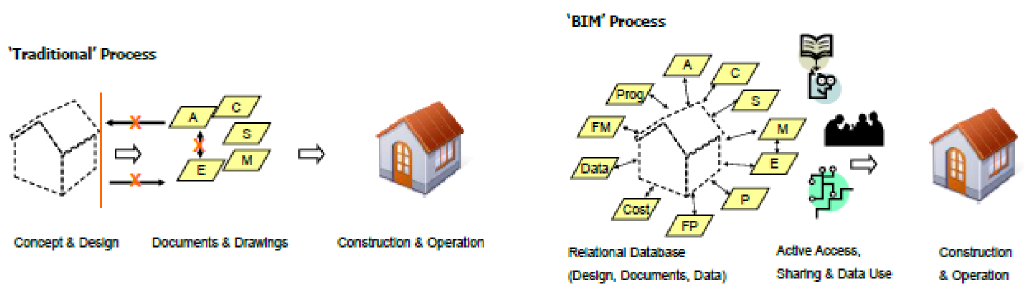

Figure 2.4. Traditional project (left) and BIM project (right) processes (Azhar et. al, 2012).

Azhar et al. (2008) described the purposes of use of BIM tools. These are listed below:

- Rendering: It is possible to prepare visualizations through a detailed 3D model.
- Detail Drawings: Once the model is completed, drawings at different scales such as detail drawings and shop drawings can be prepared.
- Time Schedule: BIM allows managing project delivery times for different disciplines and supply and manufacturing times for construction.
- Clash Detection: Relationships between architectural, static, electrical and mechanical disciplines are established through a central 3D model. Coordination of pipes, beams, channels, and other architectural elements in the structure can be easily achieved.
- Cost Estimation: BIM tools provide the opportunity to make approximate cost estimates. Estimates for this cost are updated as decisions affecting the design change.
- Maintenance Operations: Facility management issues such as organizing spaces and making necessary renovations can be managed through BIM.
- Diagrams: It can be used to prepare diagrams describing the design and structure of all disciplines involved in the project.
- Project Approval Processes: Official organizations that need to control and approve the project, such as the fire department, can do this process through BIM.

Building Information Modeling has many advantages. The most important of these advantages is the 3D geometric representation that combines all design inputs and the process (CRC Construction Innovation, 2007). The information mentioned above as purposes of BIM can actually be shown among the advantages of BIM. In short, these advantages are the effective and efficient design of the project process, the environmental performance of the building being more predictable, and the practices for construction being more effective and planned (Azhar, 2008). In a study conducted by the Stanford University Center for Integrated Facilities Engineering (CIFE) involving 32 large-scale projects using BIM, it was concluded that there was a 40% reduction in extra-budgetary changes and a 7% reduction in project time. At the same time, the accuracy in cost estimation was seen as 3% (CIFE, 2007).

BIM is software that enables project preparation and delivery of 3D smart models and allows programming of the workflow. However, BIM is also a process as it provides control of this entire workflow (Hardin & McCool, 2015). Since this process establishes a platform where different disciplines can work together, it provides more efficient solutions for each stage of the project. Thus, the roles of all stakeholders of the project become integrated (Azhar, 2011). Therefore, Glick and Guggemos (2009) stated that this situation creates a paradigm in the AEC sector.

The use of BIM in the construction industry is increasing and therefore employees are expected to be proficient in this technology (Ku & Taiebat, 2011; Pikas et. al, 2013). BIM, which has been developing for three decades, has become a very important development in the AEC sector (Azhar, 2011). In other words, BIM is at the center of technological developments in the sector. (Lu et al, 2013). According to the survey held by McGraw-Hill Construction (2012) of employees in 582 AEC industries in North America, 71% of architects, engineers, contractors, and owners have started using BIM effectively in their projects. According to these data, it can be said that 75% increase in the last five years was achieved. When the stakeholders in this sector are examined separately, contractors have the highest rate of usage with 74%. While the usage rate in the architecture discipline is 70%, the usage rate of civil engineers is 67%. With this survey, it is possible to predict that BIM usage in the construction industry in North America will reach 90% (Zhao et. al, 2015).

While developments in BIM technology increase the number and percentage of sector employees using this technology, they also affect job opportunities and potential in the sector (Figure 2.5).

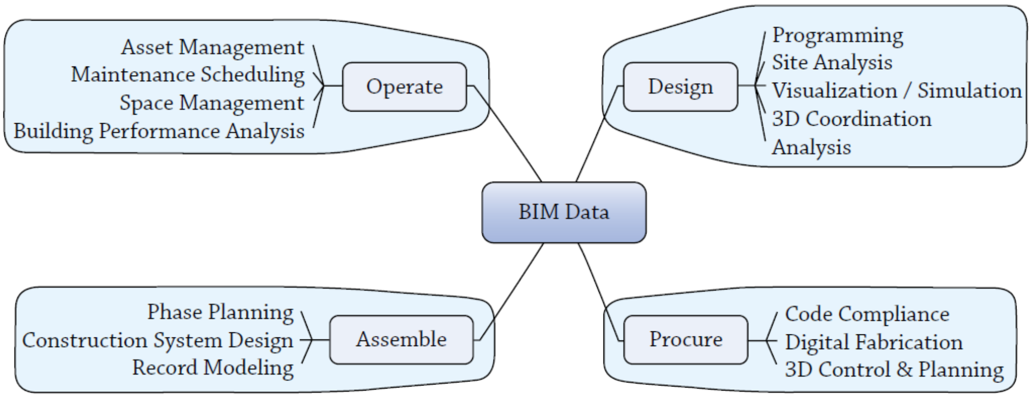

Figure 2.5. Opportunities and potentials in the AEC sector provided by BIM (Krygiel & Vandezande, 2014).

Thanks to BIM, these rapidly increasing and developing opportunities in the construction process show their impact in the design, coordination, controlling, and operation phases. Benefits such as clash detection, visualization, and technical drawing support provided through the three-dimensional model also increase the work efficiency of the technical staff who are using BIM. Despite this, traditional CAD programs continue to exist widely in the industry. BIM, which is in a continuous development process, provides a solution to the needs in the sector. Instead of programs that only offer architectural documentation and visualization, BIM, which provides design support for different stages of the construction process and helps manage this entire process, is increasing its importance in the sector (Azhar, 2011).

There are many studies on this development process of BIM. For instance, researchers at Penn State University have developed BIM uses and project implementation guides. It is important to develop open standards to support the effective use of BIM, and buildingSMART International provides a global platform in this field. Various groups around the world are working on information exchange standards that will affect model data sharing. Recent developments include standards such as IFC (Industry Foundation Classes) version 4, COBie (Construction Operations Building Information Exchange), SPie (Specifiers' Properties

Information Exchange) and BCF (BIM Collaboration Format). These studies are also supported by the BIM Task Force in the UK (Krygiel & Vandezande, 2014).

The working principle of BIM tools is based on a parametric system. The functions that form the basis of the parametric system were added to solid modeling systems later and developed over time (Eastman et. al, 2011). First, these functions are related to structural elements such as columns, beams, floors, doors, and windows. Dimensions and measures of these building elements are determined and managed by parameters. Changing the parameters allows to be changed and managed the structural elements which are the smart objects creating the model (Luciani et. al, 2012).

Secondly, it is the positioning of the objects in the model. This change in building elements can be managed in different ways. These are listed below (Luciani et. al, 2012):

- Parameters for different structural elements ensure that the control of these structural elements is independent of each other. Eastman (2011) called this 'parametric-procedural'. For example, when the parameter of the wall size is changed, this change does not affect the window position (Figure 2.6).
- The variational approach allows one to create the model without limitations. However, the basis of this method includes complex rules that are beyond traditional design and modeling knowledge.
- While the building elements in the model are positioned, their relationships with each other are automatically provided by the system. However, when these elements are created by the user, these relationships may not be maintained and as a result, errors may occur.
- The placement of structural elements such as columns can be connected to the axis system. This parametrically created grid affects all components of the model. In this case, manual control by the user may not be possible.

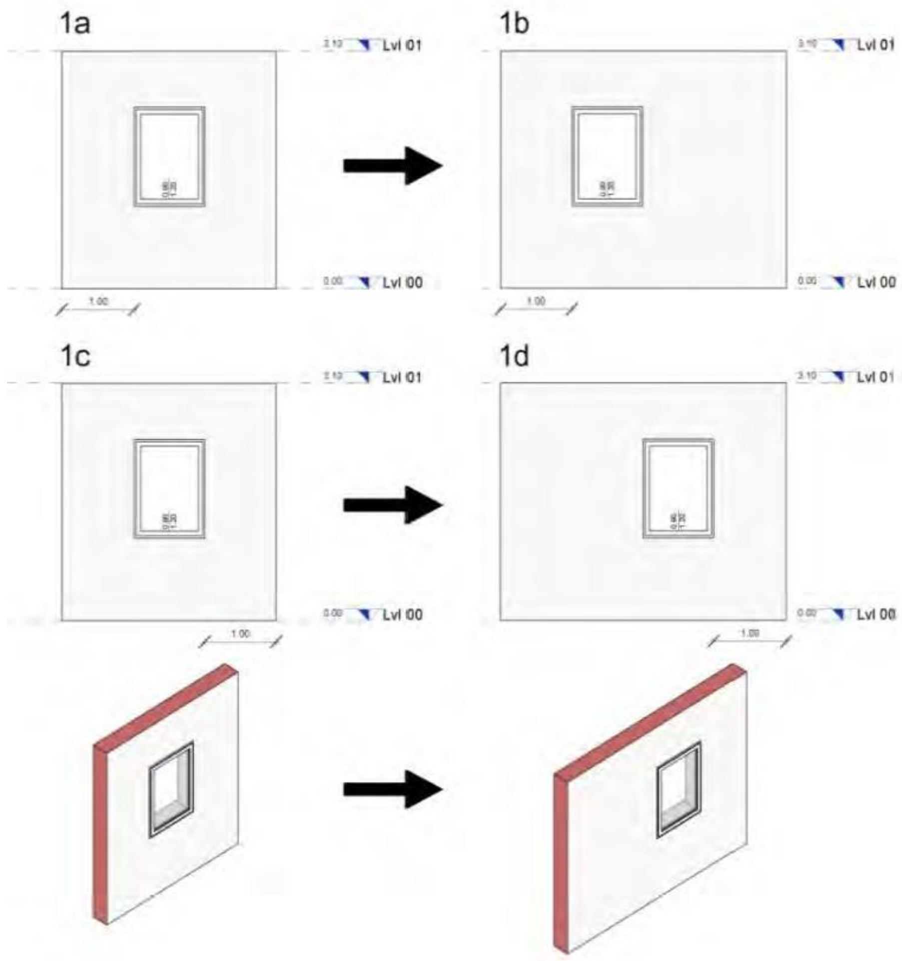

Figure 2.6. The relationship between the position of the window and the dimension change of the wall (Luciani et. al, 2012).

2.1.2 Historical Development of BIM

The emergence of the concept of computer-aided design dates back to the doctoral dissertation of Ivan Sutherland, who is also known as the father of computer graphics, in 1963. His doctoral thesis was a project which was named Sketchpad. It stands as the earliest interactive graphical computer program. This innovation provided users visualizing and manipulating the functions of the program (Pyfer, 2017). He and his thesis advisor Claude Shannon's academic work pioneered the fields of computer graphics, the graphical user interface (GUI), and computer-aided design (Hosch, 2023). These studies did not remain only in the academic environment, Sutherland founded a company related to high-performance computer graphics. Thus, a technological development has occurred that will take an active role in the design and production processes. After a six-year development period, CAD began to be used in the production system (Eastman, 2018).

The current technology has been made possible by the development and follow-up of information and experiences since this date. Eastman (2018) mentioned that after the release of the Sketchpad program in 1963, the CAD program, which provides the opportunity to draw using written commands, began to be used commercially in the late 1960s.

In the early 1970s, the CRT display tube was introduced. Cathode-ray tube (CRT) works on the principle that an image is formed when electron beams hit the phosphorescent surface on the screen (Britannica, 2023). While by using a single electron gun, a monochrome color image is obtained, by using a 3-electron gun, a colored image can be obtained. This color scale consists of the basic color’s red, green and blue. RGB color model is the color representation system in digital devices (Zelazko, 2023). With these developments, new CAD companies were established in the 1970s.

CAD continued its development with the development of personal computers in the 1980s and the spread of multimedia in the 1990s. In the process until today, it has evolved into software that will allow different representation tools to meet the needs of different disciplines in the building, construction, and production processes. This evolution process continues by representing building information in a central model (Table 2.1).

Table 2.1 The important dates and key events in the development of CAD systems

Dates	**Developments**	**Explanations**
1963	Sketchpad program by Ivan Sutherland	The pioneer of the interactive CAD systems. Drawing assistance helps to create drawings and geometrical shapes.
1969	Commercial CAD system	The first commercial CAD system to display drawings defined by text commands on a plotter, introduced by Computervision Corporation.
1970	Early CRT display tube	An early CRT display tube was introduced that allowed direct interaction.
1970s	Establishment of new CAD companies	Companies such as Applicon, Calma, Autotrol, Intergraph, CADAM were established.
1980s	The rise of CAD (personal computers)	CAD trended upward enthusiasm with the personal computers' becoming widespread in the 1980s.
1990s	The rise of CAD (multimedia)	With the proliferation of multimedia and increased media attention in the 1990s, interest in CAD increased.
Recent Years	Evaluation of CAD systems	CAD systems have evolved with the addition of a geometric editor, an environment that develops discipline-specific applications, and a central model that represents building information.

The evolution of CAD systems has developed according to three main different parameters (Eastman, 2018):

- *CAD as Geometric Editor*: This paradigm expresses the idea that the primary function of CAD systems is to organize and design geometric shapes. Users use the tools provided by the CAD system to create, edit and modify drawings. This approach was the main use of CAD in its early days and focused on basic design and engineering operations.

- *CAD as an Environment for Developing Discipline-Specific Applications*: This paradigm involves using CAD systems as a platform from which to develop customized applications for specific disciplines or industries. This approach enables the development of tools and functions that meet specific needs in specific fields, for example in architecture, engineering, or industrial design. In this sense, CAD ceases to be just a drawing tool and becomes a more complex tool used to solve industry-specific problems.
- *Systems that Support Domain-Specific Applications by Adding a Central Model*: This paradigm refers to CAD systems supporting domain-specific applications with a central model that represents building information. Early efforts focused on the development of what is now called the "building model" rather than viewing CAD as merely a graphics editor. This approach enables CAD systems to be used throughout the entire lifecycle of a building or product, including design as well as construction planning, operation, or management.

In the years when CAD technology first appeared, this technology challenged and even exceeded the computer capacities of the period. For this reason, increasing the prevalence of technology use has been more difficult than today. Over time, with the development of technology, computers have become able to meet these demands of CAD software. CAD depends on three main technological areas in terms of display technology, processor capacity and software capabilities. Advances in display and processor technologies enable more effective use of CAD, while software advances include real-time rendering and more complex 3D editing capabilities (Eastman, 2018). These technologies form the basis of high-quality, dynamic imaging capabilities used today in many different disciplines, including architecture.

In the 1950s, computer-aided applications were developed for automatic calculation of mathematical formulas. This technological development has affected business activities, workflow, and efficiency in different sectors. When it was realized that this technology could be included in the design and production processes, the discipline of architecture was also nourished by this development.

Since CAD is directly dependent on technological developments, the development and evolution of CAD software has occurred with the development of display and processor technology. Pixel-based bitmap displays have been actively used in CAD technology. It became more practical and accessible with mini-computers in the 1970s. The continuous improvement of the representation of complex geometric data and the ability to process data has led to the interactive design programs used today (Eastman, 2018). That is, these technological developments directly affected the CAD technologies (Figure 2.7).

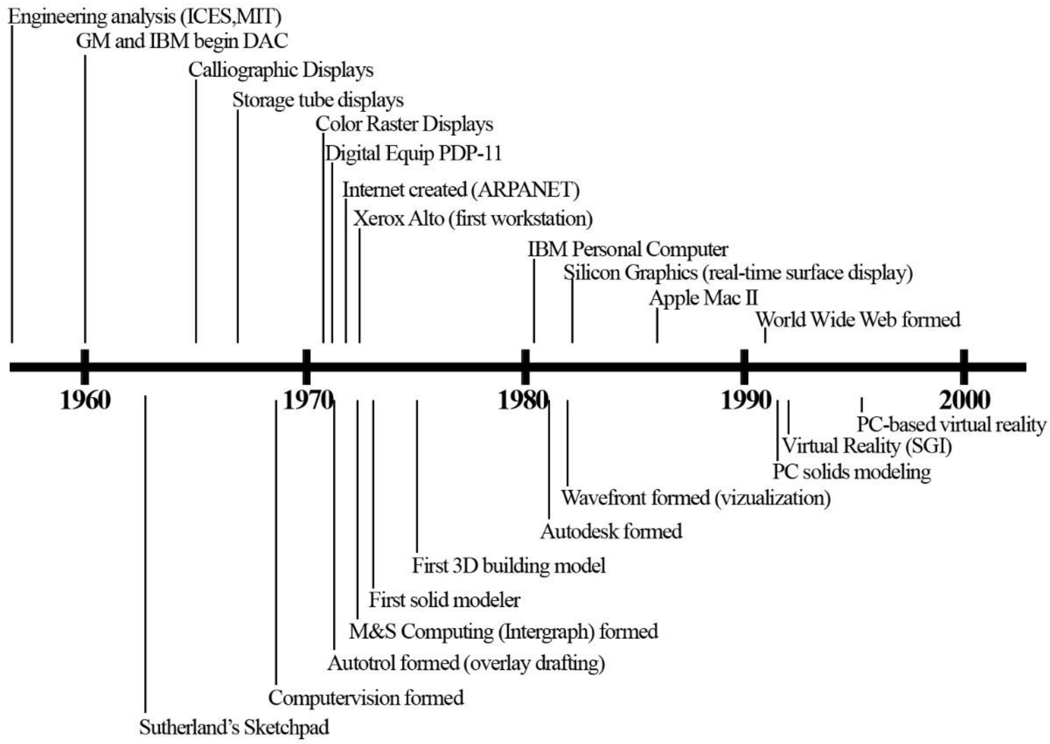

Figure 2.7. Timeline of the technological developments related to CAD technology (Eastman, 2018).

This continuous technological development has been important for CAD companies' share of the market. In other words, CAD companies have continually innovated geometric data representation. Companies that could not follow this development process lost their share of the market. The key features that develop and emerge in

CAD software over time represent the dynamism of the software and the competition in the sector. These features are listed below (Eastman, 2018):

- Symbol: When it was invented, it was just a geometric representation. Later, the data was loaded.
- Layer: It is the method used to organize data.
- User Application Language: It provides users with programming opportunities to meet specific needs.
- Associative dimensioning: This allows objects to relate to each other.
- Modeling: It is important to create 3D-wireframes of three-dimensional structures and to allow surface modeling. Later, objects could also be created as three-dimensional solid models.
- Rendering: Visualization programs integrated into the model have been developed.
- Parametric Modeling: It is possible to create solid models with parameters and use advanced visualization techniques.

The developments that triggered the creation of CAD tools date back to the beginning of the 20th century. So, in fact, technological developments have directly affected CAD.

As mentioned above, computers and software have been continuously developed to solve engineering and design problems since the 1960s. This enabled significant advances in computer-aided design and graphics throughout the 20th century. From the first interactive graphics to the evolution of CAD, advances in this field have formed the basis of modern engineering and design practices. This evolutionary process is also directly related to certain events and developments (Ingram, 2020). The events until the foundation of the CAD tools in the historical process are shown in the table below (Table 2.2).

Table 2.2 Events which provide technological developments in the fields of graphics and computers.

Date	Event
1925	Robert Watson-Watt demonstrated radio signals from lightning strikes on an oscilloscope by using graphics.
1941	The first computer built by Konrad Zuse was used for aerodynamic calculations.
1948	The first truly programmable computer became available.
1967	Professor Sir Leslie Martin founded the Center for Research in Architecture.
1968	Ivan Sutherland founded the first company, Evans and Sutherland, which was a pioneer in the field of computer graphics.
1970	Computer Aided Design began to develop.

Following the invention of the CAD system in 1970, Building Information Modeling emerged in the mid-1980s to address deficiencies and problems in the AEC industry. Issues affecting the design and construction process, such as planning the design and construction phases, interdisciplinary coordination, cost calculation, and material use, have caused this need (Tommasi and Achille, 2017). The development of this technology has accelerated with the use of BIM by large-scale architecture and construction companies. This development has directly affected the design process in architecture. One of the most important changes is the establishment of a new communication network between different disciplines such as architects, investors, clients and engineers. In addition to that, it offers designers the opportunity to create environmentally friendly buildings with the help of smart blocks and objects. In other words, BIM offers designers the opportunity to measure the performance of buildings and calculate the project cost (Ingram, 2020).

BIM generally specializes in building design and drawing. Applications required for modeling the building play a critical role in the BIM system. In order to provide these features and customizations, BIM research is carried out and various systems that finance this research are established. The most important of these systems are generated by Applied Research of Cambridge (ARC), the US Department of Environment, and the Scottish Special Housing Association (SSHA) (Ingram, 2020). These systems were developed for architectural drawing and construction management of buildings that can be standardized, such as hospitals, residences, and official institutions.

BIM is a set of parametric systems that enable interdisciplinary integration and offer information-based modeling opportunities. To reach the BIM system used today, there were serious initiatives and studies on building modeling and architectural drawing in the 70s and 80s. These systems, which help the design of buildings, emerged with the funding of certain institutions. At that time, computers were very expensive, and this software was not affordable. Therefore, it did not spread to the construction industry and market until the 1980s (Ingram, 2020). These are listed below:

- *BDS (Building Design System) by Applied Research of Cambridge*: This system was initiated by the ARC, founded in 1969, and then, developed OXSYS7 for the Oxford Regional Health Authority in 1971. This system was one of the first building design systems and it could produce drawings and various additional results (Reynolds, 2014). BDS enables architectural organization by dividing the building into independent zones and allowing the characteristics of each of these units to be determined. The system had deficiencies in the positioning of the components that create the building and the management of the relevant data.

- *HARNESS*: Developed by the University of Cambridge's Architectural Research School with funding from the UK Department of Health and Social Security, HARNESS was created for the design and preparation of necessary documentation for hospitals (Figure 2.8). It has helped simplify the design process by using distinctive architectural standards, especially in hospitals. Provided analysis regarding building, environment, and cost. This was also used for hospital management (Ingram, 2020).

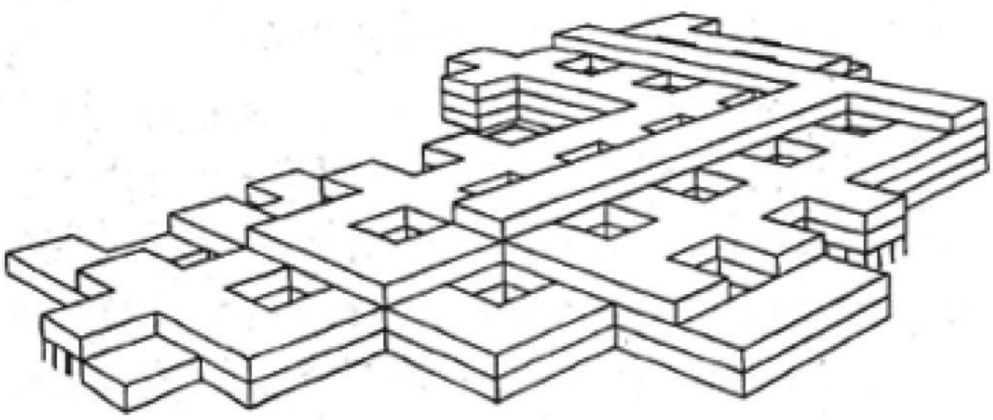

Figure 2.8. Perspective view from HARNESS (Gero, 1976).

- *ARK-2*: Developed in the early 1970s by Perry, Dean and Stewart in collaboration with Design Systems and Decision Graphics. Being a 2D system, ARK-2 allowed integrating multiple standard elements within a single plan, although it had screen refresh limitations (Ingram, 2020).
- *EDCAAD/ SSHA*: Carried out by the University of Edinburgh's School of Architecture, with funding from the SSHA, this project focused on developing housing design units and site plans for them between 1969 and 1973 (Ingram, 2020).
- *CEDAR*: It was developed by the Department of Environment in the early 1970s for the design of post office buildings. This software, which was used to design and draw architectural elements in detail, also provided cost estimates and environmental data. By presenting standard details to the

designer, it offered the opportunity to compare the cost and efficiency between design alternatives (Ingram, 2020).

- *CARBS*: Developed in 1972 by the University of Liverpool and Clwyd County Architects, the CARBS system focused on plan drawing and documentation generation.
- *SPACES:* Developed by the ABACUS unit at the University of Strathclyde in 1972, it was designed to assist in the initial phase design of schools. Architectural drawings could be produced by creating and analyzing space. In addition, necessary evaluations could be obtained by entering information about construction and architecture (Ingram, 2020).
- *GABLE*: Developed by the University of Sheffield in the mid-1980s, GABLE CAD was an advanced 2D and 3D design tool. It allowed the creation of complex 3D models, 2D drawings and visualizations. As the system generated IDS (2D Integrated Drawing System), this situation provided creating AutoCAD type drawings (Ingram, 2020). While it allowed the generation of 2D files supported standard drawing formats, the 3D components offered versatile viewing and object creation. This system was discontinued in 1996.
- *RUCAPS*: It was developed by the Gollins, Melvin, Ward Partnership (GMW) and was first used in parts of Riyadh University and later in the design of many major hospitals. This program, also defined as two and a half dimensions (Reynolds, 2014). Basically, RUCAPS enabled the rapid production of 2D architectural representations such as plans, elevations, and sections (Figure 2.9). Additionally, this software offers basic programming.

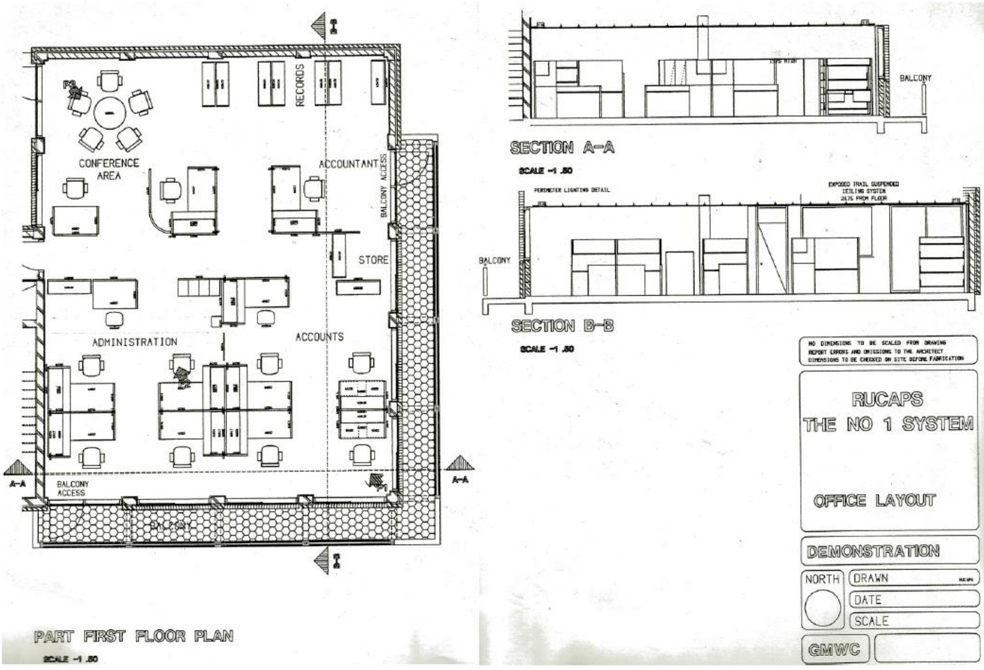

Figure 2.9. Plan and elevation drawings in RUCAPS (Ingram, 2020).

- *GLIDE II:* Developed under the leadership of Charles Eastman at Carnegie-Mellon University's CAD Graphics Laboratory, GLIDE aimed to advance solid modeling techniques for building design and integrate this modeling with databases and other necessary tools. This system used Interpretive; an extended version of the Pascal programming language popular at the time (Eastman, 2018). GLIDE formed the basis for the BDS, which was introduced in 1974 and was based on solid modeling. It also served as a general-purpose GUI design language capable of performing Boolean geometric operations on building definitions (Ingram, 2020).
- *CAEADS:* The University of Michigan Architecture and Planning Research Laboratory had worked on Computer Aided Architectural Design (CAAD) since the early 1970s and developed the Computer Aided Engineering and Architectural Design System (CAEADS). This work, led by Harold Borkin, was supported by the Army Corps of Engineers Construction Research Laboratory and was used specifically in the design of military facilities. CAEADS offers an integrated workset to automate the data development

process and to support work in the early design process (Ingram, 2020). This system can work in interaction with other independent programs such as energy analysis, structural analysis and drawing systems.

These systems, listed above, which facilitate the drawing and construction process, have been funded by universities and various public institutions. After 1980, private companies also gained a place in the market and various software emerged (Ingram, 2020). This software allows two-dimensional and three-dimensional drawing and provides a relationship between these two dimensions. This software is listed below:

- CALCOMP
- ARRIS
- ARCHITRON
- ARCHICAD
- CADAIM, CATIA, FASTDRAFT by IBM
- AES
- INTERGRAPH/BENTLEY
- COMPUTERVISION

BIM has been studied and developed by universities in building design and automation for more than a decade. During this period, many systems focusing on the automatic design process were developed, but three-dimensional modeling and automatic updating were not fully integrated. In this process, a system was developed that allows designers to derive various drawings from a model and automatically updates all edits. SONATA, which was written by Ingram in the early 1980s, has created a system that takes this approach, integrating 2D drawings and 3D modeling and combining building information into a single database. In other words, this system uses an integrated model that synchronizes graphical and non-graphical data of each element of the building. This model includes 'smart' components that can design and adapt themselves to environmental conditions, thus dynamically responding to users' needs. Additionally, the system includes a variety of additional design tools such as network planning, steel structure design and thermal analysis, giving users access to a more comprehensive and integrated design process. This is a very important step in the evolution of BIM (Ingram, 2020).

2.2 BIM Tools in Architecture

There are almost seventy different BIM software available currently on the market. This software is shaped according to diverse needs in the architecture and construction industry and responds to these needs and expectations. The most common ones on the market are listed below (Ingram, 2020):

- Autodesk Revit
- Graphisoft Archicad
- Nemetschek Allplan
- Nemetschek Vectorworks
- Bentley OpenBuildings
- Beck Technology
- Bricsys BricsCAD BIM

According to The National BIM Standard 10th Annual BIM Report (2020), Autodesk Revit was the most used tool by research participants by a significant margin (Figure 2.10). Graphisoft Archicad ranks second (Bain, 2020).

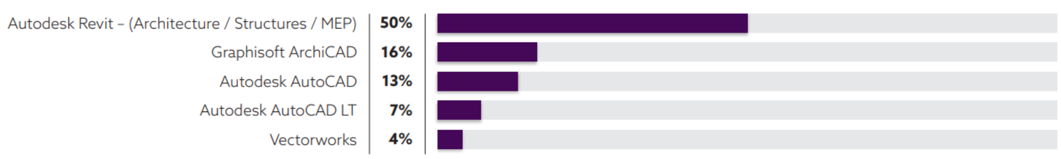

Figure 2.10. The most preferred design and drawing tool (Bain, 2020).

In another study conducted on the BIM program in the construction sector in Vietnam, Revit was again the most common BIM tool used by relevant employees, with a rate of 72% (Figure 2.11).

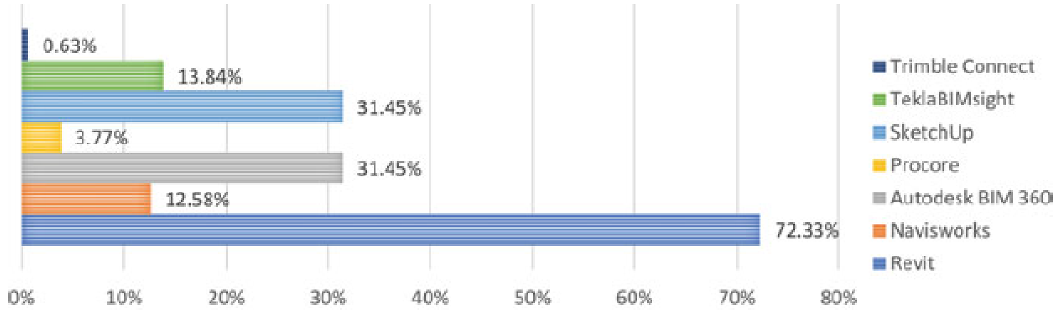

Figure 2.11. Usage rate of BIM tools according to the research in Vietnam (Toan et.al, 2022).

Considering the above information and its use in BIM projects, Revit, which is the most common program, provides a working environment not only for the architectural discipline, but also for structural, mechanical, and electrical engineers serving the construction industry. In fact, Revit™ software offers 3 different packages: Revit™ Architecture, Revit™ MEP, and Revit™ Structure. At the same time, it connects and associates the working environment of all these disciplines by producing a central system (Azhar et. al, 2008). In addition, it enables the import and export of different file formats such as IFC and DWG, which are widely used in the industry (Toan et. al, 2022).

2.2.1 Overview on Autodesk Revit

Revit is the most commonly used BIM application software that was developed by Charles River Software Company in 1997 which was renamed as Revit Technology Corporation in 2000 and later acquired by Autodesk Company in 2002. Autodesk is specialized in software development that is used in manufacturing, construction, media, and entertainment industries. It was already known for popularization of CAD tools thanks to the AutoCAD, but they aimed to have an easier way of building simulation and representation with Revit which they supported with a similar layout and user interface to the AutoCAD that was already widely used in AEC industry in 2002 (Waas, 2022).

Waas (2022) also states that the name Revit was abbreviated from Revise-Instantly which reflects the main aim of the software that is changing the overall model and documents easily correspondingly with any minor change in any component or sub-model. Revit uses parametric 3D instance models to create all necessary documentation of design of a building that includes not only plans, sections and elevations but also details and schedules (Joseph et al., 2020). The drawings created in Revit are not just representational lines and shapes, but they are dynamic views that extract their information from the virtual model that consists of intelligent components containing information on both physical and functional attributes. All the instances of components have that stored information within themselves which act as part of a central database of the project.

The components, sub-models and the overall model can be changed and managed with respect to a hierarchy of parameters, and since the drawing set is responsive to the changes in the model, any change in any component affects the related drawing and becomes visible on them. Moreover, since this interaction is bidirectional, it works vice versa. For example, when a window is moved in an elevation, since the information of the new location properties is stored in the window itself, the model adapts to that change and automatically moves that window in all sections, elevations and perspectives where it is seen. That automatic update feature guarantees an always up-to-date model to be viewed and accessed by any actor of the project (Ingram, 2020). This characteristic of BIM, when compared with the traditional use of CAD tools, provides the actors of a project with the opportunity to extract information, organize project data and collaborate with other actors more easily (Krygiel & Vandezande, 2014).

One of the main advantages of Revit is being able to reference to the principal floors which makes it easier to reproduce any floor without a need for reproducing the detail every time, that saves a remarkable amount of time while working on multistorey building design projects. In addition to the easier management of drawing sets, Revit offers many other advantages when compared with other BIM tools. Revit is provided with a wide range of file formats including the ones that are used in 2D drawing tools, 3D modeling tools, video, and image files, and also several standards for structural analysis and energy simulation. That wide range and large market presence make it easier to share components or models between different actors of the large development teams. The large market presence also provides users with many supportive media on learning Revit, and the community supports the software with developing add-ins thanks to the strong development platform which enables it. Another feature of Revit that paves the way for easier development is that it supports NET scripting and visual scripting by using Dynamo (Ingram, 2020).

It also enables users to export different file formats like PDF, IFC, CAD formats like DWG, DXF, OBJ, etc. (Figure 2.12).

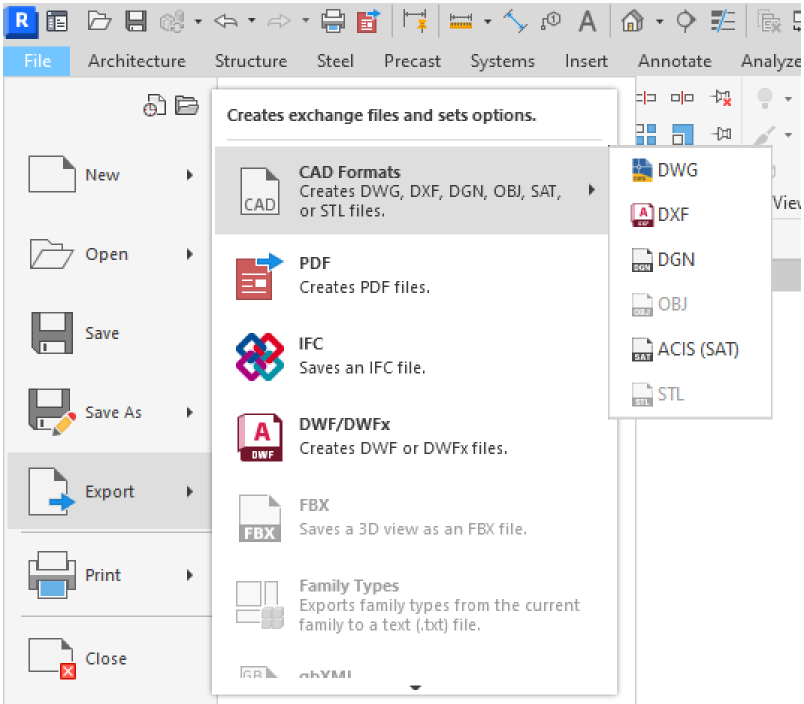

Figure 2.12. Revit export options

Revit works with groups of elements called families, which is a debated issue. Even though the automatic creation of relations between different families is perceived as useful, the prebuilt constraints might become an obstacle during the design. Each building component has multiple relations with the other ones which might cause inflexibility problems during the design phase and require rebuilding in the correct order to resolve those problems. Moreover, another disadvantage of working with Revit families might be stated as losing the ability to add external functionality to the components or the overall model.

There are also more disadvantages of Revit, except from the problem with families stated before, when compared with other BIM tools. The first disadvantage might be that the interface of Revit might be perceived as more complex when compared with the similar BIM tools since it includes sub-menus within each menu. The second disadvantage is that file sizes might get too big, that it might require too much time to load, and the interface might get slow and laggy. Since it generally not multi-threaded, it requires fastest CPUs and might not scale well to big models. Another disadvantage is that Revit files are not backward compatible, and it might make difficulties in version jumps even though it is forward compatible (Ingram, 2020).

An examination of the development of Revit reveals that numerous versions have been released with updates since its inception. Autodesk website (n.d.), Shaan (2019) and Krygiel (2015) mention all versions of Revit with their year of release as follows:

**Charles River Software*

- (Early Adopter 1 – private release) November 1999
- (Early Adopter 2 – private release) January 2000

**Revit Technology Corporation*

- Revit 1.0 April 2000
- Revit 2.0 September 2000
- Revit 2.1 October 2000
- Revit 3.0 February 2001
- Revit 3.1 June 2001
- Revit 4.0 November 2001
- Revit 4.1 January 2002

Autodesk Revit

- Revit 4.5 May 2002
- Revit 5.0 December 2002
- Revit 5.1 May 2003
- Revit 6.0 December 2003 (Figure 2.13)

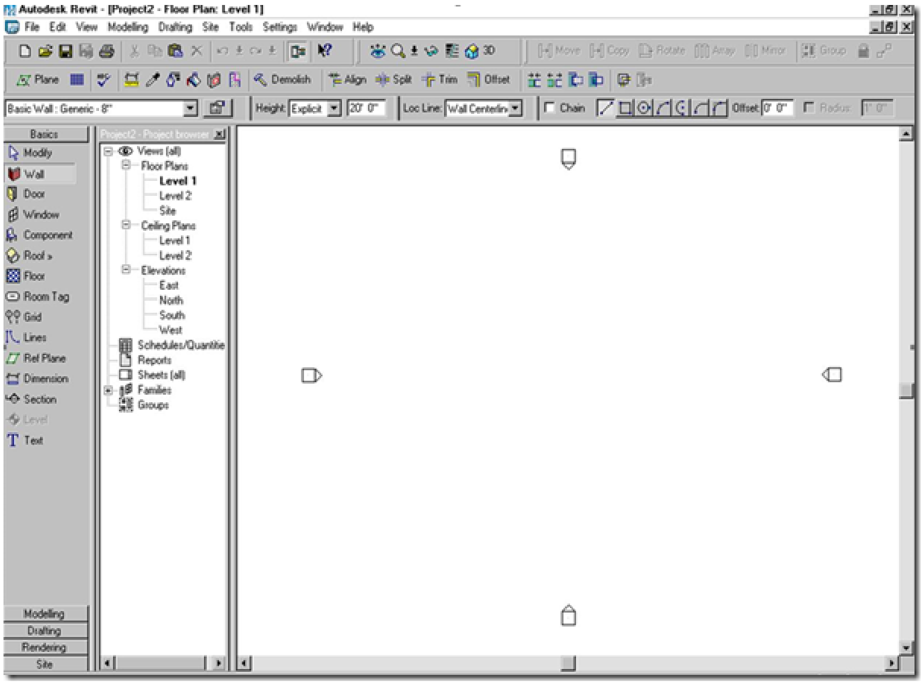

Figure 2.13. Interface of Revit 6.0 (Shaan, 2019)

- Revit 6.1 March 2004
- Revit 7.0 December 2004
- Revit 2009 - April 2008
- Revit 2010 - April 2009
- Revit 2011 - April 2010
- Revit 2012 - April 2011
- Revit 2013 - March 2012
- Revit 2014 - April 2013
- Revit 2015 - April 2014: Sketchy Line feature, anti-aliasing, Ray trace, hidden Lines, revision clouds, IFC import, schedules and material take-off

features, duplicate view, view references, trim/extend features, manage links improvements, keynoting settings, family parameters, tag leaders, temporary view properties, pinned elements, view title families, attached detail groups, assembly code file, some performance enhancements.

- Revit 2015v2 - September 2014 Codename Sundial
- Revit 2016 - April 2015 Codename Copernicus
- Revit 2016v2 - October2015 Codename Sunrise
- Revit 2017 - April 2016 Codename Kepler
- Revit 2018 - April 2017
- Revit 2019 April 2018: Cloud models for Revit, high resolution texture support for rendering tool, placing an instance of an image, zooming in schedules, moving elements detailed distances, parts from imported bridge and tunnel geometry, background fill patterns, 3d views: levels, projection modes, uncropped perspective view, or condition for rule-based view filters, dimensions for curved objects in section views, perspective views, resizable dialogs (Figure 2.14).

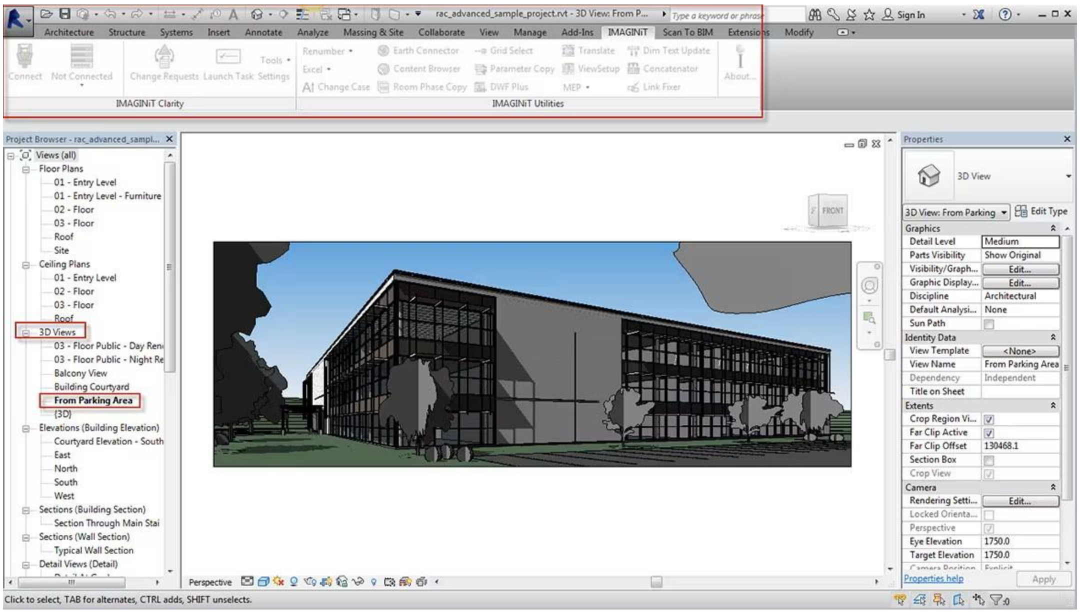

Figure 2.14. Interface of Revit 2019 (Autodesk, n.d.)

- Revit 2020: Underlaying PDF feature, creating elliptical walls, opening a Revit model with desktop connector, improvements in materials features, enhanced or condition for rule-based view filter, scheduling scope boxes, improved Revit home, SketchUp 2018 models support, large schedules: freeze/unfreeze header, active row and cell highlighted, path of travel.
- Revit 2021: Developments in generative design features, enhanced realistic views, slanted walls, link pdf files or images, electrical circuit naming scheme, cloud models on Europe data centers, enabling/disabling view filters, new standard 3d rebar shapes, improved Revit home, customized workspace.
- Revit 2022: Improvements in exporting PDF, wall enhancements, shared parameters in key schedules, interoperability with FormIt, linking Rhinoceros files, tags, multiple values indication, move rebar in a set (Figure 2.15).

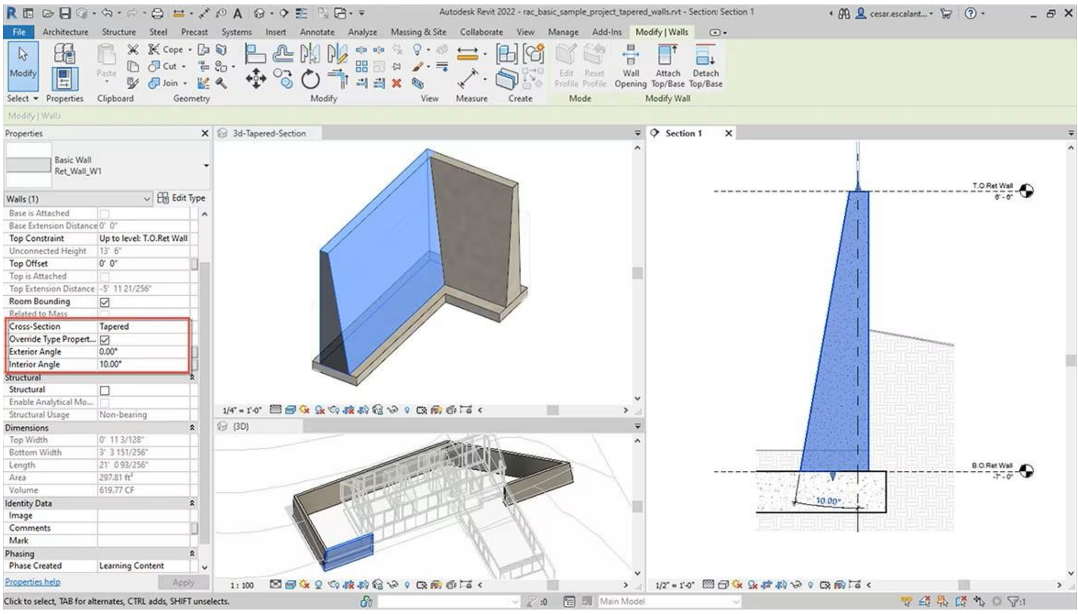

Figure 2.15. Interface of Revit 2022 (Autodesk, n.d.)

- Revit 2023: Twinmotion for Revit, shape editing elevation controls, sheet layout tools, swap views on a sheet, structural analytical model automation and enhancements, MEP modeling upgrades, carbon insights tech preview, edit revisions on multiple sheets, publish cloud models without links, improved tagging, and tag leaders.

- Revit 2024: UI modernization features, My Insights in Revit home, scheduling revision clouds, new site tools with Toposolids for landscape design, Autodesk forma to Revit synch, auto-synch with Twinmotion for Revit, new features for rebar bending, detailing, and scheduling, enhancements to structural analytical modeling, enhancements to electrical load analysis, enhancements to ductwork stiffening, export fill patterns, simplify topography, shape editing enhancements, linking coordination model from Autodesk docs.
- Revit 2025: Total carbon analysis integration with Insight and Forma, developments to the site design tools, developments to concrete modeling, developed room perimeter accuracy, expanded link and export support for STEP files, quick align annotations for keynotes, updated filter disciplines, background PDF export features, new IFC category mapping, sheet collections, arrays of one to zero for families, development to Fabrication Data Manager, etc.

2.2.2 Overview on Graphisoft Archicad

The company, Graphisoft, was founded by Gábor Bojár in 1984 to develop CAD tools like RadarCH which was a 3D architectural design software and TopCAD which was a high-end 2D drafting software that promised "precision, advanced editing, associative dimension, 2D parametric and other features normally found in workstation or mainframes" (Ingram, 2020). After the Graphisoft company was founded in 1982, two years after this time, in 1984, with the development of Archicad, a three-dimensional modeling program, they entered the market with Archicad 1.0. This software was first released to be integrated with the Apple Macintosh Plus computer with a monochrome screen (Martens & Peter, 2007).

With the 4.5 version of RadarCH published in 1990, the tool has gained a new name as Archicad and started to offer most of the functions of BIM tools. From then on, new versions of Archicad have started to be released regularly while gaining a significant role in the market of AEC industry.

Graphisoft website (n.d.) clearly identifies all versions with their year of release as follows:

- 1984, Radar CH: Separation of two- and three-dimensional modules (Figure 2.16)

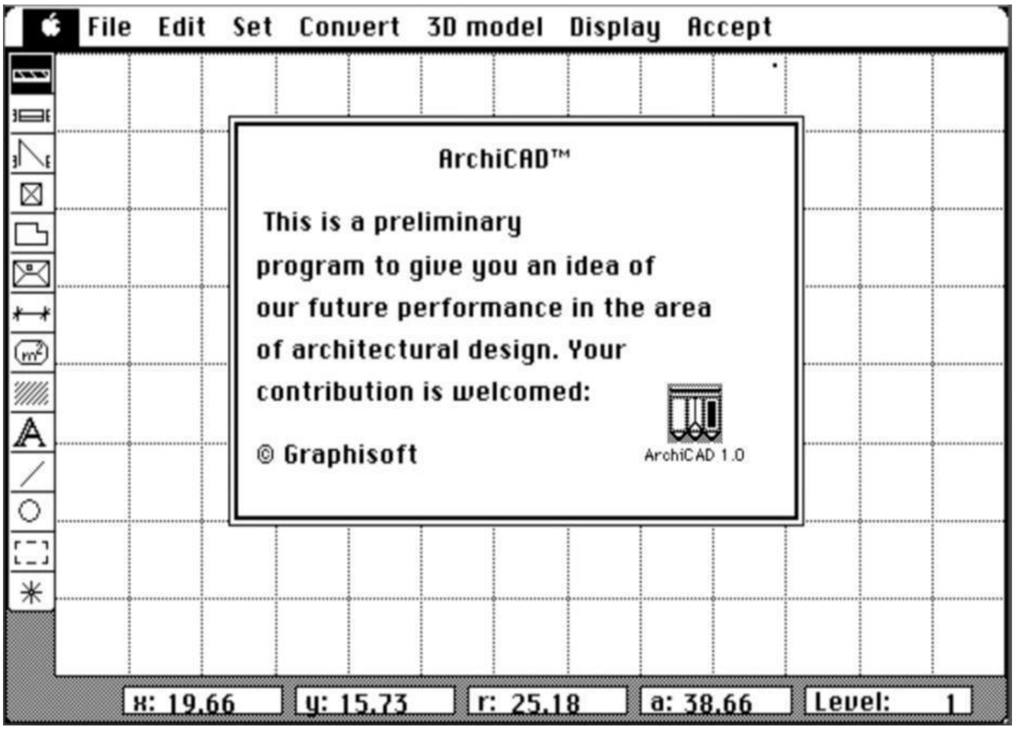

Figure 2.16. Interface of Radar CH 1984

- 1986, Archicad 2.0: Integration of two- and three-dimensional modules.
- 1987, Archicad 3.0: Adding color properties.
- 1988, Archicad 3.1: General update.
- 1989, Archicad 3.3: General update.
- 1990, Archicad 3.4: General update.
- 1991, Archicad 4.0: Adding the rendering feature to the program.

- 1992, Archicad 4.1: General update.
- 1993, Archicad 4.16: Release of the first Windows version.
- 1994, Archicad 4.5: Advanced text editing and addition of various tools, making general improvements.
- 1995, Archicad 4.55: First common version for Macintosh and Windows.
- 1996, Archicad 5.0: Addition of new tools and methods for drawings, addition of 3D texture feature,
- 1997, Archicad 5.1: Teamwork feature.
- 1998, Archicad 6.0: Adding new wall types, providing working in a three-dimensional environment, Adding quick editing tools like the magic wand.
- 1999, Archicad 6.5: Development and addition of tools that will facilitate two-dimensional and three-dimensional drawing, File format improvements i.e.DXF/DWG conversion options.
- 2001, Archicad 7.0: Development of viewing tools for three-dimensional working environment, Adding features such as publisher, review, markup, library manager.
- 2002, Archicad 8: Introducing OpenGL support, adding features such as solid element operations, navigator, and editing to improve modeling.
- 2003, Archicad 8.1: Development of composite structures in the library of the software, automatic adjustment of intersections of structural elements such as walls during the drawing process, adding keyboard shortcuts to make it easier to use.
- 2004, Archicad 9: Development of tools that will increase the quality of architectural drawings such as line thickness, fills in the section, rotation of the text, customization of the work environment, Updating the autosave feature, Adding the XREF tab.
- 2006, Archicad 10: Developments regarding layout, additions of new features for three-dimensional and two-dimensional views, adding levels to sections and views, making the drawing process easier with features such as guideline and tracking (Figure 2.17).

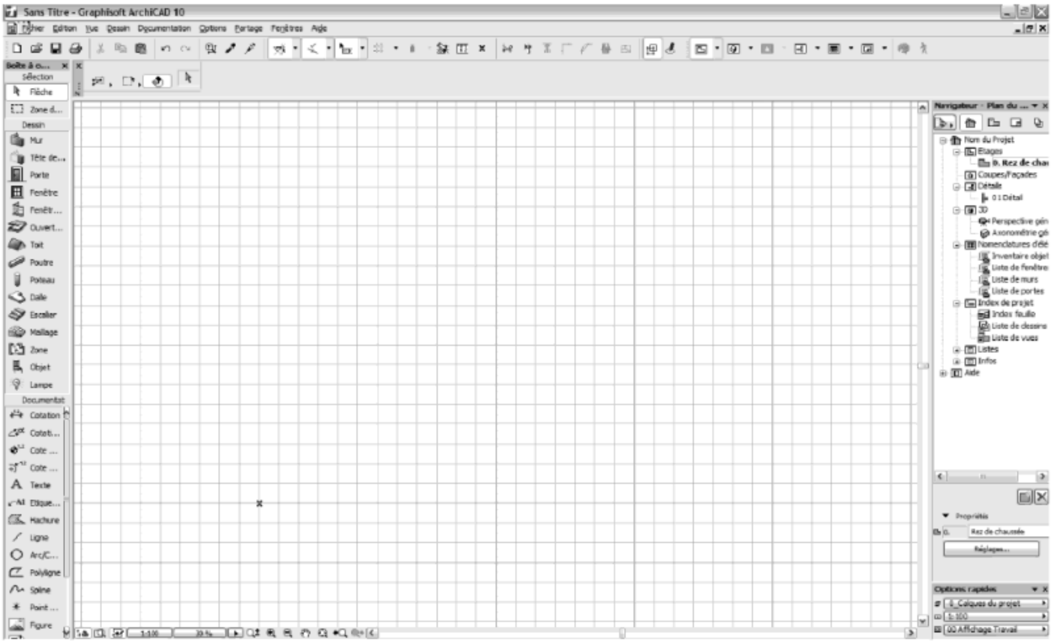

Figure 2.17. User Interface of Archicad 10 (Sperber, 2007)

- 2007, Archicad 11: Separating the section and elevation tabs and adding the interior elevation feature, adding new features to drawing tools such as line and pencil, ability to export PDF, enhancements to XREF.
- 2008, Archicad 12: Adding the curtain wall feature, making improvements to documentation and view features, improvement of the hotlink feature.
- 2009, Archicad 13: Release of a new Team Work feature that is connected to the BIM server, making improvements to drawing, schedule management and library.
- 2010, Archicad 14: Developments regarding design collaboration, innovations in drawing features such as find, select, offset, and dimension, schedule can be exported as Excel file, providing more details about errors arising from the relationships between the structural elements that make up the model.
- 2011, Archicad 15: Using IFC properties as Archicad parameters, adding the shell tool, developing details for the roof drawing, improvements to three-dimensional drawing tools, making improvements to the fast automatic saving and customer experience improvement program.

- 2012, Archicad 16: Developments regarding building energy calculations, improvements in IFC, DXF, DWG file extensions, adding the morph tool.
- 2013, Archicad 17: Improvements in conflicts between building materials and objects in the model, adding the three-dimensional section plane feature, providing direct connections with Google Earth and SketchUp software, improvements in IFC, energy evaluation and building performance.
- 2014, Archicad 18: Improvements for DWG, IFC and PDF formats, developments in project management, improvements to lighting, library models and rendering engine.
- 2015, Archicad 19: Performance improvements, adding the point cloud feature, improvements to the user interface, IFC, PDF and library.
- 2016, Archicad 20: Intuitiveness feature comes with renewed user interface and graphic add-ons, development of information management feature, adding the NURBS feature, improvements to file formats.
- 2017, Archicad 21: Improvements in modeling tools and BIM management issues, developments that will increase productivity in the user interface.
- 2018, Archicad 22: Developments in the tools and libraries that will affect the design such as staircase and wall drawing, performance, and interface improvements, ensuring integration between Archicad and Grasshopper.
- 2019, Archicad 23: Improvements in architectural elements such as columns and beams, developments regarding software performance, user interface, library, information management.
- 2020, Archicad 24: Development of an integrated design system for structure design and analysis, project coordination can be done thanks to BIMcloud, Python can be used in Archicad using The Archicad JSON Interface.
- 2021, Archicad 25: Ensuring Android compatibility of large models with the BIMx feature, allowing viewing on the web and enabling developments on desktop, developments for two-dimensional and three-dimensional imaging, improvements to the staircase tool and library.

- 2022, Archicad 26: Creating a building material property set for life cycle assessment and sustainability calculations, more effective web and desktop viewers for BIMx, improvements in file export and modeling tools, providing modeling documentation for kitchen cabinets.
- 2023, Archicad 27: Improvements in design tools and visualization, developments in workflow and project management.

Since the first version, Archicad software has continuously made software innovations and improvements almost every year. With each new version released, various features and improvements have been added that improve the software's capabilities and user experience. These improvements are gathered together by Graphisoft Company (Kmethy, 2023).

Archicad was built around the “container of views” concept that might be explained as objects having multiple views attached to them and that specification enables it to offer a variety of objects with its powerful scripting language used in describing different views of these objects, making iterations, and making internal design calculations. Archicad offers a parametric object library that can be used to construct new objects with the help of interactions during the design of manufacturing processes. It is also supported with MEP object library and Toolbox provided by Graphisoft company. Even though MEP system can be designed within the software itself using a variety of MEP objects included in the provided library, structural design requires communication with external systems using IFC file format. In case of any error during the design phase, editing of the parametric objects can be done using 3D work field in the ToolBox with the help of dialogue boxes (Murphy et al., 2021). It also supports many file formats to be imported and exported including standard image formats like PSD and JPG, 2D drafting formats like DWG and DXF, and 3D modeling formats like OBJ and 3DS (Figure 2.18).

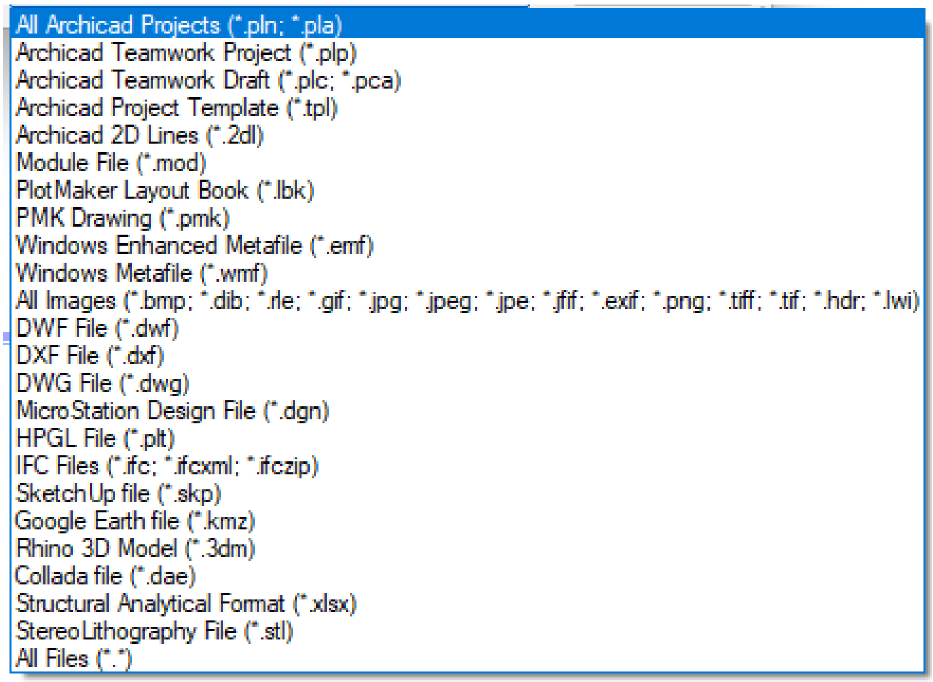

Figure 2.18. File formats supported by Archicad

Archicad has many advantages when compared with similar BIM tools. It not only has smaller file sizes which make it easier to handle larger and more complex geometries, but also is completely multi-threaded which makes it work better both on MacOS and Windows. Archicad supports Rhinoceros3D and Grasshopper to generate computational models and IFC file format to reduce the loss of information during migration of it. The objects and their parameters are very flexible because of the GDL scripting they use. Moreover, the user interface is perceived as more user friendly than similar tools and it also enables easier addition of custom property sets.

On the other hand, it has some disadvantageous features. Even though it has recently been evolving into a fully integrated BIM system together with the addition of more MEP modelling tools, it is mainly focused on architectural design and lacks the specifications to attract the attention from other actors of the construction industry. Another disadvantage is that Archicad has limited supportive documentation. Because of that limited support, some extensions could not be updated properly, or some troubles were never resolved (Ingram, 2020).

2.2.3 Overview on Nemetschek Allplan

Allplan which is a widespread used BIM software, is developed by Nemetschek. According to Allplan website (n.d.), in 1963, Georg Nemetschek established "Ingenieurbüro für das Bauwesen" in Munich. The first version of Allplan, a CAD system, was released in 1984. In 1997, Nemetschek introduced a database-based platform which is known as BIM nowadays.

Tse et al. (2005) states that Allplan is an object-oriented BIM software, produces 2D drawings such as plans and sections like other BIM software, while simultaneously containing all information about the project such as schedules and reports in the same nD model. It enables interdisciplinary planning between architects, engineers, and other individuals. While Onur & Nouban (2019) mentioned that information transfer has increased in BIM projects, they stated that designers have the opportunity to instantly collaborate with other teams all over the world with the same information.

According to data obtained from the Allplan website (n.d.) and the Software Informer website (n.d.), the released Allplan versions are as follows:

- Allplan V1 - Released in 1984
- Allplan V2006 - Released in 2005
- Allplan 2008 - Released in 2007
- Allplan 2009 - Released in 2008
- Allplan 2011 - Released in 2010
- Allplan 2012 - Released in 2011
- Allplan 2013 - Released in 2012
- Allplan 2014 - Released in 2013
- Allplan 2015 - Released in 2014
- Allplan 2016 - Released in 2015
- Allplan 2017 - Released in 2016
- Allplan 2018 - Released in 2017
- Allplan 2019 - Released in 2018

- Allplan 2020 - Released in 2019
- Allplan 2021 - Released in 2020
- Allplan 2022 - Released in 2021
- Allplan 2023 - Released in 2022 (Figure 2.19)

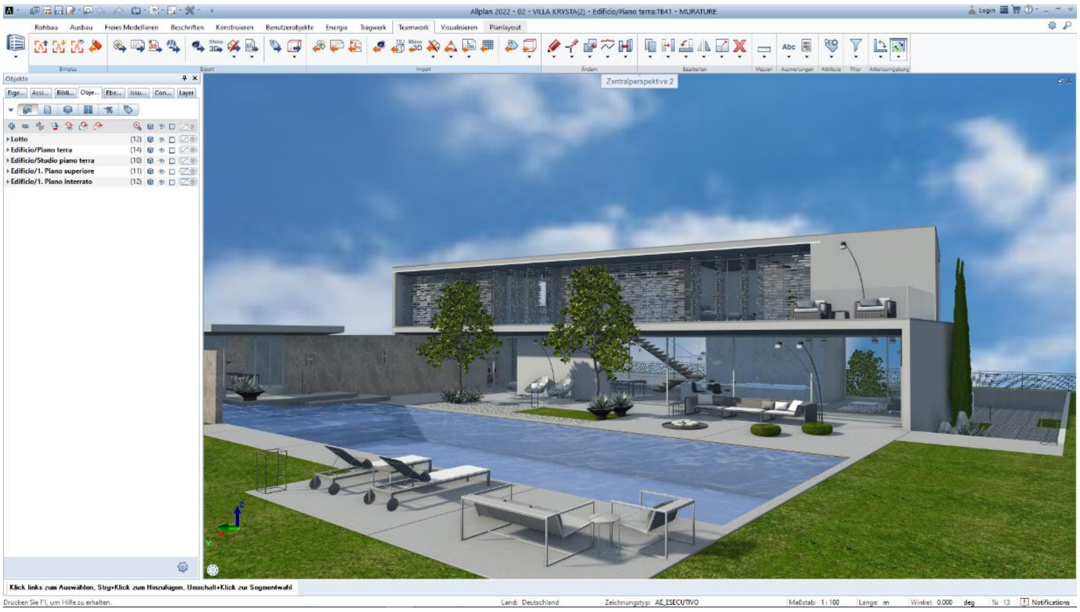

Figure 2.19. User Interface of Allplan 2022 (Allplan, n.d.)

- Allplan 2024 - Released in 2023

It can be said that various updates and changes have been made in the different versions with the aim of significantly improving the functionality, efficiency, and user experience of the Allplan software, making it a comprehensive tool for architects, engineers, and construction professionals.

Allplan has a wide range of export and import file options. Xie et al. (2018) says that it is possible to export IFC, DWG, DWF, 3DMAX, PDF, SKP, C4D, 3DM, etc. as 3D models.

Allplan integrates architecture, reinforced concrete structures, engineering systems, general layout, construction volumes, cost estimation, metal structures, design, etc. (Levchenko & Kashchenko, 2017). It allows simultaneous project collaboration, enabling visibility of changes made by engineers from different specialties and the application of some changes across the entire project.

2.3 Definitions on User-Software Interaction

Interaction between user and software is vital in today's technology-driven world. To effectively manage and understand this relation, it is necessary to be aware of several key terms and concepts. These terms help us understand how the user interacts with the software, how the software responds to the user, and the impact of these interactions on the overall experience. Terms such as Human-Computer Interaction, User Interface (UI), User Experience (UX), Usability are the elements that define and shape these interactions. Each concept approaches users differently to better understand, design, and optimize their interactions with the software. These terms are examined one by one below.

The first term is *Human-computer Interaction* which is a field that focuses on the creation, evaluation, and use of interactive computer systems designed for human use and the study of important issues related to these systems (Hewett et. al, 1992). This interaction is also handled separately by humans and computers. In other words, inputs from these two contexts create this relationship. While topics such as design disciplines, cognitive psychology, linguistics, social sciences, communication theory are discussed in the human context of this relationship, computer-based graphics, operating systems, programming languages and digital development tools are positioned in the computer discipline.

The other term is *User Interface* which is the part where the user directly interacts with the program. Whether the interface is complex or easy to understand directly affects the user's approach to the program. The interaction mode between the program and the user, the user's approach to the program, and the technology used when creating the interface are among the factors that affect the success of the interface design (Miraz et. al, 2021).

Another term for user-software interaction *is User experience* (UX) which is the process that includes all aspects of the interaction of the user who experiences an application with this application and system. This experience can be measured by task success rate, task duration, mouse clicks, keystrokes, and users' satisfaction ratings. Thus, the user experience can be understood and evaluated, and necessary improvements can be made.

The last term that is defined in this research is *Usability*. It is about purpose-oriented interaction between the user and the software. A similar concept is UX focuses on the user's perceptions and reactions, including their emotional response (Inan Nur et. al, 2021).

The concept of user experience and usability are often compared. Usability is the ability of users to accomplish a purpose and task, while UX represents the entire interaction between the product/software and the user (Albert & Tullis, 2010).

The development of software programs, especially today, is not limited to only technical features and functionality, the role of user interface and user experience is gradually increasing. To gain competitive advantage in the market and increase the preferences of users, software designers need to maximize human-computer interaction and optimize the usability of programs. A well-designed interface increases the impact and preferability of programs in the market by understanding the needs of users and providing them with fast and effective solutions. Thus, user experience becomes one of the key factors of the success of the software. In other words, users prefer programs that offer an easy, understandable, and enjoyable experience. Therefore, the concepts of user interface, human computer interaction and usability are of great importance.

2.3.1 User Interface

While software is being developed, great importance and effort is given to user interface design and operation. The reason for this is that the usability of this environment where the software and the user meet is very important (Nielsen, 1994). For example, an average of 48% of program coding is devoted to the user interface (Myers & Rosson, 1992).

The increasing importance given to user interfaces is related to the demands of users and the increase in the number of users. In other words, the usability issue directly affects the software development process and increases the development of user interfaces (Nielsen, 1992). Thus, the interaction between the user (human) and the software (computer) is increasing, and in this process, a user-centered approach is developing. The evolution process of software is not only based on technological developments but is also shaped by a user-oriented approach. As a result, interfaces created with user experience at the center can be more intuitive and interactive (Nielsen, 1994).

Rapidly continuing technological developments also affect architectural software. Therefore, software companies constantly update their products by releasing new versions of them. These changes and updates also increase the influence of companies in the market. Darejeh and Singh (2013) stated that this activity in the market is also very important in the user interfaces of the programs along with the updates.

BIM, a 3D modeling tool that comprises the life cycle of a building, including the design, construction and use stages, is increasing its use by companies and offices in the sector. However, due to the difficulty of inputting intense information into projects, users also use traditional CAD programs extensively. Therefore, user interface and user experience issues, especially for BIM tools, are of great importance in the architecture, engineering and construction sectors (Park et. al, 2022).

Especially users who do not use BIM tools think that the BIM software system is complex and has high hardware requirements. In other words, while those who are not BIM users think that this situation is an obstacle, yet those who actively use BIM do not have any problems in the use of this technology (von Both, 2012). However, since BIM software has some limitations, especially in the design process, different software requirements arise. With the involvement of different software in the design and construction process, data losses and communication difficulties occur from data exchange between programs (Park et. al, 2022).

Considering the concept of user interface, while there are similar and common features for all software, in addition to these, some features that must be present for BIM tools have been determined (Singh et. al, 2011). These are listed below:

- There must be three-dimensional imaging and positioning.
- Users should be able to view the real-time model online and make necessary comments by interfering in the model.
- The interface should allow users to select the objects in the model, as well as to see the properties of these objects and their subgroups, if any. At the same time, these subgroups should be able to be changed if necessary.
- Users should be able to personalize the functions in the interface and change them according to their preferences.

2.3.2 User Experience

The principles emphasized by Gould & Lewis (1985) have been effective for shaping the design processes and practices used today in the field of user experience and usability. These three principles are listed below:

- Early Focus: This principle emphasizes the importance of considering the needs and preferences of the users from the early stages of design and throughout the development process.
- Measurement of Usage: Measuring and evaluating provide determining how the system can be improved.
- Iterative Design: Repeated tests and changes made to the system enable improving the system continuously.

By taking some principles into consideration, the UX can be significantly improved. These principles have been determined as striving for consistency, taking universality into account, providing informative feedback, bringing dialogues to conclusion, preventing mistakes, ensuring that actions are easily reversible, supporting control, and reducing short-term memory load. These principles are derived from many years of experience and serve as a guide in creating user-friendly interfaces for UI design (Shneiderman et. al, 2016).

Especially when considering BIM projects, there are different factors that affect user experience. Creating information using BIM, sharing, and using this information interdisciplinarily are among the factors that positively affect the user experience. In other words, the integrated system and interaction provided by BIM during the project process also positively affects the user experience. However, BIM may seem difficult to manage and exercise for users who are not adapted to this system. Therefore, this complexity may negatively affect the user experience (Jiang et. al, 2021).

When the concept of usability for smart working environments is considered, studies on BIM have examined these concepts and standards. In this regard, the factors required for the usability of software that serves architectural drawing were determined by considering user behavior and user experience (Figure 2.20).

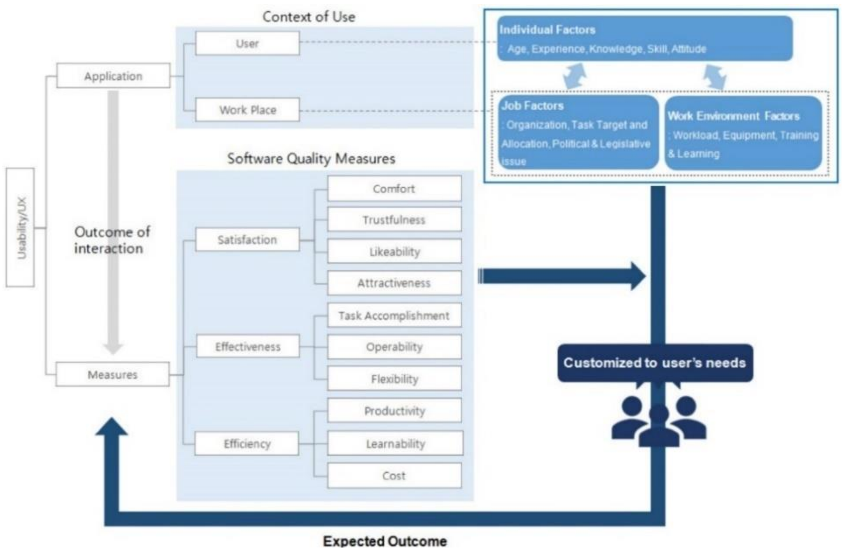

Figure 2.20. Usability and user experience factors for software usability (Park et. al, 2022).

The framework of the usability concept is discussed with two components. The first of these is the software related to users and working environments. The second is the measurement component that provides objective performance evaluation (Park et. al, 2022). The concepts in the measurement component are very similar to the factors in usability measurement examined in the next sections below.

2.3.3 Metrics for Usability Terms

To evaluate different aspects of software usability, there are the ISO 9241-11 (1998) and the ISO/IEC 9126-1 (2001) standards, also recommended by the HCI and the Software Engineering (SE) communities. In addition, Directive 90/270/EEC of the Council of the European Union is also recommended to determine the required minimum health and safety standards in computer use (Seffah et.al, 2006). Integrating these standards allows for a more consistent and holistic approach to addressing software. Efficiency, learnability, adaptability, cognitive workload, and effort for error correction are the criteria for the concept of usability. In line with these criteria, considering the user-related features as well as the features and functions of the software ensures a comprehensive product. That is, to obtain a user-friendly product, it is necessary to consider users' goals, skills, and expectations. Usability metrics are systems that measure user experience with numerical data. These metrics enable user experience and interactions to be evaluated and measured (Albert & Tullis, 2010).

Constantin & Lockwood (1999), Nielsen (1993), Shackle (1991), Shneiderman (1992) and Preece et al. (1994) models and standards were compared by Seffah (2006). Although each model has similar approaches to the subject, they all offer a unique perspective:

- Constantin & Lockwood (1999), Nielsen (1993) and ISO 9241-11 (1998) directly linked the concept of efficiency with usage in their models, but Shackle (1991) and Schneiderman (1992) linked efficiency with speed.

- Learnability is stated as an important element in the mentioned models. However, Shackle (1991) discussed the learning time factor for this concept.
- While the concept of user satisfaction describes the comfort between the software and the user in all models, Preece et. al (1994) and Shackel (1991) discussed this concept as an attitude.

In addition to that, Albert & Tullis (2010) said that usability can be measured based on user performance and presented some metrics. In fact, these metrics are quite parallel to evaluations that measure user experience. It has been stated that the concepts of task success, time, errors, efficiency, and learnability can be used for performance evaluation.

The Diagnostic Recorder for Usability Measurement (DRUM), a software developed to measure parameters affecting usability, evaluates and analyzes the relationship between the users and the software. As a result of this evaluation, measures and diagnostic data are revealed (Macleod & Rengger, 1993).

The DRUM tool enables user evaluation by providing performance-based usability metrics (Seffah et. al, 2006). These metrics are listed below:

- Time: Total time required for each task.
- Effectiveness: A metric that measures whether the user has achieved the goals for the task.
- Efficiency: The relationship of effectiveness to time.
- Search time: The inefficient time spent by users for research and help that is needed to solve the problems which are encountered in the system.
- Productive time: The period that is not spent on problems, help and searches while performing the task.

Quality in Use Integrated Map (QUIM) is used to determine the metric factors, criteria and data required to evaluate the interfaces of the programs (Seffah et. al, 2001). This system includes ten usability factors determined as efficiency, effectiveness, productivity, satisfaction, learnability, safety, trustworthiness, accessibility, universality, and usefulness. These factors are critical in determining the quality and usability for evaluating the software (Seffah et. al, 2006).

User interface design is crucial in improving user experience. Important components of usability include security, effectiveness, efficiency, functionality, and ease of learning and remembering. These components ensure that interfaces are user-friendly and enhance the overall interaction experience (Miraz et.al, 2021).

Shneiderman et. al (2016) emphasized that usability measurements include criteria such as learning time, performance speed, rate of user errors, time, and subjective satisfaction. These metrics align with effectiveness and efficiency goals. For example, the time it takes to learn a new system and the speed of performing tasks are critical metrics that reflect the efficiency of the UI. In addition to that, surveys and interviews are also helpful for measuring the effectiveness of the interface and user satisfaction.

General guidelines and recommendations have been put forward to develop and improve user experience and interaction by Badashian et. Al (2008). These are listed below:

- Time to learn how to use the program: The average time required for the user to actively use the relevant program.
- User error rate: The average number of errors made by certain user groups.
- Knowledge retention: How users maintain and improve their knowledge of using the program over time.
- User satisfaction: Processing the feedback obtained through surveys and interviews with program users.

In short, effective UI design is about organizing the user needs and preferences in a balanced way. The principles and criteria mentioned above provide a framework for creating interfaces that are not only functional and efficient, but also enjoyable and easy to learn, ultimately leading to a positive UX.

2.4 Critical Analysis of the Literature

In the literature review chapter, comprehensive research on Building Information Modeling (BIM) is presented. The conceptual framework and historical development of BIM, especially in the discipline of architecture, are discussed. In addition to that, important BIM tools used in the field of architecture, especially Autodesk Revit, Graphisoft Archicad and Nemetschek Allplan are explained. The features of each of these tools were examined in detail. The concepts of user interface (UI) and user experience (UX) are examined within the context of BIM tools, exploring their impact on architecture and construction.

The literature provides detailed information about UI and UX, and their relationship with usability can be measured and evaluated using metric systems. It was observed that these concepts are not extensively discussed within the architecture discipline and BIM tools, highlighting a gap this study aims to address.

The development of computer-human interaction has influenced the evolution of BIM software in architecture. This thesis comprehensively examines the user interfaces and experiences of BIM tools, revealing how they have revolutionized the field of architecture. In particular, the different features offered by these software determine how effectively and efficiently new and experienced users can use these tools. This study analyzes in detail the challenges and successes users face, their learning curve, and their overall experience while using these software.

Moreover, the research emphasizes the importance and effectiveness of BIM software. Detailed analysis of the user interfaces of BIM tools in terms of time, mouse movement and keyboard usage helps improve the efficiency and usability of these tools in the field of architecture. This study highlights the importance of user experience and interface design in the process of improving BIM software.

As a result of all these researches, the methodology was determined. Software and other tools that will serve to realize the system and purpose in this methodology have been used as material.

CHAPTER 3

MATERIAL AND METHOD

In this chapter, the materials and method of the research are explained.

In the first part, the participants of the research and the computer programs used in the research are introduced. First, information is provided about the research participants and their selection criteria. Then, BIM software to be used in the exercises was explained. Moreover, the auxiliary applications used to carry out the experiment are mentioned. Visual Studio Code and OBS Studio are applications used for recording and coding for analysis. And then Microsoft Excel is introduced as an analysis software.

In the second part, two different methods used in the research are explained, these are hands-on exercises in the computer environment and interviewing the users. The method is explained in detail step by step.

3.1 Material

The materials of this research are two different BIM software, coding software Visual Studio Code, desktop recording application OBS Studio, analysis software Microsoft Excel and the participant group of the experiments that used all these programs.

3.1.1 Participants of the Research

While participants are selected in this study Albert and Tullis (2010) suggestion was followed who claimed that to effectively plan a usability study, it is important to address the following questions:

1. What types of participants are needed?
2. Should data be compared from a single group of participants or from several groups?
3. How many participants are required in total?

In this manner, the first issue that was taken into consideration was the selection of participants from a population that would represent the study (Sauro & Lewis, 2016). Since the aim of this study is to compare and evaluate the usability of different BIM tools for architects in terms of user interface and experience, the participant group consists of architects.

The second important issue is whether to separate the data by different groups of participants. User interface and user experiences of software may vary depending on the person's professional experience, purpose of using the software, frequency of using the software, etc. Accordingly, the participants consist of three different groups: beginner students, intermediate students, and professional users. Participant groups are also separated for two different software, thus experiments are conducted on five experienced, five intermediate and five beginner users for each software, as shown in the diagram below.

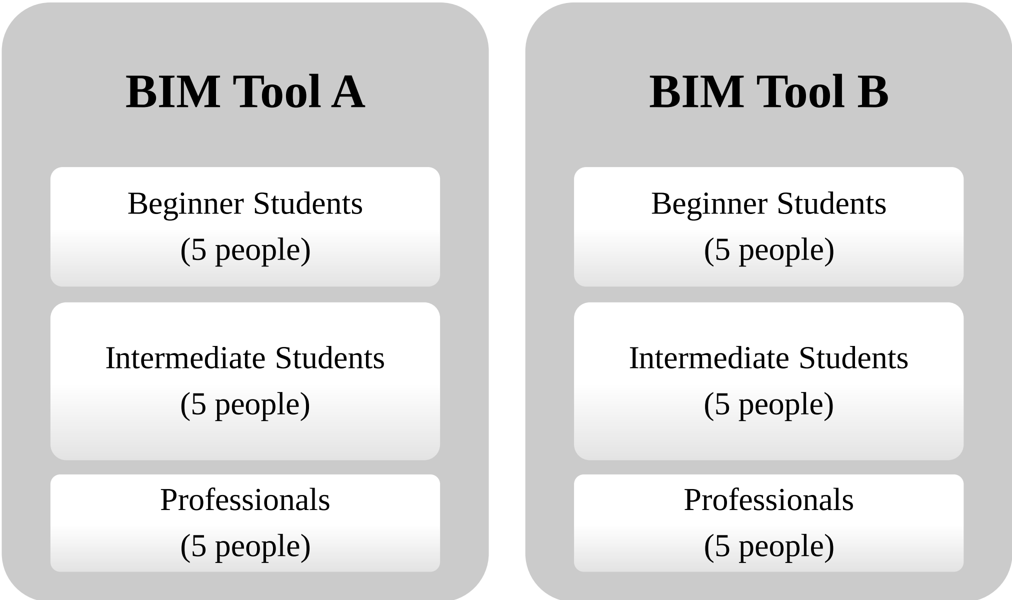

Figure 3.1. Participants numbers and types for BIM tool A and BIM tool B.

The third concern was sampling, that is, deciding how the participants were selected. Albert and Tullis (2010) describe three main sampling techniques which are random sampling, systematic sampling, and stratified sampling. Based on these terms, these three methods were used to create different groups in this research.

Firstly, two of the architectural offices in Turkey who use the specified BIM tool (one office for BIM tool A and one office for BIM tool B) were selected both using the random sampling and the stratified sampling methods in the selection of experienced users. There is no specified standard for people's years of experience. However, importance was given to the fact that they regularly produced architectural projects using these tools and that they were not recent graduates.

For the intermediate level users, students were selected from Middle East Technical University, third year students. This group of students were preferred because they were given equal basics of both BIM software about a year ago. The selection of students was decided randomly but the selection of the group was systematic sampling.

For the beginner users, students were again selected from Middle East Technical University, but second year students. This group of students have equal basics of both BIM software in the semester. The students were selected randomly but the selection of the group was systematic sampling.

In their book, Albert and Tullis (2010) stated that if there are different participant groups for a study, it would be beneficial to have at least four people from each group. Following this information and similar studies, the number of participants was decided to be 5 people for each group, 30 participants in total.

In the study, participants are specified with following abbreviations:

- BIM tool A - Professional Participants: AP1, AP2, AP3, AP4, AP5
- BIM tool B - Professional Participants: BP1, BP2, BP3, BP4, BP5
- BIM tool A - Intermediate Student Participants: AS1, AS2, AS3, AS4, AS5

- BIM tool B – Intermediate Student Participants: BS1, BS2, BS3, BS4, BS5
- BIM tool A - Beginner Student Participants: AB1, AB2, AB3, AB4, AB5
- BIM tool B – Beginner Student Participants: BB1, BB2, BB3, BB4, BB5

3.1.2 BIM Software

In this study, applications were conducted with different user groups in a computer environment to evaluate the interfaces and user experiences of two different BIM software, referred to as BIM tool A and BIM tool B. These software applications are widely used in BIM processes and are known for their different functional features. The research involved analyzing user interactions with the software interfaces through specific tasks. Measures such as the speed of users, distance travelled on screen, mouse clicks etc. were evaluated.

The names of the software used in this study are kept confidential out of respect for the companies involved. Thus, the software is referred to as BIM tool A and BIM tool B. This approach is adopted to maintain the impartiality of the research and to minimize any commercial influence. The evaluation of software interfaces and the analysis of user experiences provide valuable insights into the effectiveness and user satisfaction of BIM software. These insights can be utilized in future software development processes and contribute to industry standards.

3.1.3 Recording Software

One of the auxiliary software tools used in this research is Visual Studio Code (VS Code). It was used to collect data instantly by working simultaneously with the program during computer exercise. It is a powerful and lightweight code editor that does not require purchase or subscription. VS Code can run on Windows, MacOS and Linux operating systems and can be used to code in all possible programming languages. Even though it comes with built-in support for common languages as

JavaScript and TypeScript, its ecosystem includes many extensions for other languages like Java, Python, C# and C++ (Visual Studio Code, n.d.). Eight of the most popular language extensions are shown in Figure 3.2.

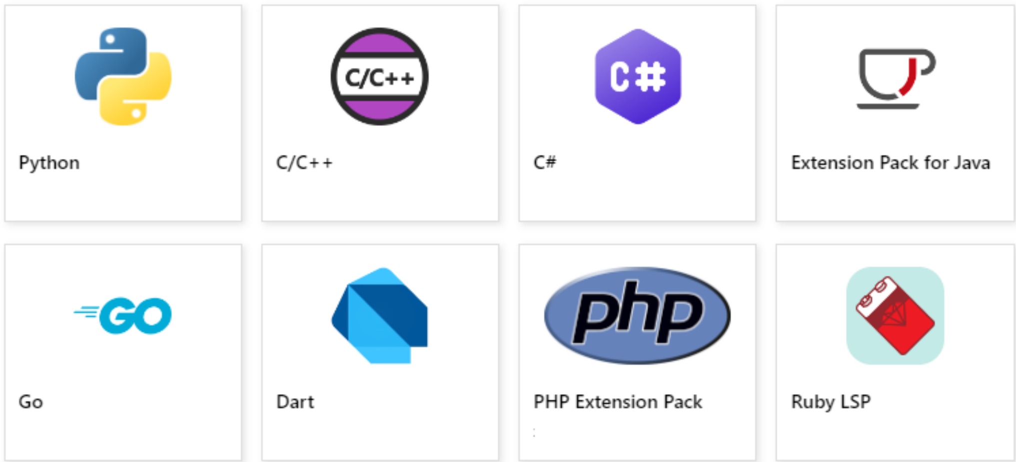

Figure 3.2. Most popular language extension for coding.

There are many advantages of the use of VS Code for coding. The first advantage to be emphasized might be that, together with the use of Live Share extension it offers, VS Code enables workmates to work on the same task remotely while editing and debugging the code simultaneously. Another advantage to be mentioned is that VS Code highlights keywords using different colors for the user to easily identify the coding pattern. That feature also helps the coders on beginner level to understand how functions and their interrelations in programming environment work. It also makes suggestions on completing lines, fixing common mistakes and debugging that enables user to step through the lines of code to understand the errors in their code. The last but not least advantage to be mentioned is that, even though it comes with a simple user interface (UI) as shown in Figure 3.3 and a common layout that places the explorer on the left and the editor on the right, it provides options and settings for the customization of themes and colors in the UI which enables user to personalize the look and feel of VS Code that can play a key role for the motivation of user.

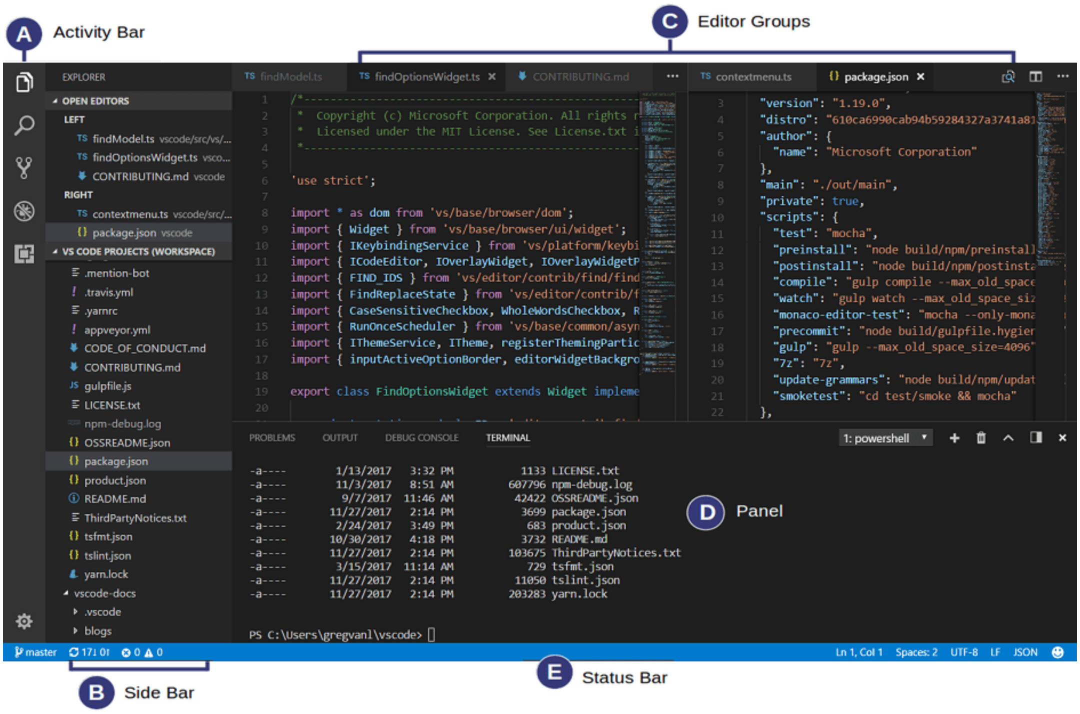

Figure 3.3. Interface of Visual Studio Code.

Together with the VS Code, Python is used as the programming language in this study. Since Python requires an interpreter to be installed depending on the specific use of the user, Jupyter Notebook was also used alongside the Python extension of VS Code. (Visual Studio Code, n.d.). Jupyter notebooks are very powerful additions to the VS Code for data science and data visualization projects since they enable coder to visualize their code for better communication and perform interactive computing. Jupyter Notebooks are used to visualize the outputs of the code cells in many different representation methods including texts, images, graphs, plots, mathematical computations, tables and interactive widgets.

In this study, it is aimed to evaluate the user behaviors and user experience while the user successfully performs a given task during the time spent in the applications. Therefore, it is aimed to record mouse movements and keyboard keystrokes and to monitor user behavior while BIM software is open and to evaluate these behaviors in order to compare the time spent and user behavior in this process. Therefore, a

Python code was written to record user mouse movements and keyboard usage while these two drawing programs are open. This process was prepared using the Jupyter Notebook in the Visual Studio Code program.

It is aimed to make many evaluations and comparisons with these records. The most important of these, firstly, is task times. Secondly, these records can be used to measure distances of mouse movement, such as pixel measurement and cm measurement. In addition to that, heat maps and graphics showing the location of clicks can be prepared from the recordings of mouse movements. That is, left click and right click numbers were aimed to be analyzed. With keyboard recordings, it was aimed to obtain which keys and how many times were pressed.For this entire evaluation process, Python codes have been prepared to extract data from the main recording file.

The other auxiliary software, Open Broadcaster Software (OBS Studio) is a recording and live streaming tool which was used to follow the practices of the participants by recording the screen in this study. Since the software is free and open source, it is a popular choice among broadcasters and content creators mainly for capturing imagery on their screen or specific windows and blending them with additional audio and video content. Another reason for the wide use of OBS Studio is that it is a cross platform software that can work on Windows, MacOS and Linux.

There are five parts in the main interface of OBS Studio (Figure 3.4) which are Scenes, Sources, Audio Mixer, Scene Transitions and Controls. Using different sources as audio, images, texts, video captures and screen captures, and layering them with specific orders, users can create dynamic and customizable scenes or content. Under the control bar there are start streaming, start recording, start virtual camera, studio mode, settings and exit buttons, and recording is started from this panel. In this study, only the pc screen was recorded to analyze and crosscheck the input from the keyboard and mouse while participants were working on the given tasks.

Using the OBS Studio program, all processes in BIM tools were recorded while the users performed the given tasks. These records were also compared with the records obtained with the help of Python code and the entire recording process was completed.

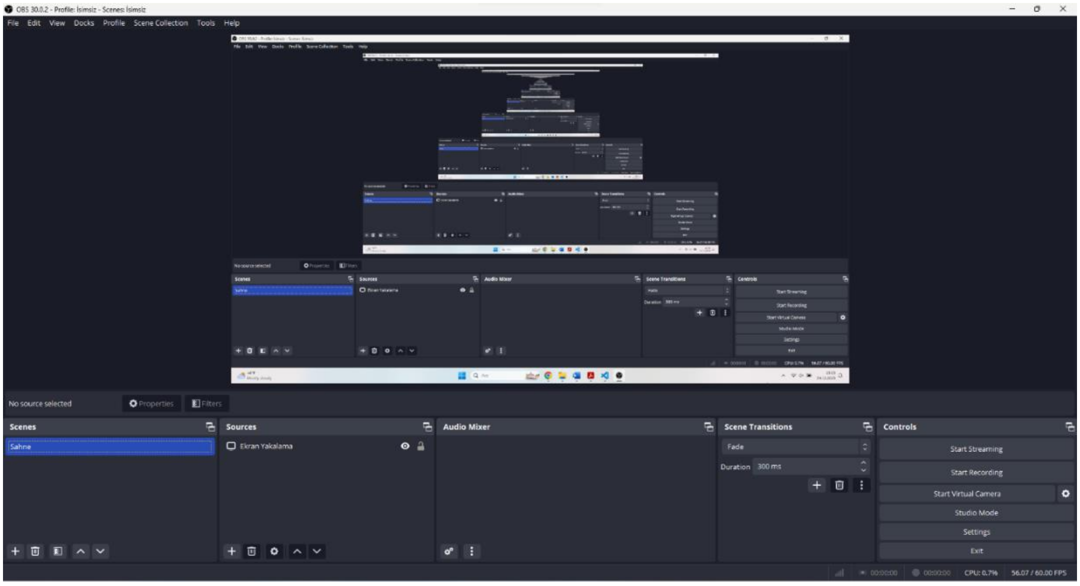

Figure 3.4. Interface of OBS Studio

3.1.4 Analysis Software

Data obtained from users regarding the testing process was collected in an integrated manner using Microsoft Excel. Through this software, all results were systematically organized in tables and graphs, and then evaluated by performing a comparative analysis on this visual data. This process played an important role in analyzing the data and interpreting the results, thus allowing the findings to be examined in more detail and comprehensively.

3.2 Method

This research aims to propose a methodology for comparing and analyzing the user interfaces and user experiences of different BIM tools with the data obtained from the literature review. For this reason, both qualitative and quantitative research methods were used to evaluate both user interface and user experience.

Based on these two types of research, a new methodology has been developed as follows:

1. Determining the metrics of the research according to the literature review and customizing them according to the scope of the study. These are:

    a. Time
    b. Distance on screen
    c. Number of mouse clicks
    d. Number of keystrokes
    e. Time to first click
    f. Heat maps

2. Selection of the people who will take part in the research following the criteria mentioned in Section 3.1.1.
3. Deciding on the tasks that the participants will perform in the computer environment.
4. Determining the questions to be asked to the participants for the interview.
5. Creating model templates for each task in both BIM software.
6. Performing the exercises on computer by the participants.
7. Simultaneously start data recording in the VS Code software on the computer and record the screen from OBS studio.
8. Completion of the tasks by the participants.
9. Interviewing with the participants.
10. Analyzing data obtained from both methods.
11. Comparison of the results of the hands-on modeling exercise according to different user groups.
12. Comparison of interview results according to different user groups.
13. Evaluation of the results of both results compared to each other.

This method is shown with its main structure in Figure 3.5.

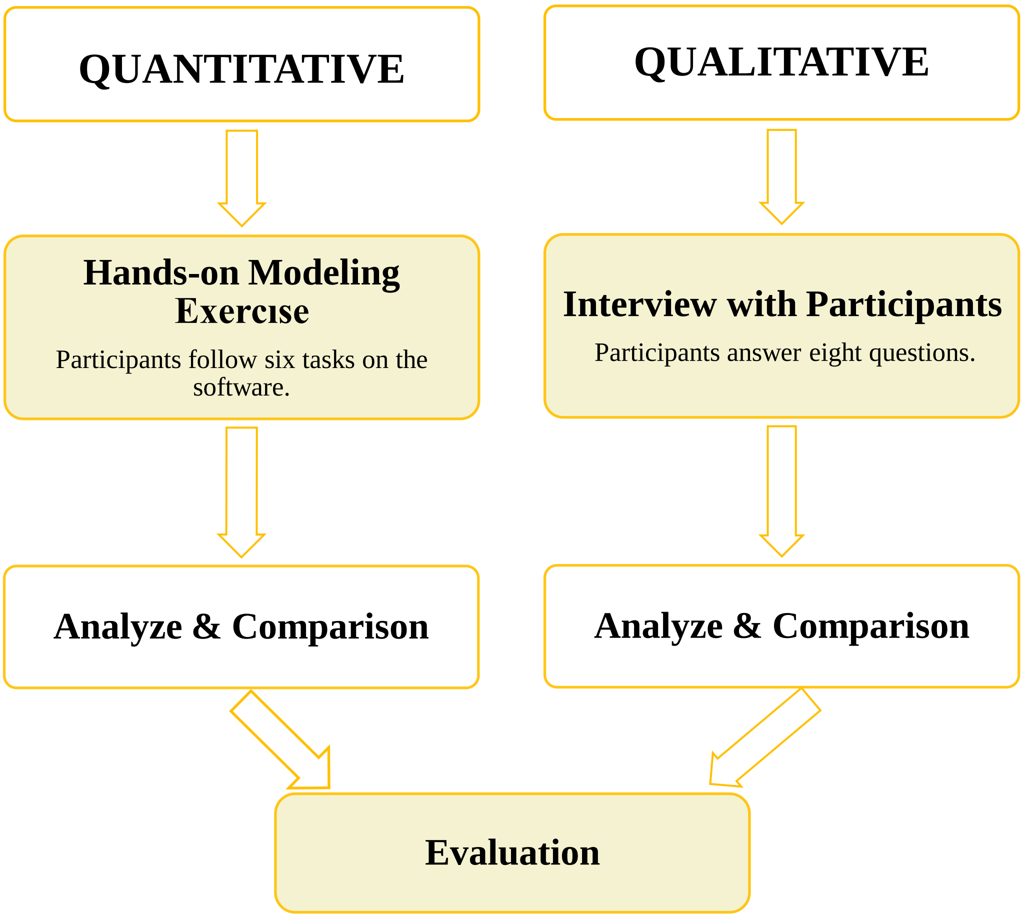

Figure 3.5. Main structure of the methodology

3.2.1 Hands-on Modeling Exercise - Experimental Research and Data Collection

The purpose of the modeling exercise is to evaluate the participant's relationship with the interface. During this study, the VS Code program will run simultaneously in the background and the following data will be obtained from this tool.

- Time: Calculating the participant's application time for each task separately will help to get an idea of how practical the interfaces of the software are.
- Distance: Calculating the total distance traveled with the mouse can similarly give ideas about the practicality of the interface.
- Mouse clicks: The number of users clicking the mouse is expected to vary depending on the content of the tasks. However, another purpose here is to see whether users click more than necessary. In this way, the effective use of the interface can be evaluated by comparison of different measurements.
- Keystrokes: Like the number of mouse clicks, keyboard use should also be evaluated. The issues to be considered here are operational keys (such as Ctrl, Shift, Space, Enter, Esc, etc.), letter keys (such as a, s, d, f…) and number keys (such as 1,2,3, 4…). is the distinction. The keyboard keys that users use for hotkeys will also be evaluated.
- Time to first click: Time to first click shows the reaction of the users with the software.
- Heat maps: In addition to the metrics above, heat maps obtained with the help of VS Code are also an important output. As a result, the most used parts on the interface will attract attention.

The tasks to be implemented to measure these metrics were determined according to criteria specific to BIM software. It can be said that selected BIM software have three basic modeling methods for creating model elements depending on the users' experiences:

1. Elements/families generated by extrusion (walls, columns, beams, etc.)
2. Elements/families added to the model by substitution method (doors, windows, furnishes, etc.)
3. Surface-based elements/families (floors, roofs, etc.)

A total of six tasks, including two tasks for each of these criteria, were prepared to compare the user interface in BIM software. These tasks were explained to the participant one by one before the exercise, a written document was provided (Appendix-A) and the participant's questions were answered.

Each task has been created as a separate file, and the necessary template for the exercise is provided in each file. The purpose of providing common templates to each participant is to prevent wasting time on anything other than the assigned task and to prevent different factors that may occur during the exercise, which means making sure that all participants follow the same steps.

During the exercises, importance was given to applying each one of the modeling methods mentioned above and to progressing the tasks independently of each other.

Before the tasks started, OBS Studio, which is a screen recording program, and VS Code, which collects data, were run. The participant was expected to open and complete the tasks in order, starting from the first task.

Once all tasks were completed, the recording software was closed, and the results were checked to ensure that they were accomplished completely.

3.2.1.1 Task-1

In task one, it is aimed for the participant to work on elements generated by extrusion, that is, based on height, width, and such information. For this purpose, the user was given a floor in the template with certain boundaries and was asked to model a 350 cm in height and 700 cm in length wall on any edge of this floor.

The purpose of this task is to see how to access the wall tool from the user interface and to analyze the practicality of integrating the given height and length information into the model.

3.2.1.2 Task-2

In the second task, the users again worked on a wall, however they have experienced how to create a new type with certain layers and sub layers. In that purpose the participant were given a template including a generic type of wall. It requested them to create a new one by using this wall and create the layers on it in the order specified below.

From Interior to Exterior

- Plaster (2 cm)
- Brick Wall (25 cm)
- Mineral Wool/ Rock Wool (8 cm)
- Exterior Plaster (3 cm)

As a result of this task, it was aimed to see what the difference is between the user interfaces of the two software in detailing the elements.

3.2.1.3 Task-3

In the third task, it is aimed for the participants to use the elements generated with the in-place method and to make some arrangements on these elements. For this purpose, they were asked to place two windows size of 150x200cm on the wall given in the model and to change the material of these windows to aluminum or metal.

3.2.1.4 Task-4

Task four has the same logic as task three which is dependent on in-place element and its properties. Differently, in this stage the users placed a door size of 110x220cm instead of two windows. However, they have again changed the material to aluminum or metal.

3.2.1.5 Task-5

In the fifth task, it is aimed for the users to work on surface-based element which is a floor. For this stage, reference lines have been prepared on the main screen of the software. The user is asked to create a 700x500 cm generic floor, that is, a floor without any features, within the specified boundaries.

The main aim of this task is to see how to access the floor or slab tool from the user interface and to analyze the practicality of integrating the given sizes into the model.

3.2.1.6 Task-6

In task six, the users again worked on a floor, however they have experienced how to create a new type with certain layers and sub layers. In that purpose the participant were given a template including a generic type of floor. It requested them to create a new one and create the layers on it in the order specified below.

From Top to Bottom

- Ceramic Tile (2 cm)
- Waterproofing Layer
- Screed (5 cm)
- Reinforced Concrete (20 cm)

As a result of this task, it was aimed to see what the difference is between the user interfaces of the two software in detailing the elements.

3.2.2 Interview with Participants - Statistical Analysis and Evaluation

As the second stage of the study, participants interviewed. The interview questions shown in Appendix-B. These questions were prepared to understand and analyze the participants' experiences, skill levels, usage preferences and difficulties they encountered with BIM tool A and BIM tool B.

One question regarding the interface has been determined under each following title and the purposes are also specified:

1. Experience of the user: It is important to learn participants' both work and software experiences to make comparison. Finding out how long participants have been using the software helps understand their experience level. Long-term users may have more knowledge about the different versions and development processes of the software, while new users can provide valuable insights into learning and beginner use of the software.

2. Usability and learning: This question aims to evaluate the ease of learning of the software. The differences between the software learning processes of students and professionals provide information about the effectiveness of training materials and methods.

3. Knowledge of the user: How participants describe themselves (beginner, intermediate, advanced user, etc.) indicates their overall proficiency and comfort level with the software. This is important in identifying training needs and potential areas for development.

4. Flexibility of the software: It aims to understand how users evaluate the architectural modeling capabilities of software interface. This question attempts to reveal how well software adapts to various design needs, especially how it performs in challenging modeling scenarios such as organic forms and complex geometries.

5. Tool accessibility and customization of the software: It evaluates users' perceptions of the software interface, the layout of the tools, and the overall ease of use. This question is intended to understand how easily users can access software tools, how they find toolbars and menus, and overall whether the software is user-friendly.

6. Custom scripts and extensions of the software: This question aims to measure the degree to which users can customize and extend software. How frequently

users use plug-ins and special commands provides information about the flexibility and adaptability of the software. This may indicate whether the user interface is user-friendly in this sense.

7. Performance and responsiveness of the software: Participants' opinions about the software's performance and response time indicate how well the software adapts to different hardware and project sizes. In this sense, being practical is very important for the project process.

8. Error handling and feedback of the software: It evaluates whether the user interface provides error handling and user feedback, whether the software is reliable and user-friendly.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, the results of hands-on exercises and interviews are clarified. Then, all findings from two different research techniques are discussed. In the first part, results of hands-on modeling exercise are shown with tables, graphs and heat maps. Then, the results are evaluated and discussed. In the third part, the interview results are examined. Finally, both research methods' results are evaluated and discussed together.

4.1 Results of Hands-on Modeling Exercises on the Computer

The results of the hands-on exercise were obtained through VS Code and supported by screen recording method. These results were transferred to tables and converted into graphs in Microsoft Excel software. In this way, the results obtained from different user groups, including AP, BP, AS, BS, AB and BB, can be seen in a single table.

In addition, as mentioned in Chapter-3, heat maps were obtained for each user group using VS Code. Therefore, the movements of different user groups on two different software can be observed.

As mentioned in Title 3.1.2, the names of the software are not specified in this study out of respect to the software companies. They are refered as BIM tool A and BIM tool B to avoid commercial influence. The images have also been blurred for the same reason. Since this research is interested in not only the interfaces but also the experiences, a similar method can be applied to compare different software.

4.1.1 Task-1

In the first task, as mentioned in material chapter, users were asked to model a single wall. Total time of the exercise, time to first click, distance on screen, mouse clicks and keystroke values for five users in six different groups were obtained through VS code, and the mean values of each group were calculated in Microsoft Excel and transferred to the Table 4.1 below. Individual values of users are included in Appendix-C, under heading C.1.

Table 4.1 Mean values of different participant groups for Task-1

	TIME		DISTANCE	MOUSE		KEYSTROKES		
USER	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP	67	4,871	32970,31	20	0	11	2	6
AP	69	3,823	35647,52	21	1	8	2	6
BS	63	4,941	29103,19	17	0	5	0	3
AS	109	2,952	38891,03	35	1	8	0	5
BB	93	5,885	32590,69	27	0	6	0	4
AB	107	4,346	40619,95	32	1	5	0	4

According to the obtained data, the order of completing the task can be listed as follows: BS<BP<AP<BB<AB<AS and the time to first click can be ordered as: AS<AP<AB<BP<BS<BB. That result shows while intermediate level BIM tool B students (BS) completed task-1 in the fastest time, the time to first click is not parallel to this result. Beginner level BIM tool A students (AB) made the first click faster, but were ranked last in total task duration.

Figure also shows, the distance on screen can be ordered as: BS<BB<BP<AP<AS<AB. Intermediate level BIM tool B students (BS), who completed it in the fastest time, also completed this application by traveling the least distance and interacting with the least amount of mouse and keyboard.

In general, it is seen that BIM tool B users (BP, BS, BB) have less interaction with the mouse and keyboard in this task than BIM tool A users (AP, AS, AB). It was also observed that there was no significant difference between professional users (BP and AP).

In addition to these results, heat maps were created showing the movements of all users on the software interface. Figure 4.1 demonstrates superimposed heat maps of different user groups which are represented with different colors.

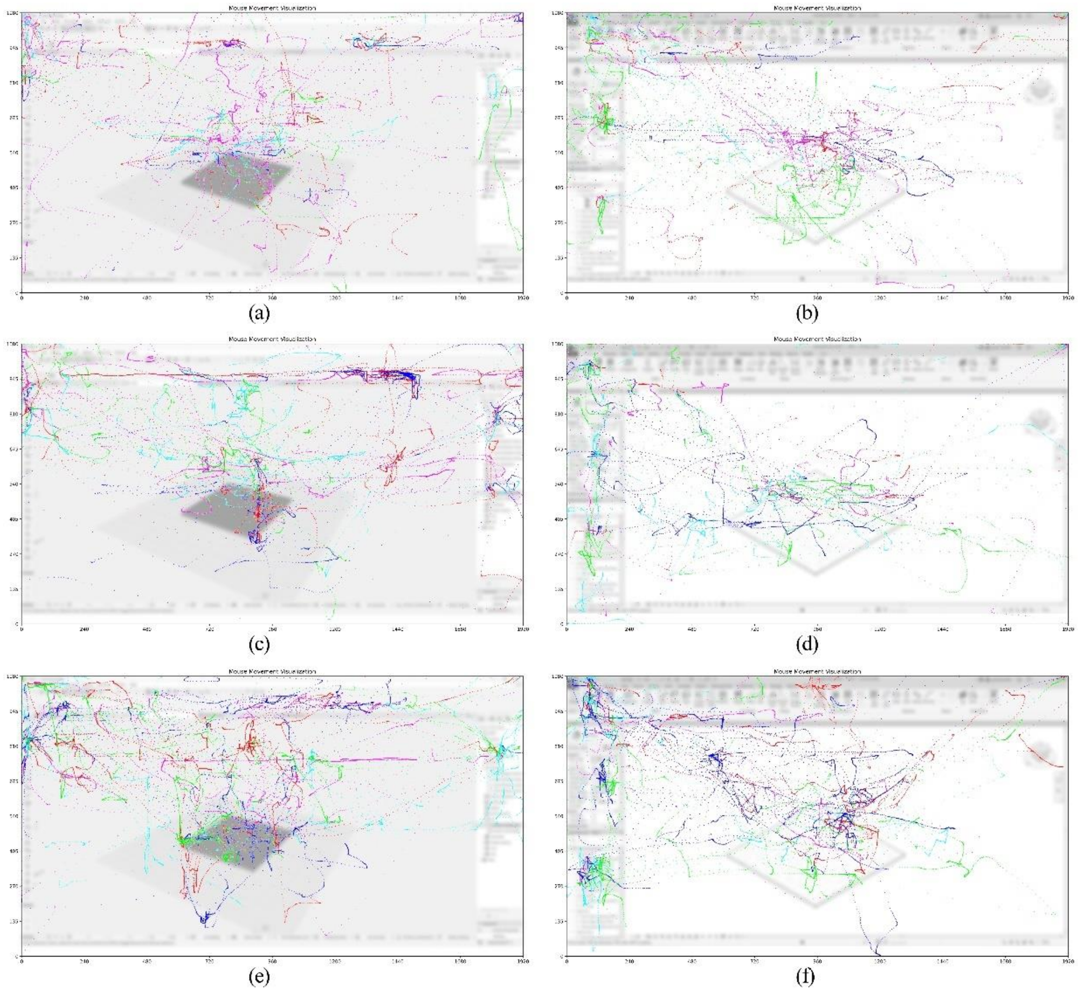

Figure 4.1. Heatmaps of users for Task-1. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f)

Enlarged images for task-1 heat maps can be seen in Appendix-C, under title C.2.

These heat maps show how the use of two different software is experienced by six different user groups for task-1. The three images on the left part (a, c, and e) represent BIM tool A users, and the three images on the right represent BIM tool B users (b, d, and f).

4.1.2 Task-2

In the second task, users were requested to add layers into a wall and change the materials. All six user groups accomplish this assignment. Similar to task-1, measurement of different metrics for each user were made through VS Code. In Table-4.2, the mean values of these metrics for each group are listed. Individual values of the users can be seen in title C.1, Appendix-C.

Table 4.2 Mean values of different participant groups for Task-2

	TIME		DISTANCE	MOUSE		KEYSTROKES		
USER	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP	162	1,557	48279,46	57	2	22	34	5
AP	189	4,002	56069,12	67	1	15	15	5
BS	190	4,023	44844,11	71	0	12	26	7
AS	260	1,638	71913,27	85	2	23	21	6
BB	230	1,906	48577,39	83	1	10	28	5
AB	248	4,550	59518,01	85	3	6	6	6

According to Table 4.2, it is seen that BIM tool B professionals (BP) completed this task in the fastest time, with faster first click data and with less mouse interaction. Again, the same group of participants is the second group to travel the least distance on screen, and is the last in terms of keystrokes.

The order for total task time is as follows: BP<AP<BS<BB<AS<AB. Similarly, for time to first click is as follows: BP<AS<BB<AP<BS<AB.

BIM tool B users traveled less distance than BIM tool A users and the ranking is as follows: BS<BP<BB<AP<AB<AS.

Beginner level of BIM tool A students (AB) have the longest time for task completition and for the first click duration. They also have less interaction with the keyboard and the most interaction with the mouse.

The number of mouse clicks of the user groups can be listed as: BP<AP<BS<BB<AS<AB.

The number of keystrokes can be listed as: AB<AP<BB<BS<AS<BP.

Another data obtained from VS code is heat maps of users. Superimposed heat maps of different user groups are ilustrated in Figure 4.2.

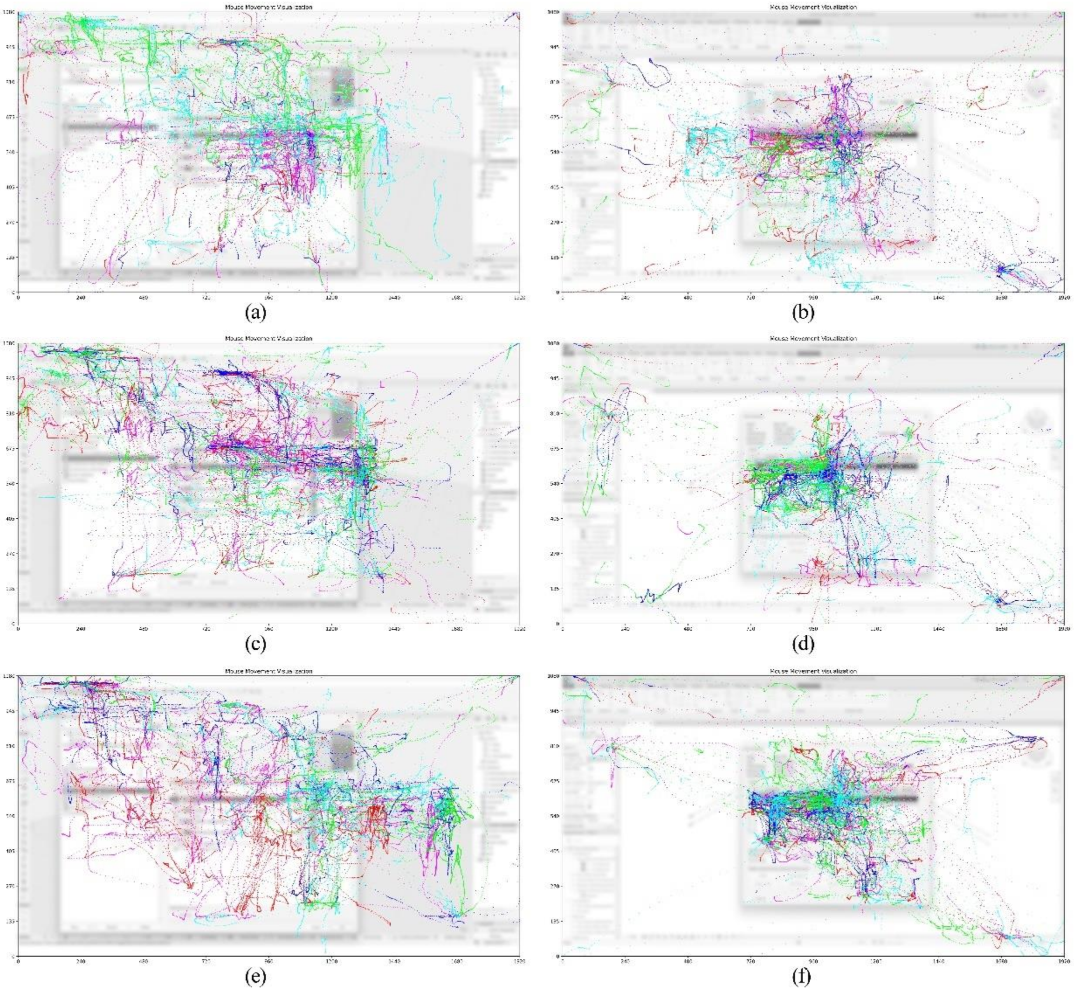

Figure 4.2. Heatmaps of users for Task-2. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f)

There are six heat maps expressed in different colors for each user, showing users' movements on the software. The images on the left represent BIM tool A users, and the others show BIM tool B users. Enlarged images can be seen in Appendix-C, under heading C.2.

4.1.3 Task-3

In this task, it was asked from users to place two windows and change some of the the properties. The same user groups with previous tasks have completed task-3. The mean values for time, distance, mouse clicks and keystrokes of different groups are stated in Table-4.3. Individual values of the users can be seen in title C.1, Appendix-C.

Table 4.3 Mean values of different participant groups for Task-3

	TIME		DISTANCE	MOUSE		KEYSTROKES		
USER	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP	118	4,197	42336,03	38	0	13	12	11
AP	129	4,327	39902,33	35	1	31	9	13
BS	127	4,147	39321,32	42	0	7	12	8
AS	311	2,721	103834,20	100	4	31	2	10
BB	144	5,123	45009,07	38	0	6	13	7
AB	217	5,390	62228,40	63	2	11	1	8

According to the graph, the completition time order is as follows: BP<BS<AP<BB<AB<AS. It can be seen that BIM tool B professionals completed this task in the fastest time, and intermediate level BIM tool A students completed it in the longest time. In general, it can be observed that BIM tool B users are faster in this task.

On the other hand, a similar inference can be made regarding the distance traveled on the screen, the order in this metric is as follows: BS<AP<BP<BB<AB<AS. Students using BIM tool a generally covered the longest distance.

Considering the interactions with the mouse, while the results of BIM tool B users were close to each other, differences were observed between the results of BIM tool A users, and the order is as follows: AP<BB=BP<BS<AB<AS. Similarly, the order of keystroke numbers is as follows: AB<BB<BS<BP<AS<AP.

User heat maps are another type of data that were obtained via VS code. Figure 4.3 shows a comparison of all user groups' heat maps.

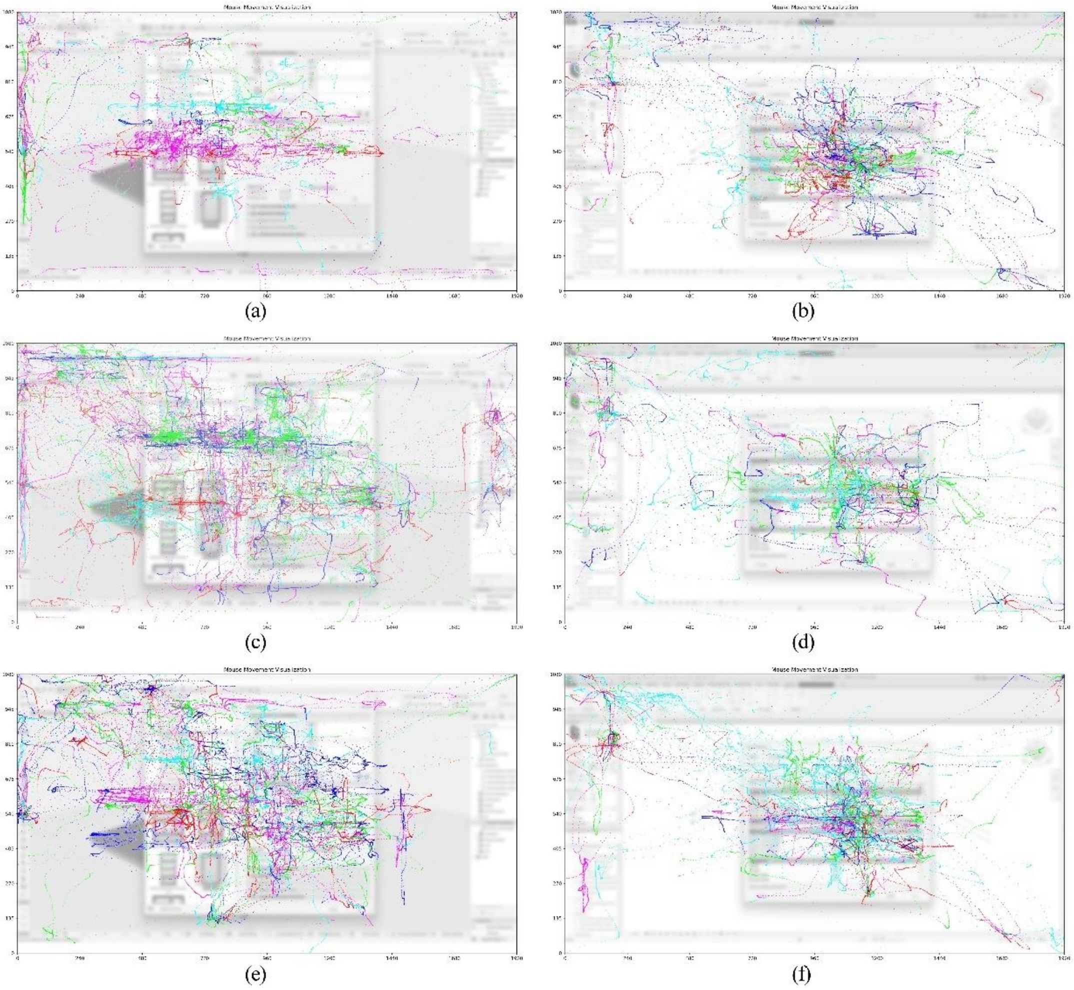

Figure 4.3. Heatmaps of users for Task-3. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f)

Each user is illustrated with different color on the heat maps showing users' that depicts how they travel throughout the software. Three images on the left part represent users of BIM tool B, while the ones on the right illustrate users of BIM tool A. In Appendix-C enlarged images can be found in under heading C.2.

4.1.4 Task-4

In this task, it was asked from users to place a door and change some of the properties of it. The same user groups have completed this task also. The mean values for the metrics of all six user groups are calculated in Microsoft Excel and transferred to the Table 4.4. Individual values of all users are revealed in Appendix-C.

Table 4.4 Mean values of different participant groups for Task-4

	TIME		DISTANCE	MOUSE		KEYSTROKES		
USER	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP	78	5,634	23809,96	25	0	6	7	8
AP	83	4,343	31853,57	28	1	12	2	9
BS	66	3,903	23640,81	25	0	6	6	5
AS	146	2,877	45199,95	48	1	8	1	8
BB	79	4,889	25243,37	25	0	4	9	5
AB	127	3,461	45685,74	47	0	11	0	7

The table shows that intermediate level BIM tool B students (BS) completed this task in the fastest time and least distance. The order in total time is BS<BP<BB<AP<AB<AS. Likewise, it can be seen that the order in total distance is quite similar and is as follows: BS<BP<BB<AP<AS<AB.

On the other hand, intermediate level BIM tool A students are first in time of first click, while BIM tool B professionals are last.

Regarding mouse clicks, it can be said that all BIM tool B users have the same value and interact less than BIM tool A users.

The order of keystrokes is as follows: BS=AS<BB=AB<BP<AP.

User heat maps are another type of data that were obtained via VS code. Figure 4.3 shows a comparison of all user groups' heat maps.

Heat maps, another method used to observe user interface interaction, is shown in Figure 4.4 for task-4.

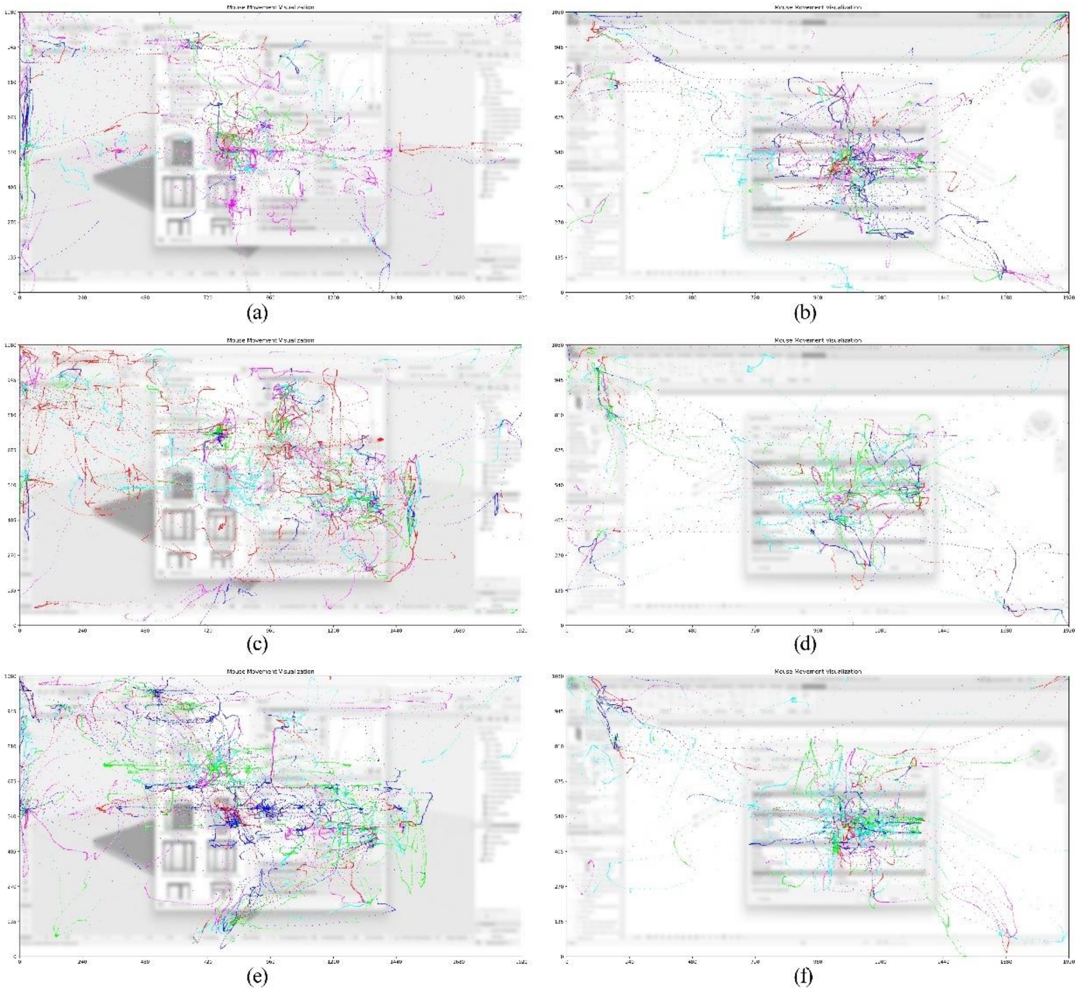

Figure 4.4. Heatmaps of users for Task-4. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f)

Different colors represents diffeent users on the superimposed heat maps. The three images on the left part (a, c, and e) represent BIM tool A users, and the three images on the right represent BIM tool B users (b, d, and f).

In Appendix-C enlarged images can be found in under title C.2.

4.1.5 Task-5

Participants were asked to model a single floor. Total time of the exercise, time to first click, distance on screen, mouse clicks and keystroke values for five users in six different groups were obtained through VS code like in other tasks, and the mean values of each group were calculated in Microsoft Excel and transferred to the Table 4.5 below. Individual values of users are included in Appendix-C, under title C.1.

Table 4.5 Mean values of different participant groups for Task-5

	TIME		DISTANCE	MOUSE		KEYSTROKES		
USER	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP	45	6,960	22666,14	17	0	5	1	1
AP	33	4,727	14599,98	9	0	7	1	5
BS	26	5,266	11939,00	8	0	0	0	0
AS	87	6,069	29618,72	27	0	10	1	8
BB	47	5,810	16937,13	10	0	1	0	1
AB	51	7,506	16376,08	13	0	3	0	2

It is observed that intermediate level BIM tool B students (BS) completed this task in the fastest time and the order for total task time is as follows: BS<AP<BP<BB<AB<AS. On the other hand, BIM tool A professionals have the fastest fisrt click time as in the following order: AP<BS<BB<AS<BP<AB.

Intermediate level BIM tool B students (BS) traveled less distance than other participants and the ranking is as follows: BS<AP<AB<BB<BP<AS.

In terms of the interaction with the mouse the order is as follows: BS<AP<BB<AB<BP<AS. On the other hand, the order of keystroke numbers is as follows: BS<BB<AB<BP<AP<AS.

Another data obtained from VS code is heat maps of users. Superimposed heat maps of different user groups are ilustrated in Figure 4.5.

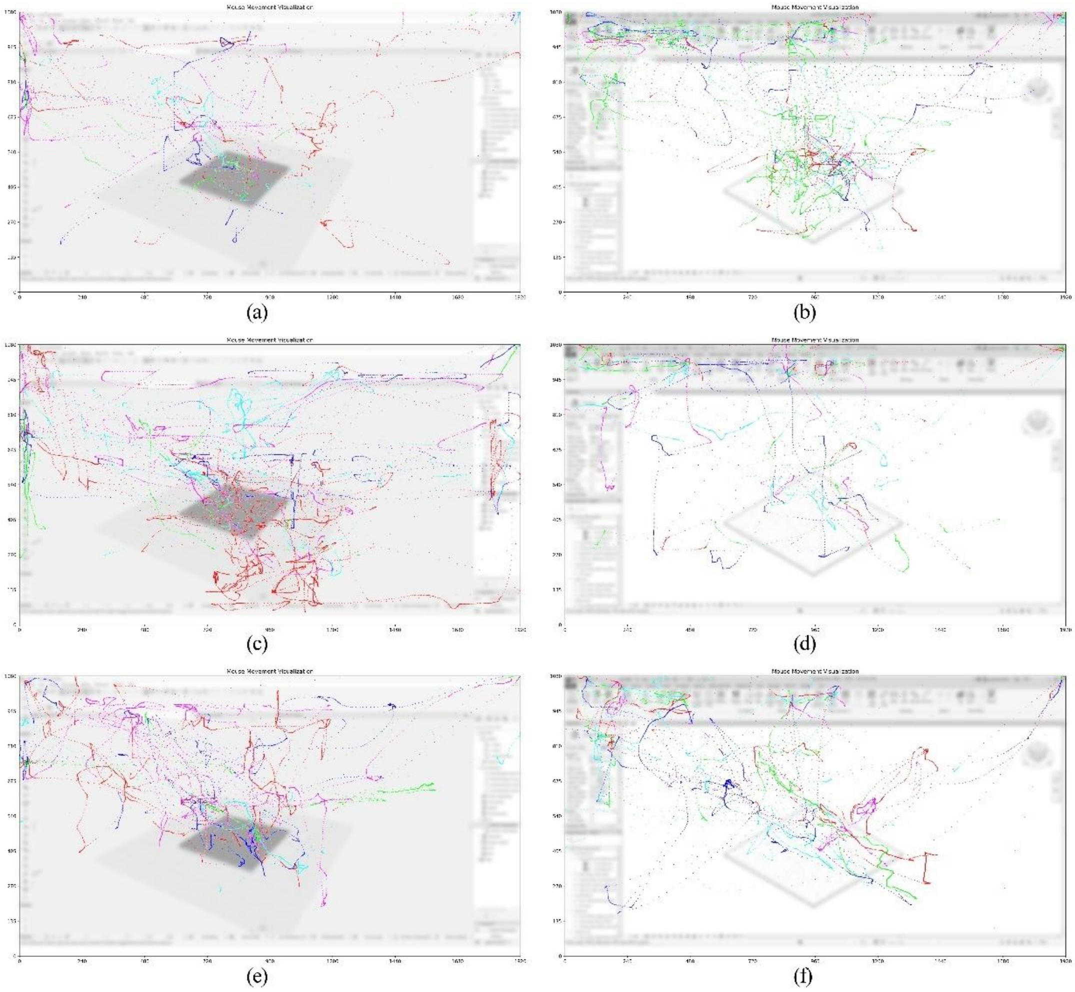

Figure 4.5. Heatmaps of users for Task-5. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f)

There are six heat maps shown in different colors for each user, showing users' movements on the software. The images on the left represent BIM tool A users, and the others show BIM tool B users. Enlarged images can be seen in Appendix-C, under title C.2.

4.1.6 Task-6

In task-6, users asked to add layers into a floor and change materials. The task was completed by the same user groups. In Table-4.6, the mean values for time, distance, mouse clicks and keystrokes of different groups are stated. Individual data of all users are revealed in Appendix-C.

Table 4.6 Mean values of different participant groups for Task-6

	TIME		DISTANCE	MOUSE		KEYSTROKES		
USER	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP	117	2,796	31653,40	46	1	9	23	4
AP	182	7,014	55098,74	67	1	17	8	9
BS	146	2,672	31068,89	56	0	16	31	5
AS	182	1,758	41453,19	64	0	20	15	4
BB	194	2,646	34908,01	76	1	21	36	4
AB	158	2,320	34957,87	59	1	7	3	3

According to the data, the order of completing the task can be listed as follows: BP<BS<AB<AP=AS<BB and the time to first click can be ordered as: AS<AB<BB<BS<BP<AP. Althugh intermediate level BIM tool A students (AS) completed task-6 in the fastest time, BIM tool B professionals (BP) made the first click faster.

Table 4.6 also shows that the distance on screen performance of the participants can be ordered as: BS<BP<BB<AB<AS<AP. Therefore, intermediate level BIM tool B students (BS) traveled the least distance while BIM tool A professionals traveled the longest.

Considering the interactions with the mouse, the order is as follows: BP<BS<AB<AS<AP<BB. Similarly, the order of keystroke numbers is as follows: AB<AP<BP<AS<BS<BB.

User heat maps are another type of data that were obtained. Figure 4.6 shows all user groups' superimposed heat maps.

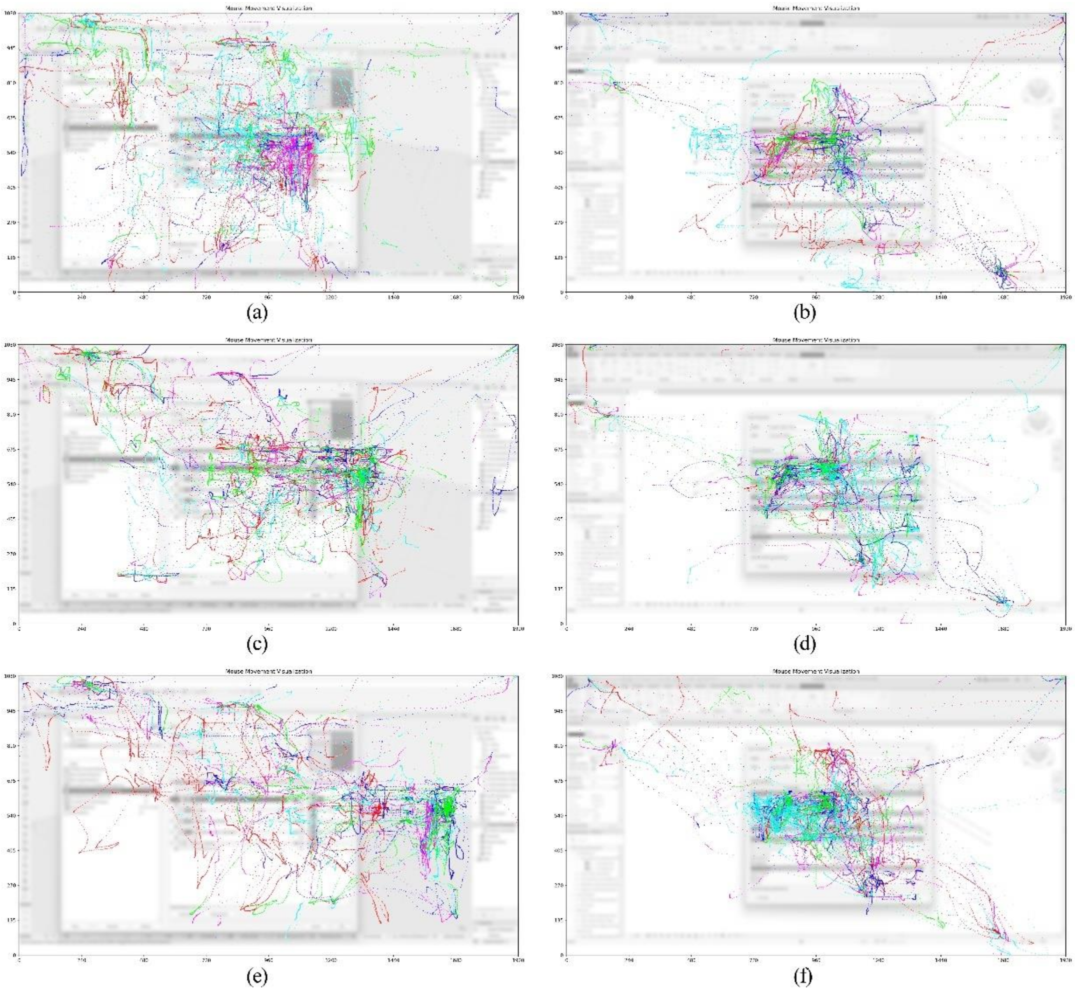

Figure 4.6. Heatmaps of users for Task-6. AP (a), BP (b), AS (c), BS (d), AB (e), BB (f)

Users are illustrated with different colors on the superimposed heat maps. The left three images represent users of BIM tool A, while the right three represent users of BIM tool B. Enlarged images are available in Appendix-C under title C.2.

4.2 Discussion of Hands-on Modeling Exercise Results

In this section, numerical data regarding the time spent on the task (in seconds), the number of pixels traveled by the mouse movement, the total number of left and right clicks of the mouse, the total number of keystrokes of all operational keys, number keys and letter keys of six different participant groups are shown by taking the mean value for each participant group. These numerical data were converted into charts and compared for all six tasks. Finally, a comprehensive evaluation and collective discussion of all tasks were conducted.

4.2.1 Task-1

The following chart was created using the mean values obtained from the hands-on modeling exercise results of six different participant groups in Task 1 (Figure 4.7). Each metric was superimposed on a single chart so that all metrics could be compared simultaneously.

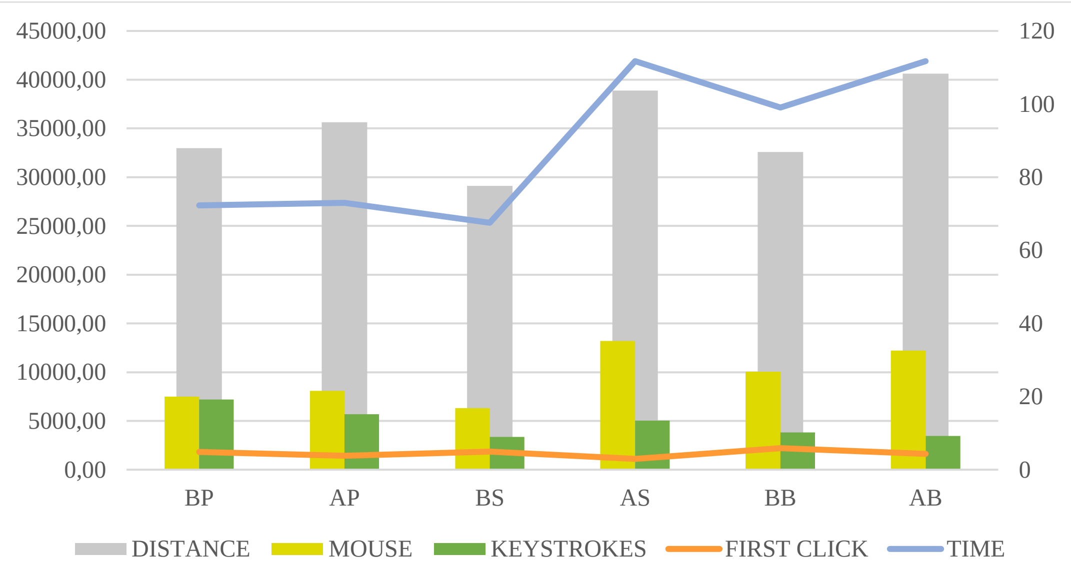

Figure 4.7. Data showing the mean values in different metrics of participant groups for Task-1.

Based on this graph, the following inferences were made for this task:

1. In terms of distance traveled on the screen, it is generally seen that BIM tool B users travel less distance than BIM tool A users at all experience levels. For the same metric, while participants experienced in BIM tool A completed

the task with less navigation, it is seen that there is no ranking directly related to experience levels for BIM tool B users. In this task, users can complete with simple commands without having to access distant points on the interface. Therefore, it can be said that users who travel longer distances lose more time on the interface of the software. Between the two software, it has been concluded that BIM tool A's user interface is less convenient for users in this task, since BIM tool A users generally travel more distance.

2. There appears to be notable variation among users in terms of time to complete the task. Although it seems to be no obvious difference between the professional groups, there is a notable time difference between these two software for students. Intermediate level BIM tool A students spent more time than other users. Likewise, BIM tool A beginner level students are among the groups that complete the work in the slowest time. Therefore, similar to distance metric, it can be said that BIM tool B's interface is more user-friendly for this task among the participants.
3. It can be said that the first click time was quite similar among all groups and did not differ significantly depending on the experience level or the software used.
4. Upon examination of mouse click data, it is observed that intermediate level BIM tool A students exhibits the highest frequency of clicks, followed by BIM tool A beginner students. On the other hand, BIM tool B users interacted with fewer mouse clicks on average. While this task can only be achieved with a small number of clicks using the mouse for both software, high click numbers indicate that users have difficulty finding what they are looking for in the interface.
5. Since this task does not require a command that requires letters or numbers, keystrokes are not expected. It has been observed that during task-1, especially in professional groups, too much keystroke usage is due to users' hotkey habits. On the other hand, students' number of keystroke is lower which is a positive result for this task. Also, especially operational clicks may

result in users making mistakes, searching for different things, and confusion in the user interface.

Based on all these inferences, when the user experience for this task between BIM tool A and BIM tool B is evaluated, it can be said that the user interface of BIM tool B offers easier navigation for participant groups in general and is more efficient in terms of time to complete the task.

In addition to these results, heat maps were created showing the movements of all users on the interface. Figure 4.8 is a superimposed heat map of five BIM tool A professional users.

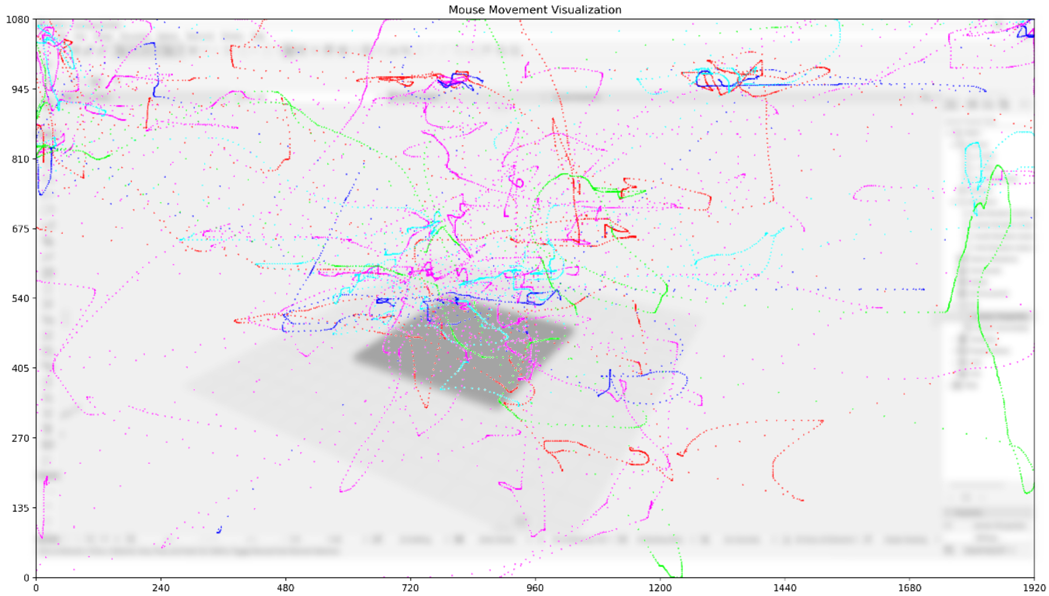

Figure 4.8. Superimposed heat map of BIM tool A professionals for Task-1.

From this image, the areas where users focus on the interface while creating a wall can be observed. Each user is represented by a different color. Red is used for AP1, magenta for AP2, blue for AP3, cyan for AP4 and green for AP5. Scattered click points are noticeable in this image. This may indicate that users are making large movements to access various features and commands spread widely across the user interface. In particular, it appears that users may have frequently used the menus at the top of the screen and the task panels on the right. Engagement density may indicate that users return frequently to a particular area or feature, or that they have to use a feature repeatedly.

The superimposed heat map of the BIM tool B professional user is given below in Figure 4.9.

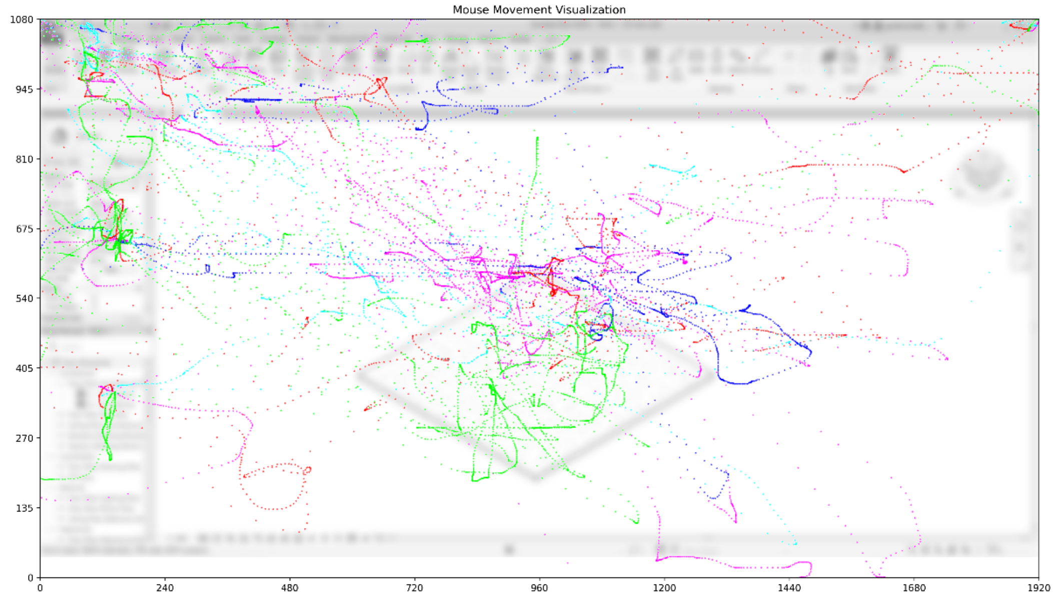

Figure 4.9. Superimposed heat map of BIM tool B professionals for Task-1.

In this heat map, red is used for BP1, magenta for BP2, blue for BP3, cyan for BP4 and green for BP5. Movements and clicks appear more concentrated and clustered specifically around the modeling area in BIM tool B professionals. Users may have generally worked on a centralized model and interacted more intensively in a particular area. However, it is noticeable that there is less variety and spread in the use of the menu bar compared to BIM tool A. This may suggest that BIM tool B users may have used a narrower area of the interface to complete tasks.

As a result, these heatmaps show us that BIM tool A users are interacting with the interface more widely and perhaps having to access more tools and features. In contrast, BIM tool B users appear to work in a more concentrated area and use certain features more frequently. This may support the interpretation that BIM tool B may have a more user-friendly interface for given tasks.

Detailed heat maps have been created for intermediate level and beginner level students as well as professional users, and these can be seen in Appendix-C. Other comparisons and outcomes to these heat maps are provided in following paragraphs.

When the heat maps of intermediate level students are compared for this task, the wider and more dispersed interaction in the heat map of BIM tool A users may indicate that users have difficulty exploring the interface or finding certain features. In contrast, BIM tool B users' heat map shows movement in menus and toolbars, but unlike BIM tool A users', it is concentrated in a specific area. This may suggest that these users find the tools necessary to complete the task more quickly and efficiently.

Similarly, among beginner students, the interaction patterns of BIM tool A users generally appear to be broader and more dispersed, while those of BIM tool B users appear to be more focused and centralized. This may suggest that the BIM tool B interface may offer a more linear way for beginners to complete this task, or it may simply indicate that BIM tool A users need more exploration in the context of this specific task.

Overall, it seems that as the level of experience increases, users' interactions with the interface become more focused and effective. Beginners often take a more exploratory approach, while professionals may use strategies that can get the most done in the least amount of moves to complete tasks. These differences may reflect users' familiarity with the software and increased efficiency in performing tasks.

4.2.2 Task-2

The following chart in Figure 4.10 was created for the total time spent, time to first click, the distance traveled on the screen, the total number of mouse clicks, the total number of keystrokes according to the results given before in title 4.1.2.

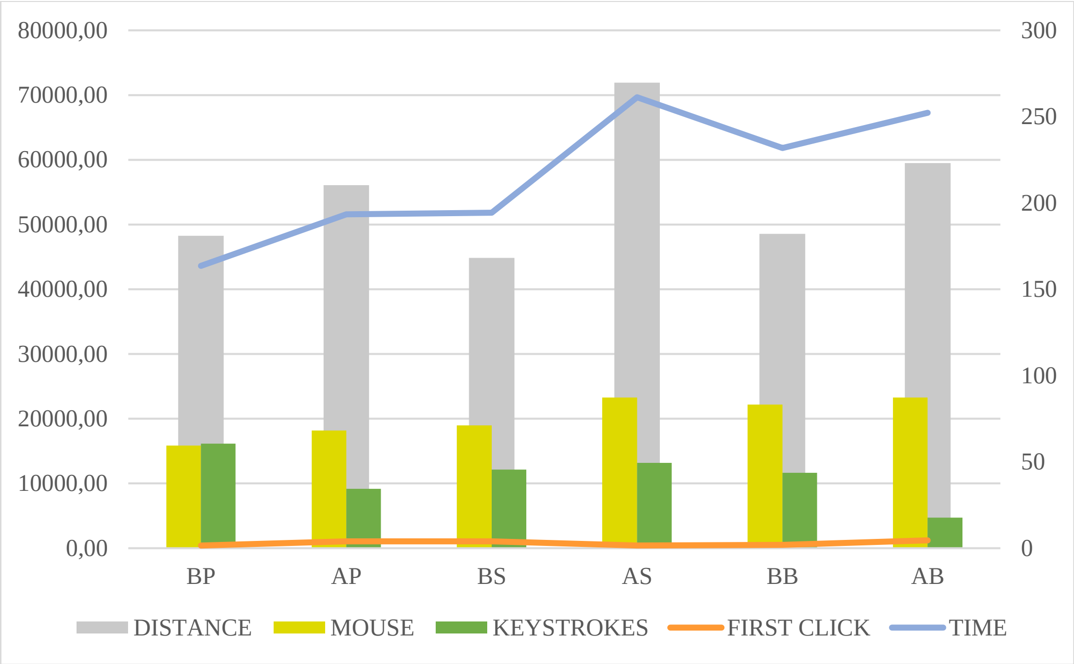

Figure 4.10. Data showing the mean values in different metrics of participant groups for Task-2.

Correspondingly with this chart, the following interpretations were made for task-2:

1. The fact that BIM tool A's interface requires nested clicks to access some commands has been a challenging issue for users in this tasks. Therefore, BIM tool B users in general completed the task with less distances.
2. Since this task requires more detailed modeling and more knowledge than the previous task, the task duration of professional users is generally less than intermediate and beginner students. The fact that BIM tool A's interface requires nested clicks to access some commands has been a challenging issue for users.
3. Although there is no significant difference regarding the users' first reactions, that is, their first click on the interface, it can be said that BIM tool B users generally clicked faster.
4. Since this task requires sequential operations, it makes sense for users to interact with the mouse more than the previous task. However, with the

participant groups of this research, BIM tool A's interface required more clicking than BIM tool B.

5. Similar to the number of mouse clicks, users need to click more letters and numbers on keyboards for task-2. Thus, users need to edit information such as material and thickness by using keystrokes. In this task, interaction with keyboard is important; apart from accidental and negligible clicks, the high number of clicks may indicate that the material was accessed by keystrokes without unnecessary searching on interface. On the other hand, students used the keystrokes less and increased the distance on screen.

For this task heat maps were created to show how the users travel on the interface. The following Figure 4.11 is a superimposed heat map of five BIM tool A professional users.

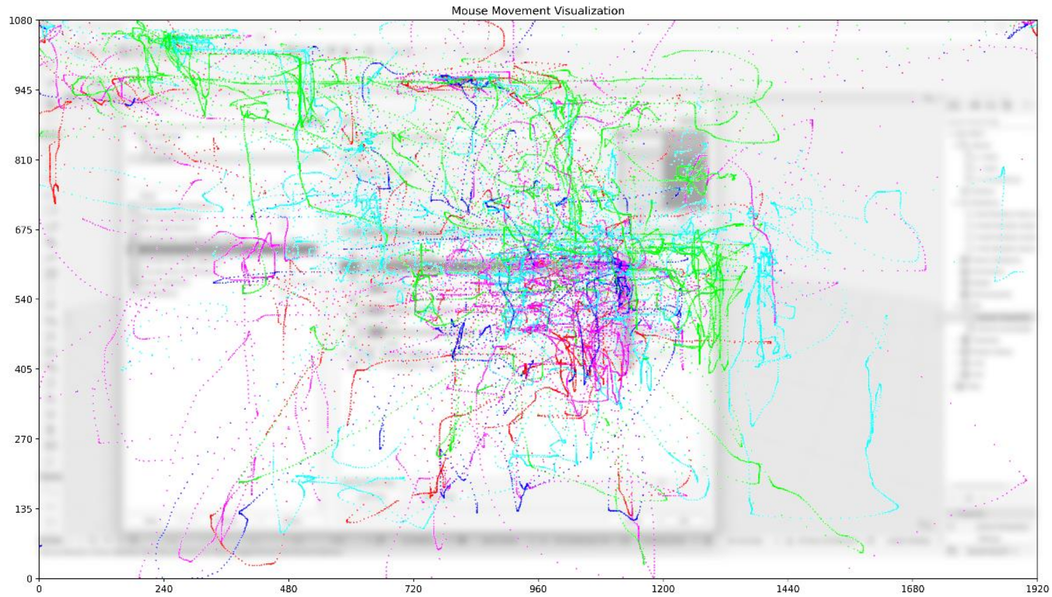

Figure 4.11. Superimposed heat map of BIM tool A professionals for Task-2.

This heat maps represent which areas of the interface users focus on when adding layers to the wall and editing their materials. Each user is represented by a different color, as in other heat maps: red is used for AP1, magenta for AP2, blue for AP3, cyan for AP4 and green for AP5.

The density of traces and the spread of interactions of BIM tool A users indicate that they frequently access various features of the software and use a wide interface area when performing a series of operations. Extensive switching between menus and constant use of toolbars occurs as BIM tool A professionals try to perform complex tasks within a specific workflow.

Besides, the image below represents five BIM tool B professionals’ heat maps for task-2 (Figure 4.12).

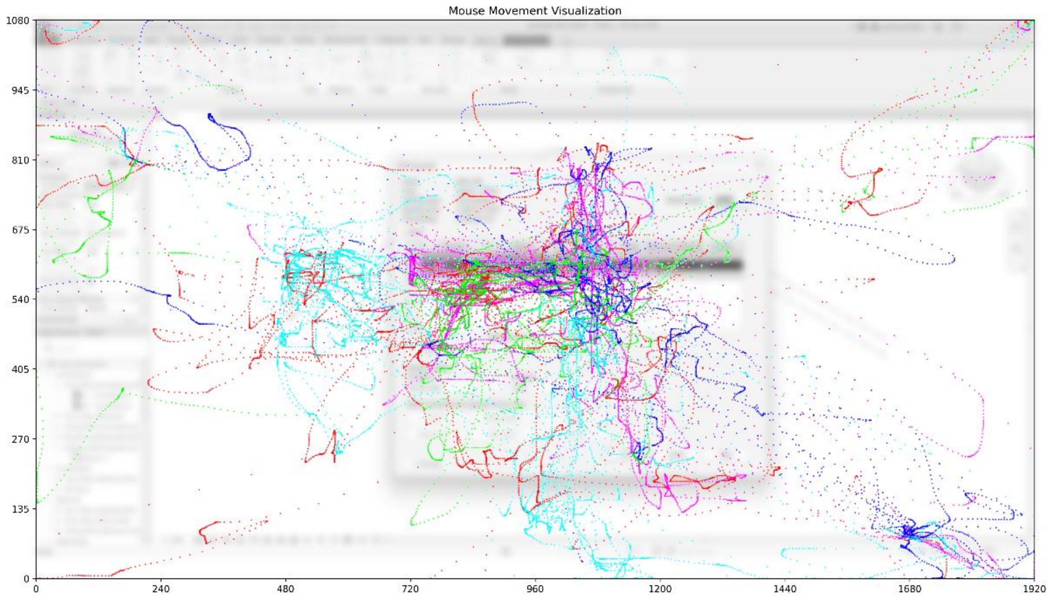

Figure 4.12. Superimposed heat map of BIM tool B professionals for Task-2.

Again in this image, users are represented with different colors, as: red is used for BP1, magenta for BP2, blue for BP3, cyan for BP4 and green for BP5.

In this heat map, it is seen that user interactions are more concentrated compared to BIM tool A. Focused traces in the modeling area and throughout the menu bars indicate that professionals' interactions in their workspaces are more intense and specialized. There are also signs that users are repeating the same actions over and over again, which may show their familiarity with a particular workflow or sequence of tasks.

In both cases, professional users' interaction patterns demonstrate their mastery of the software's complexity and functionality and how they complete specific tasks efficiently. However, the intensity of users' interactions provides clues that BIM tool B may be more suitable for this task in terms of functionality and effectiveness.

Heat maps were created also for other user groups, all of which are given in the Appendix-C. Similarly, the following observations were made for the heat maps of intermediate level students.

The distribution of interactions in the BIM tool A heat map shows that users have mastered different functions of the software but are still improving in finding the most effective workflow, while BIM tool B users find that users are more focused on a specific area of the interface, needing less exploration when completing tasks, and using specific tools and functions. It may indicate that they use it more effectively. Furthermore, both heat maps show the difficulties and learning processes that beginner users face while performing their tasks in both software. BIM tool A users' interactions tend to be more exploratory and pervasive, while BIM tool B users' interactions tend to be more goal-oriented and functional.

In general, as the level of experience increases, users' interactions with the interface become more focused and efficient for task-2. Professional users seems to know the most efficient paths and hotkeys, intermediate users are still exploring while gaining experience, while beginners make broader exploration in the process of learning the interface and software and put more effort into completing the task. These differences also indicate users' familiarity with the software and their ability to perform tasks.

4.2.3 Task-3

The chart below was obtained using mean values from the hands-on modeling exercise results for six different groups of participants in Task 3 (Figure 4.13). Each metric was placed in a single chart so all metrics could be examined at the same time.

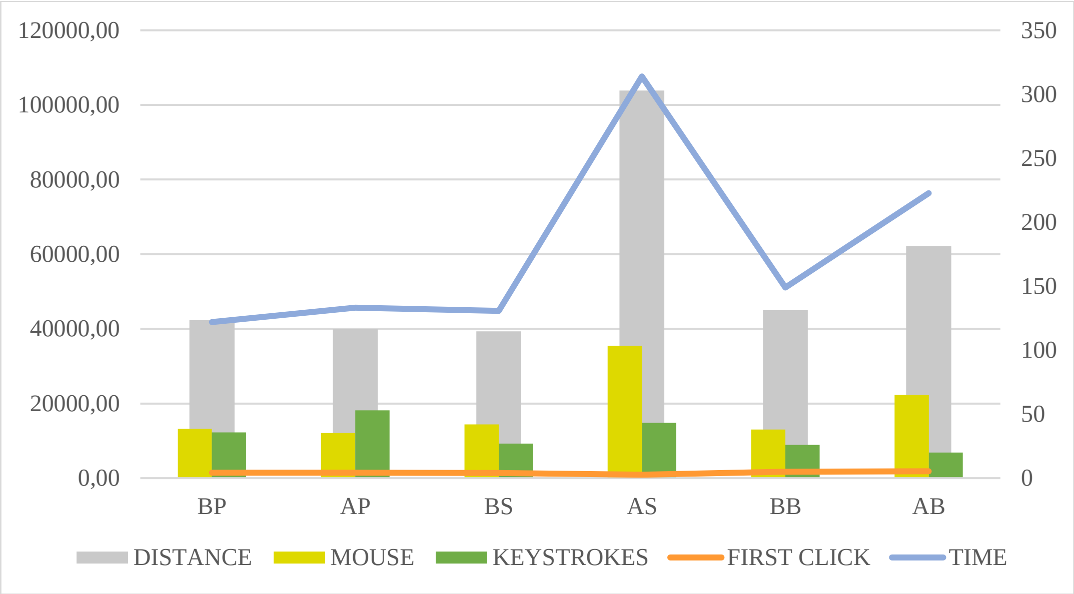

Figure 4.13. Data showing the mean values in different metrics of participant groups for Task-3.

By examining this chart, the following comparisons and inferences were obtained for task-3:

1. While approximate results are obtained in all groups in terms of distance on screen, a remarkable increase is seen especially in intermediate level BIM tool A students, and followed by beginner level BIM tool A students. It was observed that the reason for this was that the student group had difficulty with the window placement and editing command, and they could not practically access or find this arrangement in the interface.
2. Task completion time values were obtained in parallel with the distance traveled. The fact that there are similar results especially for professional users, but serious differences between students, shows that students have difficulty finding that they are searching for in the BIM tool A interface. Another important issue observed in all BIM tool A users is that they cannot do it practically because they cannot see the measurements while adjusting the window location during this exercise, which is one of the reasons why this task takes a long time.

3. The first interaction of users with the interface are almost similar for Task-3.
4. This task could require excessive usage in terms of both mouse clicks and keystrokes. However, it can be said that especially intermediate level BIM tool A students have more mistakes and therefore interact more with the mouse.
5. The noteworthy issue in the number of keystroke differences is that students have hesitation to use the keyboard. The reason of accessing tools only using a mouse could mean that they have not adapted to the interfaces of BIM software yet. It is seen that the use of keystroke-mouse clicks are more balanced for professionals.

Besides, heat maps were created as shown in previous tasks. Figure 4.14 is a superimposed heat map of five BIM tool A professional users.

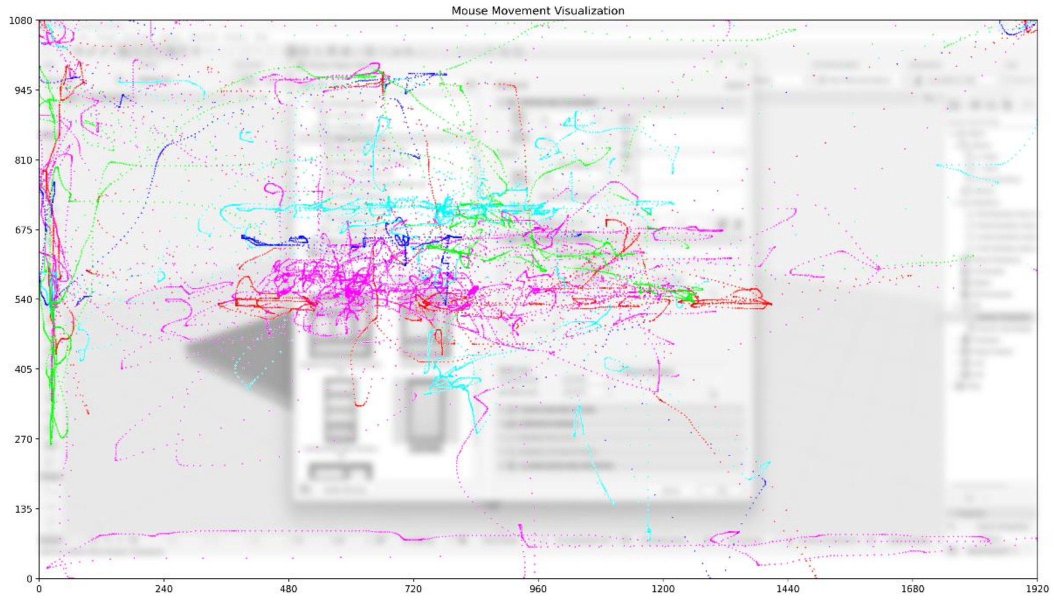

Figure 4.14. Superimposed heat map of BIM tool A professionals for Task-3.

This heat map shows which parts of the interface users focus on when adding windows and making relevant arrangements. Each user is represented by a different color similar with other heat map as follows: red is used for AP1, magenta for AP2, blue for AP3, cyan for AP4 and green for AP5.

This figure represents professional BIM tool A users showing intense activity in the top menu and toolbars of the interface. This indicates that certain tools and menu options are actively used and participants need various functions to accomplish the task-3. Interaction patterns may show that users are covering a large region of the interface, meaning users are accessing many different functions during the task.

For this task, an example superimposed heat map of BIM tool B professionals is given below (Figure 4.15).

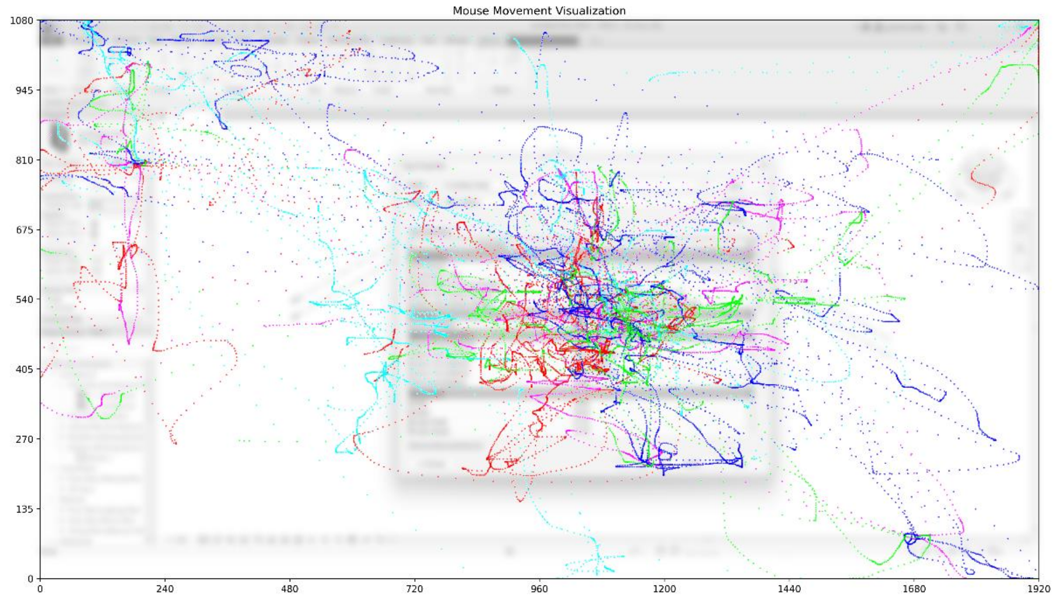

Figure 4.15. Superimposed heat map of BIM tool B professionals for Task-3.

In this heat map, red is used for BP1, magenta for BP2, blue for BP3, cyan for BP4 and green for BP5, as in previous examples.

The BIM tool B professionals heat map shows that users focus on certain areas of the interface and there is intense interaction in these areas. Users can be seen switching more precisely and purposefully between BIM tool B menu and using certain functions. Interaction patterns are notable for clusters and lines in users' interactions that give the impression of a distinct workflow or task sequence.

Overall, these two heat maps show that professional users' interactions with the interface and use of software tools differ when performing the third task in both software. While it is understood that BIM tool A users interact more with the toolbar and perhaps need more diverse functions, BIM tool B users show interaction in a narrower area and focused on certain functions.

Heat maps were created also for intermediate level students and beginner level students, all of which are given in the Appendix-C. The evaluations of other heat maps are given in following paragraphs.

Heatmaps of intermediate level students show that users have some experience completing task-3 in both software, but are still in the process of discovery and learning, unlike professional users. While BIM tool A users' interactions are more exploration-oriented, BIM tool B users appear to be more focused and oriented towards specific tools. These interaction patterns provide valuable information about how users understand and use the interfaces and functionality of both software.

Among beginner users, the interactions of BIM tool A users tend to be more dispersed and diffuse, while the interactions of BIM tool B users tend to be more focused and goal-oriented, similar to intermediate level users.

As a result, it has been observed that as the level of experience increases, users' interaction patterns with the interface become more efficient and goal-oriented. While professional users work to get the most effective results with the least amount of movement, beginners and intermediate users engage more broadly and exploratively as they learn the software and how to complete tasks.

4.2.4 Task-4

As mentioned before, a similar application was made in this task as Task-3, so similar results and inferences were expected to be obtained.

All mean values of metrics that are the time spent, time to first click, the distance traveled on the screen, the total number of mouse clicks, the total number of keystrokes, are shown in a single chart using the results obtained in 4.1.4 (Figure 4.16).

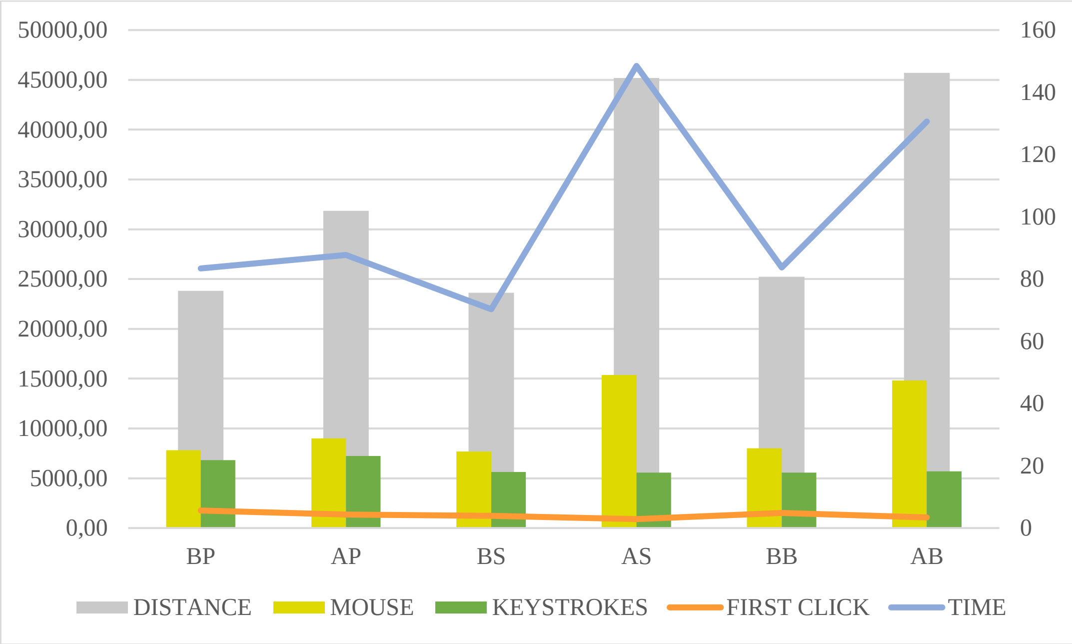

Figure 4.16. Data showing the mean values in different metrics of participant groups for Task-4.

Based on this chart, the following inferences were made for task-4:

1. Although there are similarities with the previous task, this chart shows that BIM tool B users have covered significantly less distance than BIM tool A users. BIM tool B users obtained similar values regardless of experience. However, BIM tool A students are generally the participant group that has made the most progress. It can be said that the reason for this is that users need to travel further for this command in BIM tool A's interface.
2. Also in this task, task completion time values were obtained in parallel with the distance traveled. And similar with previous task, all BIM tool A users is that they cannot locate the door practically because they cannot see the measurements while adjusting the location.
3. There is no particular difference in time to first click.

4. The mouse click values of BIM tool A intermediate level students and BIM tool A beginner students stand out. This much interaction with the mouse means that they have a difficulty from time to time.
5. There is no particular difference in keystrokes between users.

In addition to these results, again, heat maps were obtained as shown in previous tasks. While Figure 4.17 is a superimposed heat map of five BIM tool A professional users, Figure 4.18 shows BIM tool B professional users.

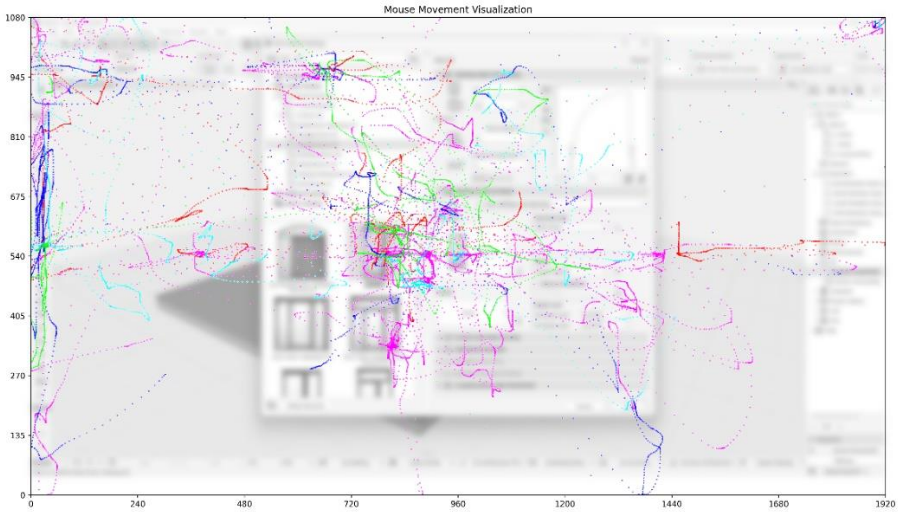

Figure 4.17. Superimposed heat map of BIM tool A professionals for Task-4.

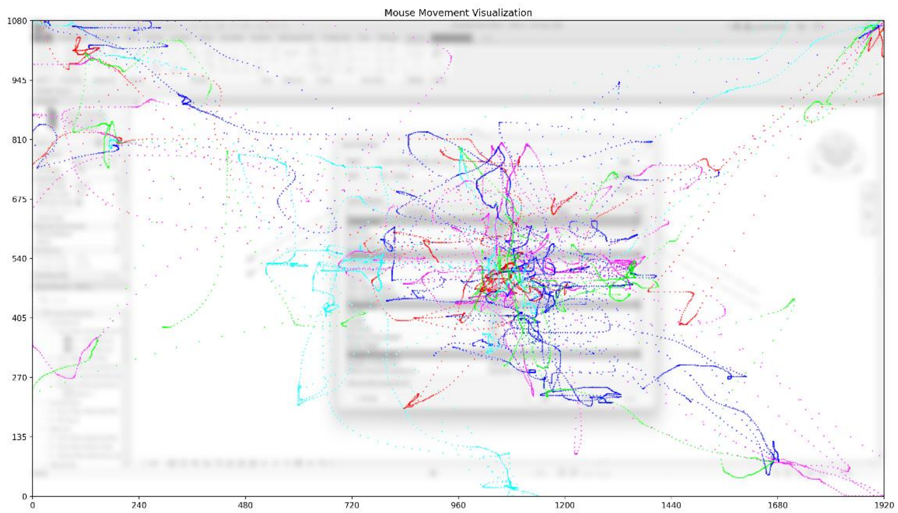

Figure 4.18. Superimposed heat map of BIM tool B professionals for Task-4.

User colors as follows: red is used for AP1 and BP1, magenta for AP2 and BP2, blue for AP3 and BP3, cyan for AP4 and BP4, green for AP5 and BP5.

The interaction patterns of professional users in both software clearly reveal how they use the interface and tools and optimize their workflows when performing this task. While BIM tool A users focus around menus and toolbars to complete tasks, BIM tool B users seem to focus more heavily on specific functions and tools.

Heat maps were created for other participant groups and given in the Appendix-C. It can be said that while BIM tool A intermediate level students show an interaction pattern that involves more exploration and discovery, BIM tool B users show more organized and focused interactions around specific tools and functions. Beginner level users have obtained heat maps very similar to these patterns.

4.2.5 Task-5

Task-5 is expected to be completed with a few operations like Task-1. The graph in Figure 4.19 was created from the results previously mentioned in heading 4.1.5.

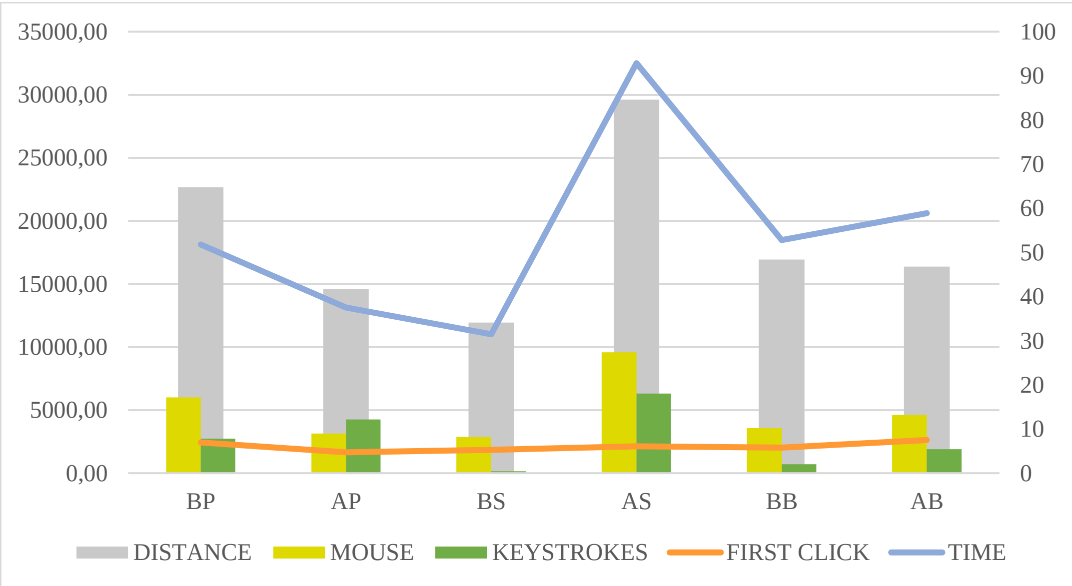

Figure 4.19. Data showing the mean values in different metrics of participant groups for Task-5.

The following items were interpreted correspondingly with this graph:

1. Although intermediate level BIM tool A students traveled the longest distance for this task, BIM tool B users of the same experience level completed the shortest distance. At this stage, the task of modeling a very basic floor type was requested. The fact that students at the same experience level get such different results shows that they have difficulty in the BIM tool A software for this application. On the other hand, there were no such differences between other experience levels.
2. A similar result to the distance parameter was also obtained for time to complete the task. Therefore, BIM tool A students who completed it in the longest time could not quickly fulfill the requirements of this application in the interface.
3. It has been observed that the first click time in this task takes longer than other tasks. That is, users were not able to interact with floor modeling as quickly as with other commands. However, in general, there is no dramatic difference between users. BIM tool A professionals are the ones who react the fastest.
4. The floor modeling task is a mouse-oriented application for both software. Even the excessive number of mouse clicks is not expected here, keystrokes use is not foreseen except the use of number keys. At the results, it can be seen that BIM tool B users generally have less keyboard interaction than BIM tool A users. The noteworthy value here is that BIM tool A professional users interact less with the mouse and more with the keyboard. The reason for this is that, as it was understood from the feedback given by users while during the exercise, especially professional users make too many keystrokes due to their hotkey habits.

In addition to these results, heat maps were created showing the movements of all users on the interface. While Figure 4.20 is a superimposed heat map of five BIM tool A professional users, Figure 4.21 shows BIM tool B professional users.

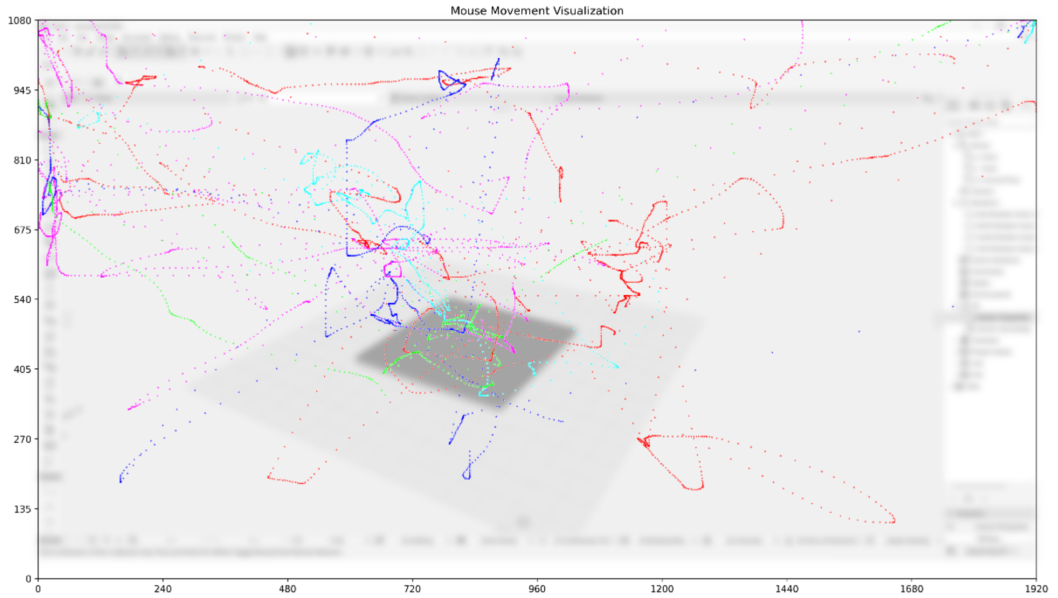

Figure 4.20. Superimposed heat map of BIM tool A professionals for Task-5.

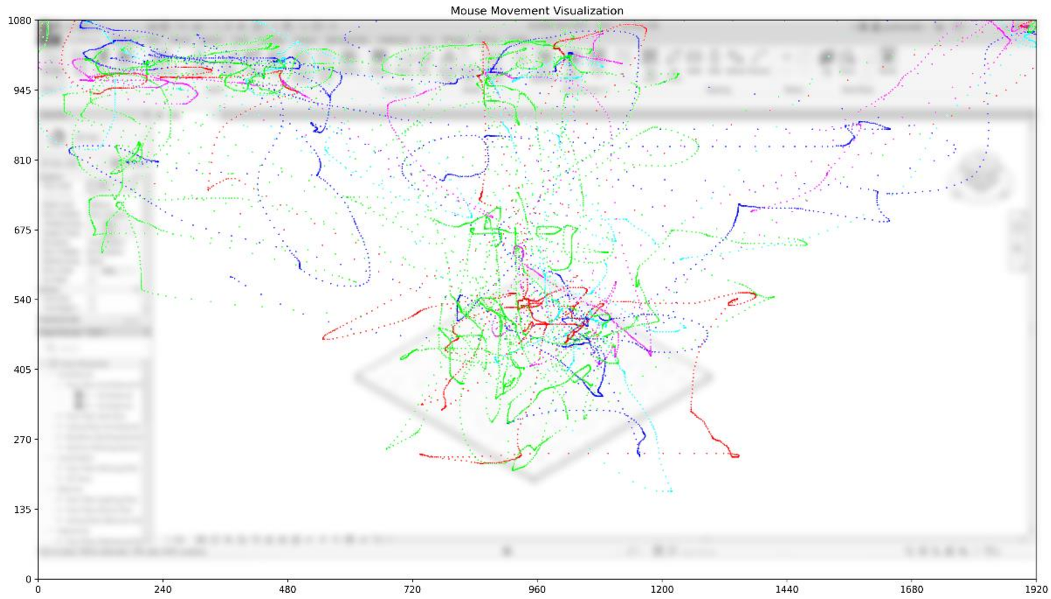

Figure 4.21. Superimposed heat map of BIM tool B professionals for Task-5.

In these heat maps, each user is represented by a different color, as in other heat maps: red is used for AP1 and BP1, magenta for AP2 and BP2, blue for AP3 and BP3, cyan for AP4 and BP4 and green for AP5 and BP5.

Interactions of professional BIM tool A users occur across a wide spectrum of the software. This wide range of interactions may indicate that users are actively exploring various features of the software and using different tools to accomplish tasks. Some users interact more specifically with the menu on the left, which may be areas where frequently used commands or preferred functions are concentrated.

The interaction patterns of professional users in BIM tool B are concentrated in different areas compared to BIM tool A users. Particularly the concentration on the top menu indicates that users are more focused on specific functions and tools when performing tasks.

Detailed heat maps have been created for intermediate level and beginner level students as well as professional users, and these can be seen in Appendix-C. Other comparisons and outcomes to these heat maps are provided in following paragraphs.

Intermediate level BIM tool A students' mouse movements seem to be concentrated in more focused areas, unlike those of professional users. This may suggest that these participants use certain tools and functions more frequently and spend more time with specific features required to complete the task. On the other hand, the interaction patterns of intermediate level BIM tool B students seem to be more dispersed but generally less intense than those of BIM tool A users. Interactions occur across a number of different tools and menus in BIM tool B's user interface. This diversity may indicate that users have a more comprehensive usage experience and are trying different methods to complete certain tasks. Similar traces are seen in beginner level students as in intermediate level. It just appears that there is less interaction on toolbars.

4.2.6 Task-6

The chart below was obtained using mean values from the hands-on modeling exercise results for six different groups of participants in Task-6 (Figure 4.22). Each metric was placed in a single chart so all metrics could be examined at the same time.

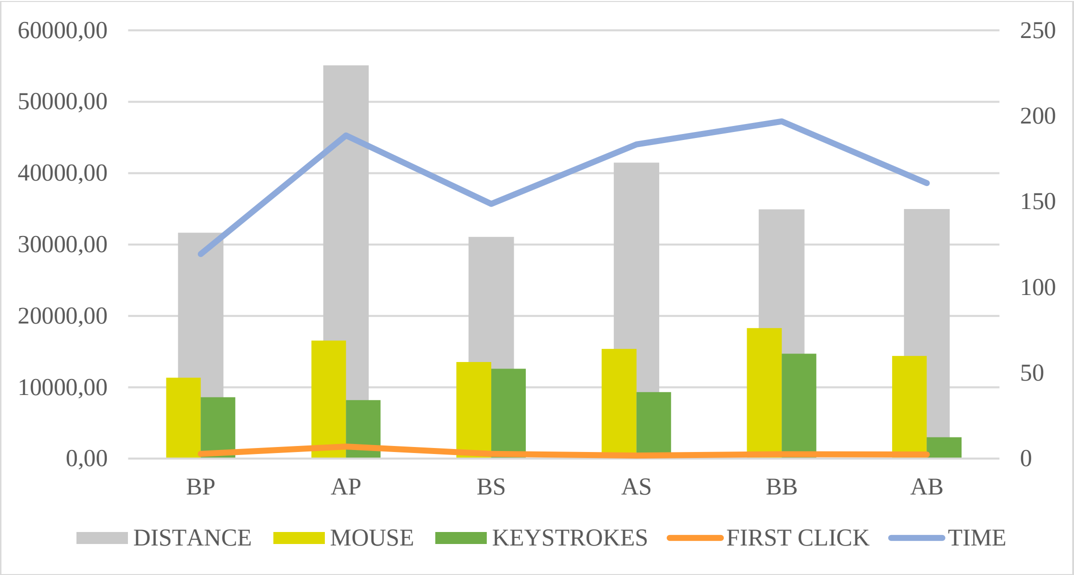

Figure 4.22. Data showing the mean values in different metrics of participant groups for Task-6.

Correspondingly with this chart, the following interpretations were made for task-6:

1. It has been observed that BIM tool A professionals traveled more distance in this particular task compared to other tasks. When the individual results of professional users are examined, some of them complete the task with the shortest distances, but it has been determined that some other users prolong the task by performing unnecessary operations and trying too hard. It could be related to the belief that professional users sometimes make the process more complicated than it needs to be. The same observation is also valid for the total task time. On the other hand, in this exercise BIM tool B users generally completed the task with less distance.
2. Although the study results are generally similar, BIM tool B users have relatively less interaction with the mouse. When it comes to keyboard commands, the situation is different. Especially beginner students using BIM tool A have completed this task with very limited use of the keyboard. However, users are interested in materials and thickness. They need to edit information via the keyboard. Therefore, keyboard use should be considered

an important criterion for this task. Accessing the tools only using the mouse may indicate that the tools in question are not yet fully integrated into the BIM software interfaces.

In addition to these results, heat maps were created as shown in previous tasks (Figure 4.23 and Figure 4.24).

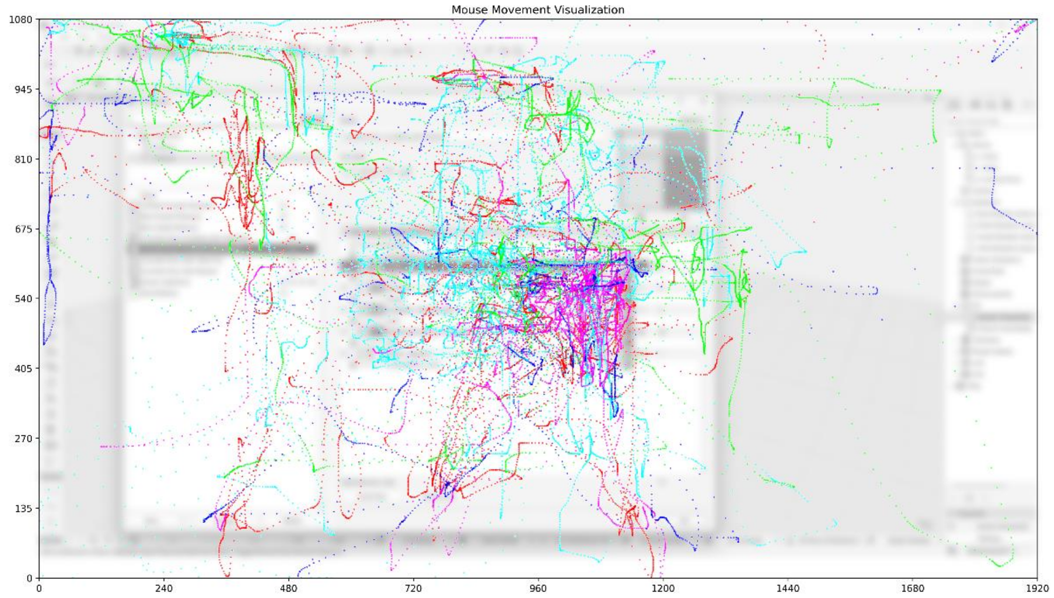

Figure 4.23. Superimposed heat map of BIM tool A professionals for Task-6.

This image represents which areas of the interface users focus on when adding layers to the floor and editing its materials. Each user is represented by a different color: red is used for AP1, magenta for AP2, blue for AP3, cyan for AP4 and green for AP5.

For this task, most of the mouse movements of BIM tool A professional users are concentrated in the toolbars at the top of the interface and the menu on the left, indicating that users access functions and settings. However, the fact that the movements are also seen in the center shows that users mostly make the edits in this part with the new window opened in the center of the opened screen.

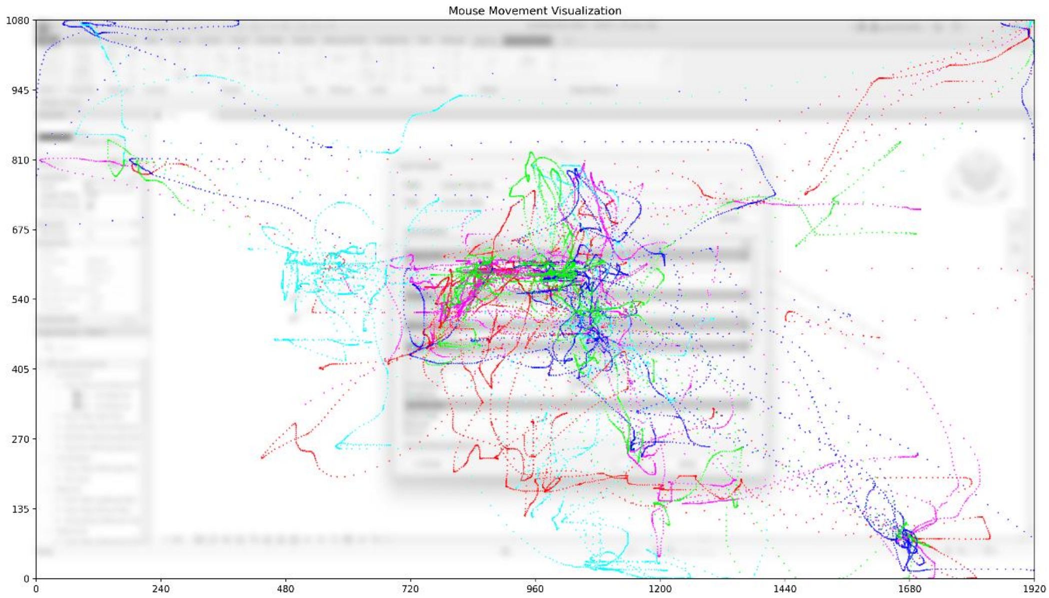

Figure 4.24. Superimposed heat map of BIM tool B professionals for Task-6.

Also for Figure 4.24 a different colors show: red for BP1, magenta for BP2, blue for BP3, cyan for BP4 and green for BP5.

For BIM tool B professional users, the mouse movements in task-6 show that a large portion of the interface is being used. Especially the intense activity on the newly opened window in the center of the canvas draws attention. Unlike BIM tool A, the user focuses more on this window and not on other parts of the toolbar. In other words, it can be said that BIM tool B users complete this task more practically by focusing on a certain location. A continuous and balanced pattern of interaction throughout the task demonstrates that professional users understand BIM tool B's complex functions and can implement them efficiently.

Superimposed heat maps were also generated for intermediate level students and beginner level students, all of which are given in the Appendix-C. The interpretations of other heat maps are given in following paragraphs.

While similar maps appear for professional and intermediate users, seeing more movement around certain tools in intermediate users may indicate that they can struggle these tools more. Visually, areas of intense traces may be less cluttered than in professional users, which may mean that these users are more familiar with a particular part of the software.

In addition, it is examined that there are more scattered traces for beginner users compared to other user groups. It has been observed that the reason for this is that there are different methods for making arrangements. However, beginner BIM tool B students had a more focused map than those using BIM tool A.

4.2.7 All Tasks

The following superimposed graph was created by taking the total average values of the results obtained in all tasks to summarize all results and evaluations (Figure 4.25).

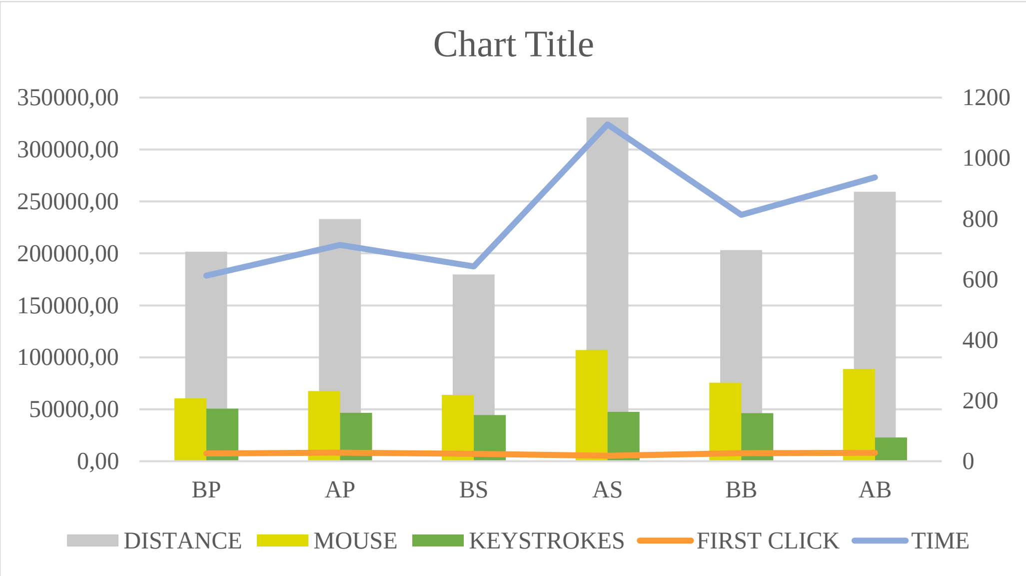

Figure 4.25. Data showing the total mean values in different metrics of participant groups for all tasks.

In the comparison between BIM tool A and BIM tool B interfaces, the analysis obtained on six different tasks reveals that BIM tool B users generally travel less distance and complete tasks in a shorter time. This shows that the BIM tool B interface is more user-friendly, especially for beginner and intermediate users, and enables tasks to be completed more effectively. Although BIM tool A offers more customization and detailing options, navigating the interface can be difficult, especially for less experienced users, and this can extend task completion times. Nested click commands and the need for more navigation have made BIM tool A users slower, especially on complex modeling tasks.

Additionally, when mouse click and keystroke data were examined, it was determined that BIM tool A users generally made more mouse clicks, but BIM tool B users were able to complete tasks with fewer clicks. This indicates that the BIM tool B interface is less cluttered and more intuitive. In comparisons made between students and professionals, it has been observed that student groups especially have more difficulty, and their task time is longer when using BIM tool A.

It has been observed that both software is used equally effectively among professional users. Professionals were able to work with high efficiency in both interfaces, but the fact that BIM tool A users required more mouse clicks and keystrokes to complete tasks suggests that these users had to go into more detail in the interface.

In conclusion, this comparative analysis between BIM tool A and BIM tool B reveals that BIM tool B is superior in terms of overall user experience, enabling users to complete tasks faster and more efficiently. It has been determined that BIM tool A presents difficulties, especially for beginners and students, due to its interface complexity. These differences play an important role in the design of user interfaces of BIM software and directly affect how efficiently users can use the software.

4.3 Results and Discussion of Interview Results

Eight questions were asked to the participants and their answers were noted. Questions and answers of the interviews with the participants are mentioned in Appendix-B. According to these answers, the results of the research are explained and discussed. Also, the answers were reflected in graphs with the help of Microsoft

Excel. In all graphs, the vertical axis represents the number of users, and the horizontal axis represents the user group, such as AP for BIM tool A professionals. Descriptions of the colors are shown below the charts.

In the first question, the experience levels of the participants have been learnt by asking about the users' work experiences and software experiences. The results are shown in Figure 4.26 and Figure 4.27.

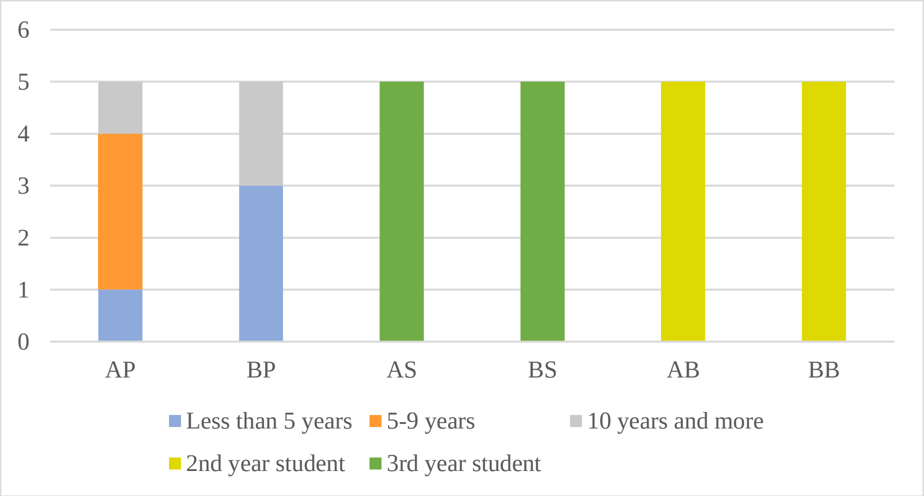

Figure 4.26. Work of experiences of the participants

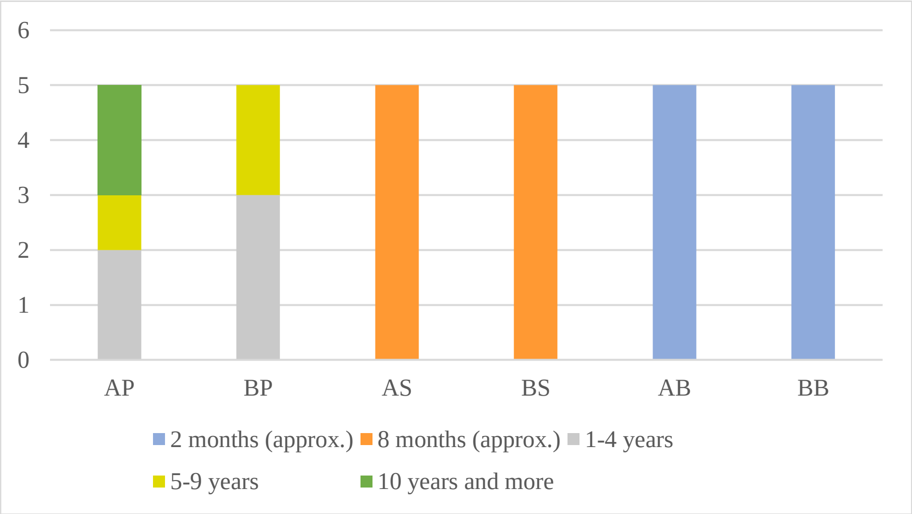

Figure 4.27. Software experiences of the participants

As mentioned in section 3.1.1, beginner students who know both software and students who have intermediate level knowledge were selected for the student groups. Therefore, this information is clearly seen in the charts. Intermediate level students, i.e., AS and BS, are 3rd year students and have approximately 8 months of experience with the software when they participated in the exercises. Besides, the beginner level AB and BB students are 2nd grade students and started learning the software approximately 2 months ago.

On the other hand, in professional users, participants with different experience levels were encountered. While there are participants in BIM tool A who have been using this software for over 10 years, BIM tool B users have closer experience.

The second question is about how long it took the participants to learn and adapt to the software's interface. Participants also described what the learning process was like. As can be seen in Figure 4.28, beginner level students were hesitant, stating that they were still in the learning phase. They also made a comparison since they had opinions about both software and the majority stated that they learned BIM tool B's interface more easily. There are also those who state that BIM tool A's interface is easier to learn.

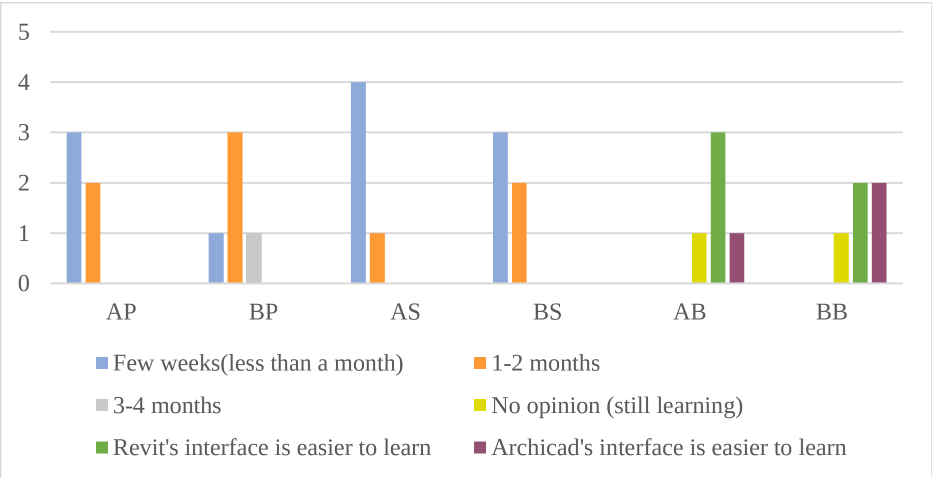

Figure 4.28. The required time for participants to learn software

On the other hand, it is understood from the same graph that both intermediate level students and professionals become familiar with the interface in less than a month, especially the number of people using BIM tool A is higher.

In the third question, users were asked about their opinions about their own levels. The results are represented in Figure 4.29.

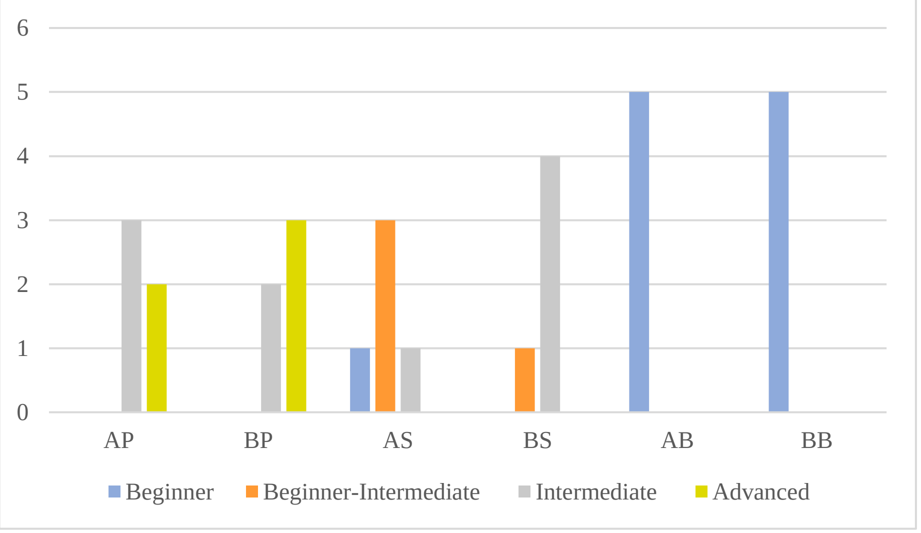

Figure 4.29. Level of users

Students classified as beginner and intermediate level also defined themselves in a similar way. However, the important data in this chart is among the professionals. Although the number of BIM tool B users who describe themselves as Advanced is more than BIM tool A users, there is a balanced distribution among the participants according to their self-declared level.

The fourth question covers participants' opinions about the modeling flexibility of the software to assess users' appraisal of the architectural modeling features of the software interface. As can be seen in Figure 4.30, the concern of most users is that both software is limited to organic forms. A significant part of the users who gave this answer stated that they did not work with organic forms, but they thought that the interface of the software did not seem suitable for this. This shows the impact of the software interface on the user rather than its capability.

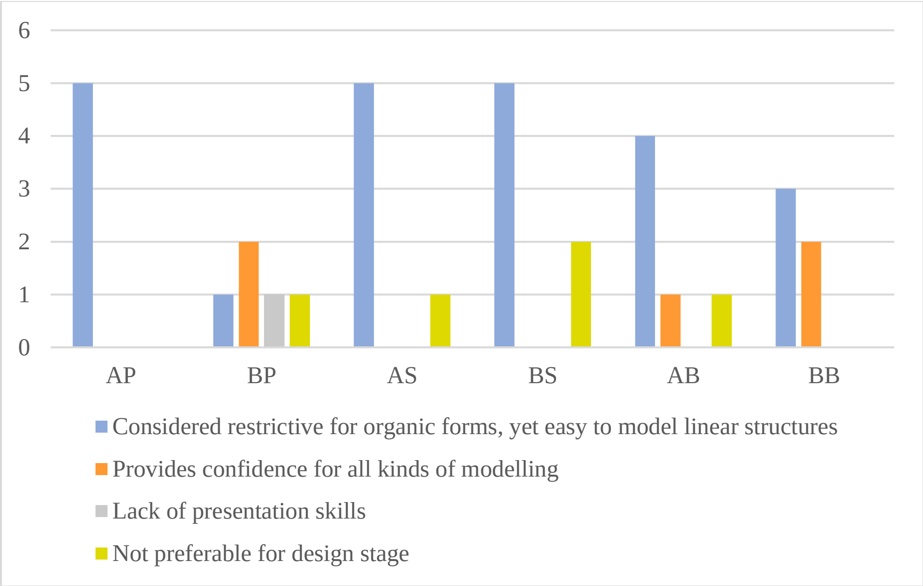

Figure 4.30. Modeling flexibility of the software

Some BIM tool B users stated that it gave them confidence that the software enables any kind of modeling. It is noteworthy that while there are BIM tool B professional users who have this thought, there are no people who make this comment about BIM tool A among participants of the interview.

Especially in student groups, there were participants who stated that this software had a restrictive interface during the design phase. Although this may not be the reality, many felt that the interface was better suited to the construction phases.

The fifth question of the interview evaluates users' perceptions of the software interface, the layout of the tools, and the overall ease of use about the interface. The results are represented in the image below (Figure 4.31). According to the answers received, there are users who think that the interface for both software is clear and understandable. However, when two software compared, the number of BIM tool B users who thought in this way is more than BIM tool A users. Regarding toolbar customization, BIM tool B professionals stated that this arrangement was not needed, while the majority of BIM tool A users stated that they used the BIM tool A interface in the layout they wanted with customization.

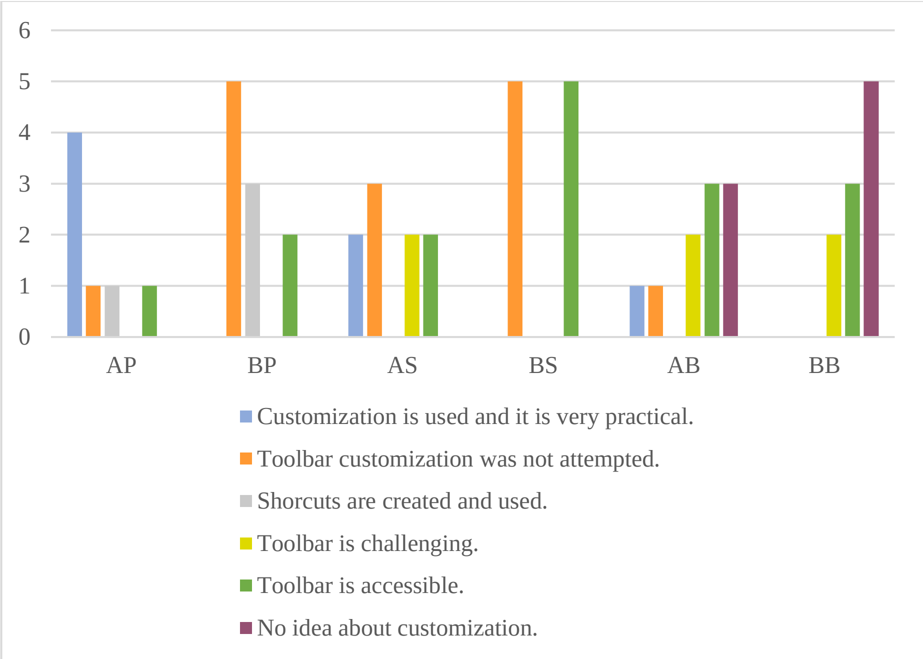

Figure 4.31. Tool accessibility and customization features of the software

The sixth question was asked to learn users' opinions about custom scripts and extensions. The answers to this question can be reviewed in Figure 4.32. While these features are not used in student groups yet, it is noteworthy that the use of plug-ins is common in professional groups in line with the needs in both software. There were BIM tool B professional users who stated that using scripts was beneficial.

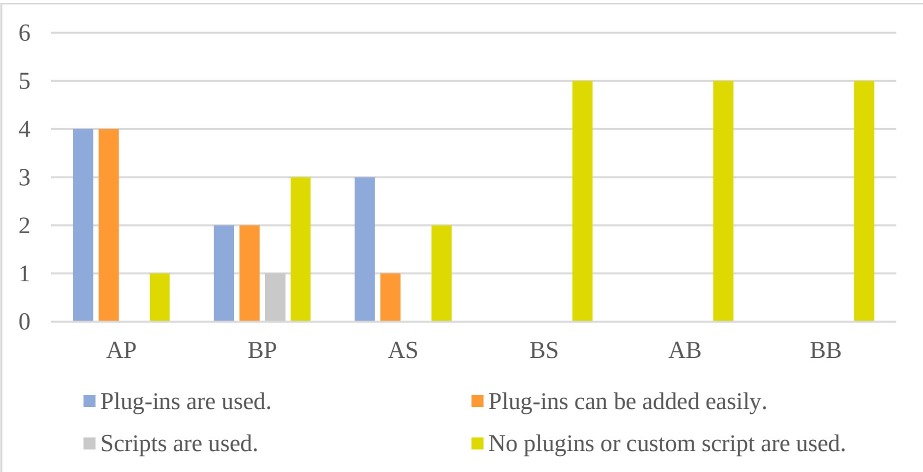

Figure 4.32. Custom script and extension feature of the software

The seventh question was about the performance and responsiveness of the software. In Figure 4.33 below the answers of the participants can be observed. Among professionals, there were users who felt that the interface had become heavy, and there were also users who stated that they did not encounter any problems. The performance of the software for both BIM tool A and BIM tool B was considered sufficient for intermediate level students, but there are different opinions among beginner level students.

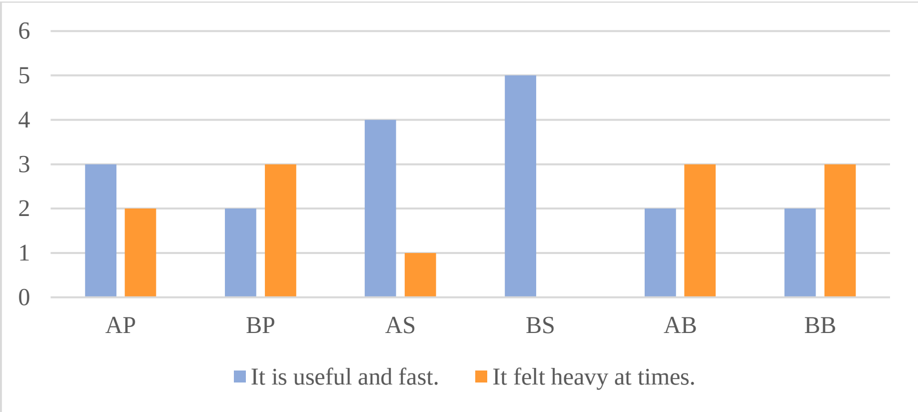

Figure 4.33. Performance and responsiveness of the software

Lastly, error handling and feedback features of the interface are asked the users, and the outcomes are shown in Figure 4.34.

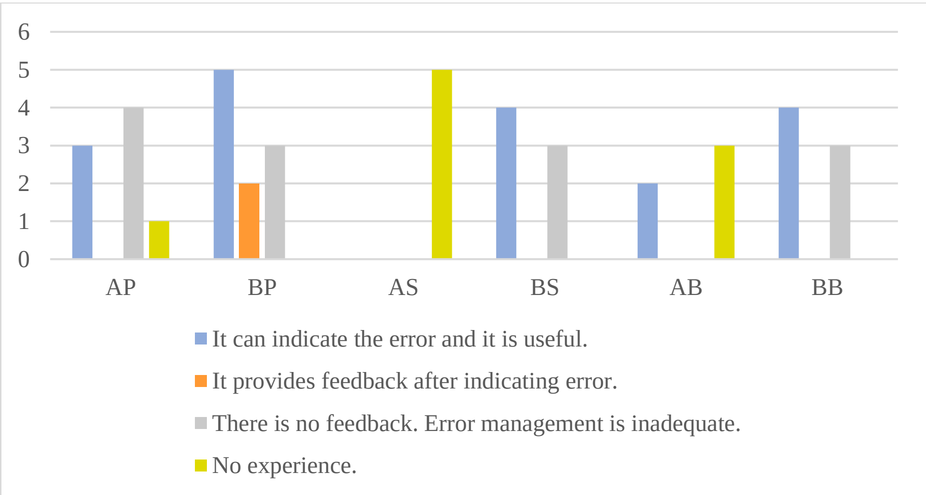

Figure 4.34. Error handling and feedback of the software

When the error handling performances of the software tools were evaluated, it was concluded among the professionals that the error handling of each software was useful, but the feedback was either not faced or insufficient. Although there is a useful tool that shows errors in BIM tool B, some users have emphasized that this needs to be improved. Some BIM tool A beginner students and BIM tool A intermediate level students have never encountered error reporting. The number of students receiving error notifications in BIM tool B is higher.

4.4 Discussion of Interview Results and Modeling Exercise Results

In the analysis conducted to compare the user experience and user interface differences of two different software, the performance data obtained through computer exercises and the feedback received from user interviews were evaluated together.

Firstly, it has been observed that tasks are completed in less time in one software compared to the other one in general. This analysis was combined with user reviews, leading the following conclusion: In BIM tool A where slower results are obtained, the interface is more complex, some commands are embedded within other commands, and the icons are small, which is challenging especially for beginner and intermediate level student users. Besides, menus located in different places on the interface require users to navigate in a larger area and reduce user efficiency. These cause users to navigate more on the interface and waste more time.

On the other hand, professional users state that when they feel they are wasting time on the computer provided to them, it is because they are used to the hotkey features on their personal computers. These comments are particularly relevant in software with nested commands. Although the default interface of this software requires more clicks than the other software, users benefit from the interface customization feature, which is seen as a positive attribute. This is also directly related to the excessive number of mouse clicks and keystrokes in the professionals' results.

While professionals reported similar adaptation times for both software programs, a significant number of beginner and intermediate level students indicated that it took them longer to become familiar with the user interface with smaller icons. These results emphasize the significance of icon sizes and their location in the interface.

In some tasks, results contrary to the average results were obtained. For example, professional users completed some tasks more slowly due to the habits of professionals such as double-checking their drawings by measuring manually.

Heat maps show that professional users have focused traces, and as their experience increases, users who find the target become more prominent. However, it appears that students are more practical and faster, especially in simple tasks, which consist of basic commands that do not require a professional approach. Additionally, student groups become more accustomed to the interface as they progress through the tasks.

Another aspect emphasized especially by student groups, that the interface affects users' perspectives. Specifically, the difficulty in easily modeling curvilinear elements influences their software preferences. The prevailing opinion is that the interface of both BIM software programs is not suitable for such structures.

The other result is that the interface that specifies references in tasks requiring object placement is more practical. Reference lines or measurements of the object's location shorten the duration of this process. When these features are not available, the user manually measures the location of the objects or tries to rearrange them using the move command.

Data obtained from hands-on modeling exercises have shown that both software programs are used effectively, especially among professional users. The interview results also confirm that professionals in both software expand the functions of the software by using plug-ins such as scripts and extensions, and that these features are useful for experienced users.

Moreover, as in the results of the two BIM software compared in this study, the performance and responsiveness is another important factor in users' software preferences.

In addition, almost all users stated that they did not find the error handling and feedback features of either software sufficient. Although some programs indicate to the user that there is an error, they do not provide specific guidance on how to resolve it. This feedback provides further insight into the ease of use and effectiveness of the software.

While computer exercise results include the actions users take during their interactions with the software, interviews provide a deeper understanding of how users perceive these experiences.

CHAPTER 5

CONCLUSIONS

In this chapter, the summary of the research and main outcomes of the thesis are stated.

5.1 Summary of the Research

The invention of personal computers and their undeniable widespread use have revealed the importance of human-computer interaction. This interaction is of great importance in how users approach the programs and the usability of the programs, especially in the software industry. Software companies aim to constantly improve this interaction through user interface designs to gain a greater place in the market and gain competitive advantage. These developments aim to make users' interaction with software more efficient and effective.

In this context, developments in the discipline of architecture and related technologies are particularly important. Building Information Modeling (BIM) software used in the architecture and construction sectors have more comprehensive and multidimensional features than traditional drawing tools. These programs play a critical role in the effective implementation of design, drawing and project management processes. In this context, the architectural community is of central importance in the use and development of BIM technologies.

This study discusses in detail the effects of technological developments on user experience and interface design and the role of BIM software in the discipline of architecture. The literature review has comprehensively examined existing studies and developments in this field. The comparative analysis of two different BIM tool was carried out on important parameters affecting the construction and architecture processes such as time, efficiency, and goal-oriented success.

The applied part of the study includes computer exercises and interviews conducted with professional architects and architecture students who actively use this two software. The obtained quantitative and qualitative data allowed the development of a new methodology for evaluating the user interfaces of architectural software. The various tasks performed by participants and the data recorded during these tasks provide valuable information about users' interactions with the software. Additionally, interviews and surveys revealed users' opinions and experiences about this two software and the positive or negative aspects of them. This study makes an important contribution to better understanding software use in the architecture and construction sectors and shaping future designs of user interface.

5.2 Main Outcomes

In the analysis conducted to compare the user interface and user experiences of two BIM software, the performance data obtained through computer exercises and the feedback received from user interviews were evaluated together. The main outcomes of the research are listed below:

1. The research found that BIM tools with small icons and with nested interfaces are impractical for beginner and intermediate students. These features may extend the adaptation process of the interface.
2. It is crucial for users that software with complex interface includes customization features. These features allow users to arrange the interface to their specific needs and preferences, thereby improving their efficiency and overall experience.
3. The menus spread across different parts of the interface again reduce efficiency and increase the time required for navigation.

4. Heat maps indicated that professional users had focused navigation patterns and became more proficient with experience. On the other hand, students aree quicker and more efficient in simple tasks and adapted to the interface as they progressed.
5. Users emphasized that the interface influenced their software preferences, especially on tasks involving complex shapes such as curvilinear elements, which they felt were lacking in both software tools.
6. Also noteworthy is the tendency of professionals in both software to extend the functions of the software by using plug-ins such as scripts and extensions. Professional users increase the modeling and detailing capabilities of the software by using these plug-ins effectively.
7. Error handling and feedback features are inadequate for users. Although some programs detected errors, they did not provide clear instructions for resolving them. This negatively affected overall usability and effectiveness.

5.3 Limitations

There are many factors that could limit this research. The first one is that participants perform tasks on the computer provided by the researcher. The research was conducted using the researcher's computer due to the installation of a lot of software on personal computers and permission problems. The limiting factor here is that the participants are more practical since they have habits and hotkeys on their personal computers. However, working on someone else's computer or even with mouse may have a restrictive effect on people.

The other limitation can be sample size and diversity of participants. The results are specific to a particular user group and new studies may be necessary to generalize to a general user population. In particular, the inclusion of users from different geographies, different cultural backgrounds, or professionals from different areas of expertise can increase the comprehensiveness of the results.

The difference between the experience levels of professional groups may be another limitation for this research. Since volunteer participants from private architectural offices were preferred, it was inevitable to work with different experience levels of professionals. However, comparing professional users with equal experience levels may provide different observations.

5.4 Recommendations

This study comprehensively examines the user experiences of two different BIM tools' interfaces and determines the effects of architectural design software on different user groups while proposing a new methodology. The findings provide important insights to make BIM software more user-friendly and enable the development of strategies to optimize the use of these software in architectural education and professional practice processes. From this perspective, this study can offer recommendations for future researches and software developers.

First, recommendations for software companies will be mentioned. The learning difficulty of nested interface was particularly noted by student groups. It is an important suggestion that software companies take their feedback into consideration and, if necessary, improve their training materials.

The following suggestions are for future studies. Users' evaluations of performance and responsiveness highlight the impact of the software's technical capabilities on the user experience. In future studies, it is recommended to examine the performance parameters of software in more detail and analyze the effects of these parameters on user experience.

Another recommendation for the future researches is that studying user groups with different experience levels, as well as users in various cultural and geographical contexts, will help us better understand how software performs globally and meets various user needs.

These suggestions will not only contribute to the literature but also provide the information necessary to improve the user experience of architectural software. The findings of this research may contribute to the design of more effective and accessible software interfaces, creating a valuable resource for software developers and educators.

REFERENCES

Albert, W., & Tullis, T. (2010). *Measuring the user experience*. San Francisco: Morgan Kaufmann.

Allen Consulting Group. (2010). *Productivity in the buildings network: assessing the impacts of Building Information Models.* Built Environment Innovation and Industry Council. Sydney. https://www.steel.org.au/getattachment/5244a9c8-0560-4331-8672-ffb24428dbec/BIMProductivity_FinalReport

Allplan. (n.d.). About Allplan. Retrieved March 13, 2024 from https://www.allplan.com/about-us/

Autodesk. (2002). *Building information modeling* [White paper]. Autodesk Building Industry Solutions. https://www.laiserin.com/features/bim/autodesk_bim.pdf

Autodesk. (n.d.). Overview. Retrieved December 12, 2023 from https://www.autodesk.com/products/revit/overview?term=1-YEAR&tab=subscription

Autodesk. (n.d.). Revit enhancement timeline. Retrieved December 12, 2023 from https://www.autodesk.com/customer-value/aec/revit

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and management in engineering*, 11(3), 241-252.

Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building Information Modeling (BIM): now and beyond. *Australasian Journal of Construction Economics and Building*, The, 12(4), 15-28.

Azhar, S., Nadeem, A., Mok, J. Y., & Leung, B. H. (2008). building information modeling (BIM): A new paradigm for visual interactive modeling and simulation for construction projects. In Proc., *First International Conference on Construction in Developing Countries* (Vol. 1, pp. 435-46).

Azhar, S., & Richter, S. (2009). Building information modelling (BIM): case studies and return on investment analysis. In *Proceedings of the 5th International Conference on Construction in the 21st Century* (pp. 1378-1386).

Badashian, A. S., Mahdavi, M., & Pourshirmohammadi, A. (2008). Fundamental usability guidelines for user interface design. In *2008 International Conference on Computational Sciences and Its Applications* (pp. 106-113). IEEE.

Bain, D. (2020). Summary of findings from the tenth annual BIM survey. *10th Annual BIM Report; Waterhouse, R., Ed.; NBS: Newcastle upon Tyne, UK,* 15-29.

Borkowski, A. S. (2023). Evolution of BIM: epistemology, genesis, and division into periods. *Journal of Information Technology in Construction,* 28.

Boston Consulting Group. (2016). *The transformative power of building information modeling.* Retrieved December 10, 2023, from https://www.bcg.com/publications/2016/engineered-products-infrastructure-digital-transformative-power-building-information-modeling

Britannica, T. Editors of Encyclopaedia (2023). Cathode-ray Tube. Encyclopedia Britannica. Retrieved December 14, 2023, from https://www.britannica.com/technology/cathode-ray-tube

Carmona, J., & Irwin, K. (2007). BIM: Who, what, how and why. *Building Operating Management*, 54(10), 37-39.

CIFE. (November 22, 2007). CIFE Technical Reports. Retrieved December 25, 2023, from http://cife.stanford.edu/Publications/index.html

CRC Construction Innovation (2007) Adopting BIM for facilities management: Solutions for managing the Sydney Opera House. *Cooperative Research Center for Construction Innovation, Brisbane, Australia*.

Czmoch, I. & Pękala, A. (2014). Traditional design versus BIM based design. Procedia Engineering, 91, 210–215. https://doi.org/10.1016/j.proeng.2014.12.048

Darejeh, A., & Singh, D. (2013). A review on user interface design principles to increase software usability for users with less computer literacy. *Journal of Computer Science*, 9(11), 1443.

Eastman, C. M. (2018). *Building product models: computer environments, supporting design and construction* (p.35-36). CRC press.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors* (2nd ed.). John Wiley & Sons. https://doi.org/10.1002/9781119287568

Fu, F. (2018). *Design and analysis of tall and complex structures*. Butterworth-Heinemann. https://doi.org/10.1016/C2015-0-06071-3

Gero, J. (1976). *Computer applications in architecture*. Elsevier.

Glick, S., & Guggemos, A. (2009). IPD and BIM: benefits and opportunities for regulatory agencies. In *Proceedings of the 45th ASC National Conference, Gainesville, Florida, April* (Vol. 2, No. 4).

Gould, J. D., & Lewis, C. (1985). Designing for usability: key principles and what designers think. *Communications of the ACM*, 28(3), 300-311.

Graphisoft. (n.d.). *The ARCHICAD User Interface*. Graphisoft Help Center. Retrieved, December 20, 2023, from https://helpcenter.graphisoft.com/user-guide/76215/

Graphisoft. (n.d.). What is Archicad. Retrieved December 12, 2023 from https://community.graphisoft.com/t5/Getting-started/What-is-Archicad/ta-p/304208

Guan, J. C., Yam, R. C., & Mok, C. K. (2005). Collaboration between industry and research institutes/universities on industrial innovation in Beijing, China. *Technology Analysis & Strategic Management*, 17(3), 339-353. http://dx.doi.org/10.1080/09537320500211466

Hardin, B., & McCool, D. (2015). *BIM and construction management: proven tools, methods, and workflows*. John Wiley & Sons.

Hewett, T. T., Baecker, R., Card, S., Carey, T., Gasen, J., Mantei, M. & Verplank, W. (1992). *ACM SIGCHI curricula for human-computer interaction*. ACM.

Hosch, W. L. (2023). Ivan Sutherland. Encyclopedia Britannica. Retrieved December 13, 2023, from https://www.britannica.com/biography/Ivan-Sutherland

Inan Nur, A., B. Santoso, H., & O. Hadi Putra, P. (2021). The method and metric of user experience evaluation: a systematic literature review. *In 2021 10th International Conference on Software and Computer Applications* (pp. 307-317).

Ingram, J. (2020). *Understanding BIM: The past, present and future*. Routledge.

International Organization for Standardization. (1998). *Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs), Part 11: Guidance on Usability* (ISO Standard No. 9241-11).

International Organization for Standardization. (2001). *Information Technology, Software Product Evaluation, Quality Characteristics and Guidelines for their Use* (ISO Standard No. 9126).

Jiang, H. J., Cui, Z. P., Yin, H., & Yang, Z. B. (2021). BIM performance, project complexity, and user satisfaction: a QCA study of 39 cases. *Advances in Civil Engineering*, 2021, 1-10.

Joseph, S., Sasikumar, R., & Anil, M. (2020). Application of building information modeling for an institutional building. *International Journal of Engineering Research & Technology,* 9(7), 1267-1281. https://doi.org/10.17577/IJERTV9IS070107

Kmethy, G. (2023, September 27). Archicad versions. Graphisoft Community. Retrieved November 20, 2023, from, https://community.graphisoft.com/t5/Getting-started/Archicad-versions/ta-p/304207

Krygiel, E., & Vandezande, J. (2014). *Mastering Autodesk Revit architecture 2015.* John Wiley & Sons.

Kubba, S. (2012). *Handbook of green building design and construction.* Elsevier. https://doi.org/10.1016/C2009-0-64483-4

Ku, K., & Taiebat, M. (2011). BIM experiences and expectations: the constructors' perspective. *International Journal of Construction Education and Research*, 7(3), 175-197.

Kymmell, W. (2008). *Building information modeling.* McGraw Hill LLC.

Levchenko, O., & Kashchenko, T. (2017). Expert systems in the BIM environment. *INTERSECTII/INTERSECTIONS*, *14*(1), 85-94.

Liu, S., Xie, B., Tivendale, L., & Liu, C. (2015). The driving force of government in promoting BIM implementation. *Journal of Management and Sustainability*, 5, 157. https://doi.org/10.5539/jms.v5n4p157

Luciani, C., Garagnani, S., & Mingucci, R. (2012). BIM tools and design intent. Limitations and opportunities. *Practical BIM*, 19-29.

Lu, W., Peng, Y., Shen, Q., & Li, H. (2013). Generic model for measuring benefits of BIM as a learning tool in construction tasks. *Journal of Construction Engineering and Management*, 139(2), 195-203.

Maina, J. (2018). CAD and BIM in architecture education: awareness, proficiency, and advantages from the student perspective. *Gazi University Journal of Science Part B: Art Humanities Design and Planning*, 6(4), 167-178.

Macleod, M., & Rengger, R. (1993). The development of DRUM: A software tool for video-assisted usability. *People and Computers* VIII, (7), 293.

Martens, B. & Peter H. (2007). *Archicad: Best practice: The virtual BuildingTM revealed.* (Second, Revised Edition). SpringerWienNewYork.

McGraw-Hill Construction. (2012). *The business value of BIM in North America.* Bedford, MA:McGraw-Hill.

Miraz, M. H., Ali, M., & Excell, P. S. (2021). Adaptive user interfaces and universal usability through plasticity of user interface design. *Computer Science Review*, 40, 100363.

Murphy, M., Meegan, E., Keenaghan, G. N., Chenaux, A., Corns, A., Fai, S., Chow, L., Zheng, Y., Dore, C., Scandurra, S., Tierney, A., Diara, F., Rinaudo, F., & Prizeman, O. (2021). Shape grammar libraries of european classical architectural elements for historic BIM. *International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences*, XLVI-M-1-2021, 479-486. https://doi.org/10.5194/isprs-archives-XLVI-M-1-2021-479-2021

Myers, B. A., & Rosson, M. B. (1992). Survey on user interface programming. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 195-202).

National BIM Standard-United States® V3. (n.d.). Retrieved November 11, 2023, from https://www.nationalbimstandard.org/nbims-us-v3

Nielsen, J. (1992). The usability engineering life cycle. *Computer,* 25(3), 12-22.

Nielsen, J. (1994). *Usability engineering*. Morgan Kaufmann.

Onur, A. Z., & Nouban, F. (2019). Software in the architectural presentation and design of buildings: State-of-the-art. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, 8(10).

Park, D. Y., Choi, J., Ryu, S., & Kim, M. J. (2022). A user-centered approach to the application of BIM in smart working environments. *Sensors*, 22(8), 2871.

Pikas, E., Sacks, R., & Hazzan, O. (2013). Building information modeling education for construction engineering and management. II: Procedures and implementation case study. *Journal of Construction Engineering and Management*, 139(11), 05013002.

Preece, J., Rogers, Y., Sharp, H., Benyon, D., Holland, S., & Carey, T. (1994). *Human-computer interaction.* Addison-Wesley Longman Ltd.

Pyfer, J. (2017). Sketchpad. Encyclopedia Britannica. Retrieved December 13, 2023, from https://www.britannica.com/technology/Sketchpad

Ramilo, R., & Embi, M. R. B. (2014). Critical analysis of key determinants and barriers to digital innovation adoption among architectural organizations. *Frontiers of Architectural Research*, 3(4), 431-451.

Reynolds, R. A. (2014). *Computer methods for architects*. Butterworth-Heinemann.

Sauro, J., & Lewis, J. R. (2016). *Quantifying the user experience: Practical statistics for user research.* Morgan Kaufmann.

Seffah, A., Donyaee, M., Kline, R. B., & Padda, H. K. (2006). Usability measurement and metrics: A consolidated model. *Software quality journal*, 14, 159-178.

Seffah, A., Kececi, N., & Donyaee, M. (2001). QUIM: a framework for quantifying usability metrics in software quality models. In *Proceedings second asia-pacific conference on quality software* (pp. 311-318). IEEE.

Shneiderman, B. (1992). *Designing the user interface: Strategies for effective human-computer interaction*. Addison-Wesley.

Shneiderman, B., Plaisant, C., Cohen, M., Jacobs, S., Elmqvist, N., & Diakopoulos, N. (2016). *Designing the user interface: strategies for effective human-computer interaction*. Pearson.

Shaan, H. (2019) Revit timeline from 1.0 to 2019.2. Retrieved October 15, 2023, from https://autodesk.blogs.com/between_the_lines/2019/02/revit-timeline-from-10-to-20192.html

Shackel, B., & Richardson, S. J. (Eds.). (1991). *Human factors for informatics usability.* Cambridge university press.

Singh, V., Gu, N., & Wang, X. (2011). A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in construction*, 20(2), 134-144.

Software Informer. (n.d.). Nemetschek Allplan versions. Retrieved March 10, 2024, from https://nemetschek-allplan.software.informer.com/versions/

Sperber, K. (2007). *Archicad 10*. United Kingdom: Pearson.

Stine, D.J. (2023). *Design integration using Autodesk Revit 2023: Architecture, structure, and MEP*. Mission, KS: SDC Publications.

Toan, N. Q., Anh, P. X., & Tam, N. V. (2022). Trends in BIM tools adoption in construction project implementation: A case study in Vietnam. In *Proceedings of FORM 2022: Construction the Formation of Living Environment* (pp. 9-19). Cham: Springer International Publishing.

Tommasi, C., & Achille, C. (2017). Interoperability matter: Levels of data sharing, starting from a 3D information modelling. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42, 623-630.

Tse, T. C. K., Wong, K. D. A., & Wong, K. W. F. (2005). The utilisation of building information models in nD modelling: a study of data interfacing and adoption barriers. *Journal of information technology in construction (ITcon)*, *10*(8), 85-110.

Van Nederveen, G. A., & Tolman, F. P. (1992). Modelling multiple views on buildings. *Automation in Construction*, 1(3), 215–224. https://doi.org/10.1016/0926-5805(92)90014-B

Visual Studio Code. (n.d.). Learn to code with Visual Studio Code. Retrieved July 12, 2023 from https://code.visualstudio.com/docs/python/python-tutorial

von Both, P. (2012). Potentials and barriers for implementing BIM in the German AEC market. *Results of a current market analysis*, 2, 151-158.

Waas, L. (2022). Review of BIM-based software in architectural design: Graphisoft Archicad vs Autodesk Revit. *Journal of Artificial Intelligence in Architecture*, 1(2), 14-22. https://doi.org/10.24002/jarina.v1i2.6016

Xie, J., Jiang, D., Bao, Z., & Zhou, P. (2018, August). BIM Application Research of Assembly Building Design: Take ALLPLAN as an Example. In *International Conference on Construction and Real Estate Management 2018* (pp. 138-147). Reston, VA: American Society of Civil Engineers.

Zhao, D., McCoy, A. P., Bulbul, T., Fiori, C., & Nikkhoo, P. (2015). Building collaborative construction skills through BIM-integrated learning environment. *International Journal of Construction Education and Research*, 11(2), 97-120.

Zelazko, A. (2023, November 10). RGB colour model. Encyclopedia Britannica. Retrieved December 14, 2023, from https://www.britannica.com/science/RGB-colour-model

APPENDICES

A. DOCUMENT PROVIDED FOR HANDS-ON COMPUTER EXERCISES

Please complete the tasks given below, in BIM tool A/BIM tool B.

1. TASK-1:

Please model a wall 350 cm high and 700 cm long on any edge of the slab in the given model. It is recommended to use a generic/default wall type, do not create a new wall type.

2. TASK-2:

Please create the layers in the order specified below on the given wall model. Create a new wall type and name it as “W”.

From INTERIOR to EXTERIOR:

- Plaster (2 cm)
- Brick Wall (25 cm)
- Mineral Wool/ Rock Wool (8 cm) (material is unimportant, you can use any type of thermal insulation)
- Exterior Plaster (3 cm)

3. TASK-3:

Please add two aluminum/metal windows fixed windows size of 150x200cm on the given wall model. Please create a new window type for this exercise by naming “P”. Sill height is unimportant. However, you need to center them on the wall leaving an equal distance from the edges.

4. **TASK-4:**

Please add an aluminum/metal door size of 110x220cm on the given wall model. Please create a new door type for this exercise by naming “K”. You need to center it on the wall leaving an equal distance from the edges.

5. **TASK-5:**

Please model a 700x500 cm floor in the specified area. It is recommended to use a generic/default floor type, do not create a new wall type.

6. **TASK-6:**

Please create layers in the order specified below on the given floor model:

From TOP to BOTTOM:

- Ceramic Tile (2 cm)
- Waterproofing Layer (material is unimportant, you can use any type of waterproof material)
- Screed (5 cm)
- Reinforced Concrete (20 cm)

B. INTERVIEW QUESTIONS AND ANSWERS

1. Experience of the Participants

QUESTION:

How long have you been using BIM tool A/ BIM tool B?

ANSWERS:

- AP1: 6 years of experience as an architect, has been using BIM tool A for 5 years.
- AP2: 6 years of experience as an architect, has been using BIM tool A for 1 year.
- AP3: 20 years of experience as an architect, has been using BIM tool A for 16 years.
- AP4: 4 years of experience as an architect, has been using BIM tool A for 1 year.
- AP5: 8 years of experience as an architect, has been using BIM tool A for 12 years. (It was stated that it was not used continuously)
- BP1: 10 years of experience, has been using BIM tool B for 3 years. (It was stated that it was not used continuously)
- BP2: 2 years of experience as an architect, has been using BIM tool B for 4 years (including as a student, 6 months as a professional)
- BP3: 4 years of experience as an architect, has been using BIM tool B for 4 years.
- BP4: 18 years of experience, 8 years of experience using BIM tool B.
- BP5: 4 years of experience as an architect, has been using BIM tool B for 6 years (including as a student)
- AS1, AS2, AS3, AS4, AS5: 3rd year Architecture student, has been using BIM tool A for about 8 months.

- BS1, BS2, BS3, BS4, BS5: 3rd year Architecture student, has been using BIM tool B for about 8 months.
- AB1, AB2, AB3, AB4, AB5: 2nd year Architecture student, has been using BIM tool A for about one and a half months.
- BB1, BB2, BB3, BB4, BB5: 2nd year Architecture student, has been using BIM tool A for about one and a half months.

2. Usability and Learning Process of the Software

QUESTION:

How would you describe your initial experience with learning the user interface of BIM tool A/ BIM tool B?

ANSWERS:

- AP1: It is stated that it adapts in a few weeks. Since BIM tool B was used before, it was learned quickly. It is stated to be user-friendly.
- AP2: Learned in approximately a month. It was emphasized that it was easy to remember in the profession because it was learned as a student.
- AP3: BIM tool A was first used in 2D. For this reason, when we switched to 3D, it adapted very quickly. It is stated that it is very practical.
- AP4: Learned in approximately in a month.
- AP5: Mastered the interface in a few weeks.
- BP1: It took about two months to learn. It was learned in a 2-month course when she was a student.
- BP2: Mastered the interface in 1-2 months.
- BP3: It took about 3-4 months to get used to it.
- BP4: Adapted to the interface in a week. Knowledge of the interface has increased over time.
- BP5: It took about 1-2 months to learn while he was a student.

- AS1: It was stated that it takes a few weeks to learn and is user-friendly software.
- AS2: It was mentioned that it is difficult first to adapt to the interface. However, it gets easier over time and takes a few weeks to adapt.
- AS3: It was said that it has an easy-to-learn interface and can be adapted in a few weeks.
- AS4: Since similar software were used before by the user, it was more difficult to adapt. However, adapted approximately in a month.
- AS5: It is thought to be not practical software and took a few weeks to learn.
- BS1: It was said that it is easy to learn and can be adapted in a few weeks.
- BS2: This student also mentioned that it has an easy-to-learn interface and can be adapted in a few weeks.
- BS3: It took about 1-2 months to learn.
- BS4: The software was adapted about a month.
- BS5: The software was leant in a few weeks.
- AB1: No opinions stated as it is still in the learning phase.
- AB2: It was stated that the learning process was easier in BIM tool B, and that BIM tool A's interface limited access to tools within each other.
- AB3: It has been stated that BIM tool B's interface is easier to adapt to.
- AB4: It is said that BIM tool A's interface is easier to learn, while BIM tool B's is more complex.
- AB5: It has been stated that BIM tool B's interface is easier to learn.
- BB1: It is said that BIM tool A's interface is easier to learn.
- BB2: No opinions stated as it is still in the learning phase.
- BB3: It is said that BIM tool A's interface is easier to learn, while BIM tool B's is more complex.
- BB4: It is said that BIM tool B's interface is easier to learn.
- BB5: It has been said that BIM tool B is easier to adapt to, but BIM tool A is easier with some tools.

3. **Knowledge of the Software**

QUESTION:

How well do you think you know the software?

ANSWERS:

- AP1, AP3: Advanced level
- AP2, AP4, AP5: Intermediate level
- BP1: Intermediate level
- BP2, BP3, BP4: Advanced level
- BP5: Intermediate- Advanced level
- AS1, AS2, AS5: Beginner-Intermediate level
- AS3: Beginner level
- AS4: Intermediate level
- BS1, BS2, BS3, BS5: Intermediate level
- BS4: Beginner-Intermediate level
- AB1, AB2, AB3, AB4, AB5: Beginner level
- BB1, BB2, BB3, BB4, BB5: Beginner level

4. **Modeling Flexibility**

QUESTION:

As an architect, do you have confidence that BIM tool A/ BIM tool B interface will allow you to make any arrangement you want?

ANSWERS:

- AP1: It was worked with circular forms but thinks that linear structures can be modeled easily.
- AP2: It worked with circular forms but thinks that linear structures can be modeled easily.

- AP3: The needs of the user in professional practice have been met by the software so far. However, it has been experienced that it is not sufficient in curvilinear forms.
- AP4: The interface was thought that is suitable for design. She was able to create the elements she wanted to model without any problems. However, it was stated that she had some hesitations about organic forms.
- AP5: There is hesitation in using organic forms and other tools are preferred.
- BP1: It was not preferred to be used during the design phase. It is used in the later stages of projects.
- BP2: It was stated that the project was generally successful but was lacking in terms of presentation skills.
- BP3: It has been stated that there are difficulties with organic forms.
- BP4: The user faced with no limitations so far. However, any deficiencies encountered have been resolved with add-ons.
- BP5: It is stated that the software provides confidence.
- AS1: There are difficulties in modeling curvilinear elements. Linear modeling is flexible.
- AS2: Thought that difficult to create organic forms.
- AS3: Sometimes feels limited, especially in curved edges, curvilinear forms etc.
- AS4: Thought that hard to model curve forms.
- AS5: There are concerns about whether modeling the building element type is expressed correctly.
- BS1: It is thought to restrict the design phase. Other software are preferred for complex forms.
- BS2: It is thought to restrict the design phase. It is not used in complex forms.
- BS3: It is considered restrictive for organic forms and other software are preferred.
- BS4: Thought that hard to model curve forms.
- BS5: Considered restrictive for organic forms.

- AB1: It is seen as restrictive. It is thought to be suitable for more rigid forms, especially those that would be difficult in curvilinear forms.
- AB2: Thought that hard to model curve forms.
- AB3: It gives confidence for all kinds of modelling, and it is thought that it will improve as you learn.
- AB4: It has been stated that tools such as topography do not feel safe.
- AB5: Considered restrictive for organic forms.
- BB1: Thought that hard to model curve forms.
- BB2: It is seen as restrictive. It is thought to be suitable for more rigid forms, especially those that would be difficult in curvilinear forms.
- BB3: It gives confidence for all kinds of modelling, and it is thought that it will improve as you learn.
- BB4: It gives confidence for all kinds of modelling, and it is thought that it will improve as you learn.
- BB5: Thought that hard to model curve forms.

5. **Tool Accessibility and Customization**

QUESTION:

In terms of tool accessibility and customization, how do the interface of BIM tool A/ BIM tool B fulfill to your specific needs as an architect?

ANSWERS:

- AP1: Toolbar customization is used extensively. Users save their own schematics, and even if they change computers, they can open this schematic on another computer and use their own customized interface in the office.
- AP2: Customization was used, it was stated that it met the needs.
- AP3: It is stated that it is very practical in terms of customization and accessibility.

- AP4: Customization is used, it is stated that the software is very suitable for customization. Hotkeys are also used.
- AP5: Tool accessibility is found practical, but customization is not used, the current version is sufficient for the user.
- BP1: Its own interface was found practical and no need for customization was felt.
- BP2: Hotkeys were created and used; toolbar customization was not attempted.
- BP3: Hotkeys were created and used; toolbar customization was not attempted.
- BP4: Since it is thought that it is not very practical, the toolbar has not been customized. Hotkeys have been created on the keyboard.
- BP5: It is stated that the original version is sufficient.
- AS1: Thought that sometimes hard to find commands, the icons are too small. But customization is used and find it useful.
- AS2, AS4: Accessibility is OK. Customization did not use.
- AS3: Customization is used and found practical.
- AS5: Not seeing the icons is sometimes difficult. Customization did not use.
- BS1: The fact that it contains icons is quite self-explanatory. No customization used.
- BS2: Its interface is quite practical. No customization used.
- BS3: Adequate and accessible. There was no need for customization.
- BS4: Interface is enough, little adjustment was made.
- BS5: Found adequate and accessible. There was no need for customization.
- AB1: It is still difficult to get used to the interface.
- AB2: The menu on the left is especially useful. Customization has been tried and found useful.
- AB3: Since the tools are nested and detailed, they are difficult to access. No idea about customization.

- AB4: Editing some settings can be time-consuming, but overall, they are easily accessible. No idea about customization.
- AB5: It gets easier as you learn the toolbar. No idea about customization.
- BB1: The toolbar is quite accessible. No idea about customization.
- BB2: Toolbar is challenging at times. No idea about customization.
- BB3: The toolbar is quite accessible. No idea about customization.
- BB4: Toolbar is challenging at times. No idea about customization.
- BB5: The toolbar is quite accessible. No idea about customization.

6. Custom Scripts and Extensions

QUESTION:

Have you used any custom scripts or extensions within BIM tool A/ BIM tool B? How user-friendly do you find the interface for implementing these enhancements?

ANSWERS:

- AP1: Some of the Plug-ins are used in the project. No custom script was used.
- AP2: Plug-in can be added, it is thought to be convenient.
- AP3: Plugins were used, no problems occurred. No special command was used.
- AP4: No plugins or special commands are used.
- AP5: Some Plug-ins were used, support of the producer company was found sufficient in this sense. However, the scripts were not used.
- BP1: No plugins or custom script are used.
- BP2: No plugins or custom script are used.
- BP3: Plug-ins are very useful. The interface is compatible.
- BP4: Scripts and plugins are used when needed. A special Plug-in was written. Found the software very suitable for these adjustments.
- BP5: No plugins or special commands are used.
- AS1: Plug-in was used but it was very difficult to edit.

- AS2: Only rendering plug-ins were used, which was useful.
- AS3: Limited Plug-ins is used and thinks that it is user friendly in terms of plug-ins.
- AS4, AS5: Not used. No idea.
- BS1, BS2, BS3, BS4, BS5: Not used. No idea.
- AB1, AB2, AB3, AB4, AB5: Not used. No idea.
- BB1, BB2, BB3, BB4, BB5: Not used. No idea.

7. Performance and Responsiveness of the Software

QUESTION:

How do you find the performance and responsiveness of the interface in BIM tool A/ BIM tool B, especially for complex projects?

ANSWERS:

- AP1: Sometimes 2D elements in the project cause the model to become heavier. However, when the right techniques are used in 3D modeling, the model does not enlarge unnecessarily.
- AP2: No problems were experienced; modeling performance was stated to be good.
- AP3: It is stated that it is very practical and not bulky.
- AP4: There were no problems while working in plan and section, but it was stated that it may occur in 3D from time to time.
- AP5: It is stated that it has a very smooth interface.
- BP1: It felt heavy at times.
- BP2: There was no problem.
- BP3: It is useful and fast.
- BP4: When other models are placed inside, it starts to move slowly.
- BP5: It is not always sufficient; it is considered a heavy software.
- AS1: Think that performance is good.

- AS2: Not slow.
- AS3: Not a heavy software, very convenient.
- AS4: Sometimes a slowdown was felt when closing a command.
- AS5: Think that performance is good, fast.
- BS1: Not faced with such problem.
- BS2, BS3: No problem occurred.
- BS4: Better performance.
- BS5: Thought that fast.
- AB1: Sometimes a slowdown.
- AB2: It felt heavy at times.
- AB3: There was no problem.
- AB4: It felt heavy at times.
- AB5: There was no problem.
- BB1: Think that performance is good, fast.
- BB2: It felt heavy at times.
- BB3: Think that performance is good, fast.
- BB4: It felt heavy at times.
- BB5: It felt heavy at times.

8. Error Handling and Feedback

QUESTION:

How do the interface of BIM tool A/ BIM tool B handle errors or provide feedback during your design process? Are these features helpful?

ANSWERS:

- AP1: It was stated that it was generally not successful in handling errors and providing feedback. However, in some cases where error warnings are given, elements are indicated by coloring on the model, and this is stated to be a positive feature.

- AP2: It is stated that it can indicate the error but does not give feedback regarding its solution.
- AP3: It has not been experienced to provide feedback on errors.
- AP4: Errors are not encountered very often. In some cases, faulty elements are indicated by coloring on the model, but there is no feedback.
- AP5: Error management and feedback are thought to be inadequate. It was stated that it was a feature that needed to be improved.
- BP1: It is stated that it gives a warning and indicates the source of the error and how to solve it, and that this is sufficient.
- BP2: Error management is not very positive. Solutions are searched on the Internet. However, it shows the error which seems a positive aspect.
- BP3: The errors shown at the beginning were difficult to understand, but he was able to find solutions to the errors by discovering them himself.
- BP4: There are some regular errors, it provides feedback on many issues. It has average success.
- BP5: It is useful to show errors. However, it is not always enough.
- AS1: Guidance for error management has not been encountered very often.
- AS2, AS3, AS4, AS5: Not faced with errors. Thinks that is not efficient.
- BS1: Error handling is found useful.
- BS2: Although it reports an error, it is thought to not provide any feedback.
- BS3: Error reporting and “show” command are useful.
- BS4: Error handling is successful, but feedback is not sufficient.
- BS5: Error handling is not sufficient.
- AB1: Error handling is found useful.
- AB2: Not faced with errors. Thinks that is not efficient.
- AB3: Not faced with errors. Thinks that is not efficient.
- AB4: Thinks that is efficient.
- AB5: Not faced with errors. Thinks that is not efficient.
- BB1: Error handling is successful, but feedback is not sufficient.

- BB2: Error handling is successful, but feedback is not sufficient.
- BB3: Thinks that is efficient.
- BB4: Thinks that is efficient.
- BB5: Feedback is not sufficient.

C. RESULTS OF THE HANDS-ON EXERCISES

C.1 Individual Results of Tasks

Table C.1 Results of BIM tool B professionals in Task-1

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP1	42	4,439	33537,1	11	0	12	2	3
BP2	95	1,501	46766,15	31	0	14	2	6
BP3	39	7,778	16981	10	0	5	4	3
BP4	48	3,04	27146,87	12	1	10	0	6
BP5	113	7,598	40420,43	34	1	16	0	13

Table C.2 Results of BIM tool A professionals in Task-1

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AP1	65	6,127	33856,44	23	1	10	1	3
AP2	117	4,418	87309,96	40	1	12	2	6
AP3	43	3,779	19768,4	14	0	8	2	6
AP4	66	3,361	21685,09	16	0	7	3	6
AP5	55	1,428	15617,69	12	1	2	0	8

Table C.3 Results of BIM tool B intermediate level students in Task-1

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BS1	25	2,994	27455,57	8	0	4	0	3
BS2	40	5,5	22346,26	11	0	6	0	3
BS3	71	3,263	28825,1	29	0	2	2	5
BS4	71	7,878	31794,85	9	0	10	0	2
BS5	106	5,072	35094,19	27	0	4	0	4

Table C.4 Results of BIM tool A intermediate level students in Task-1

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AS1	142	1,803	41228,19	41	1	7	0	3
AS2	96	2,005	40939,78	22	0	12	0	3
AS3	98	1,846	41252,6	34	2	11	0	2
AS4	158	5,32	44554,58	58	0	6	0	12
AS5	50	3,786	26479,99	18	0	5	0	6

Table C.5 Results of BIM tool B beginner level students in Task-1

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BB1	96	3,933	30256,71	33	1	2	2	3
BB2	37	2,543	18949,95	11	0	6	0	4
BB3	192	11,379	51273,68	47	0	14	0	6
BB4	58	5,752	30621,53	11	0	3	0	6
BB5	83	5,82	31851,57	31	0	4	0	1

Table C.6 Results of BIM tool A beginner level students in Task-1

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AB1	117	4,214	30167,08	36	3	1	0	6
AB2	83	1,812	32930,91	23	0	6	0	7
AB3	118	5,744	47000,96	38	0	5	0	3
AB4	93	7,329	55319,12	39	1	2	0	3
AB5	126	2,629	37681,69	23	0	11	0	2

Table C.7 Results of BIM tool B professionals in Task-2

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP1	174	1,328	52015,58	56	1	3	23	3
BP2	189	1,085	53212,49	64	0	22	32	5
BP3	154	1,457	40492,18	39	3	33	81	5
BP4	172	2,064	64693,49	84	6	15	35	6
BP5	121	1,853	30983,54	44	0	35	1	4

Table C.8 Results of BIM tool A professionals in Task-2

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AP1	120	5,529	42037,66	64	0	22	2	5
AP2	220	2,093	77196,44	79	2	7	9	6
AP3	81	4,713	29974,04	44	2	4	0	5
AP4	343	6,268	89140,36	84	1	25	46	4
AP5	183	1,409	41997,12	64	1	18	16	3

Table C.9 Results of BIM tool B intermediate level students in Task-2

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BS1	125	6,295	43792,91	87	0	6	33	3
BS2	198	4,867	32256,44	62	0	22	32	8
BS3	220	2,422	42429,76	73	0	16	22	5
BS4	188	3,974	57003,48	54	0	15	39	4
BS5	221	2,556	48737,95	80	0	3	6	14

Table C.10 Results of BIM tool A intermediate level students in Task-2

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AS1	299	0,174	76621,18	109	3	51	61	7
AS2	353	0,918	94450,36	104	3	21	15	8
AS3	256	0,666	61741,97	84	2	17	20	5
AS4	208	3,544	59763,06	72	0	9	2	6
AS5	182	2,886	66989,76	57	2	15	5	5

Table C.11 Results of BIM tool B beginner level students in Task-2

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BB1	219	2,763	39155,59	72	0	13	47	4
BB2	161	0,817	43995,15	84	0	14	32	5
BB3	297	1,804	38926,03	104	0	2	11	6
BB4	226	1,701	65165,72	67	3	15	24	5
BB5	247	2,443	55644,48	86	0	7	28	5

Table C.12 Results of BIM tool A beginner level students in Task-2

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AB1	318	8,525	64178,52	109	7	2	1	8
AB2	228	9,747	62685,19	64	0	10	1	5
AB3	231	2,232	64911,12	92	0	8	11	5
AB4	258	1,926	66973,94	100	5	10	16	5
AB5	203	0,319	38841,26	58	1	2	0	5

Table C.13 Results of BIM tool B professionals in Task-3

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP1	129	5,382	39332,15	33	0	9	22	6
BP2	86	2,517	28761,87	36	0	5	6	8
BP3	147	2,517	61476,61	55	1	24	12	21
BP4	114	2,449	49358,04	37	0	12	10	12
BP5	113	8,119	32751,47	31	0	16	8	8

Table C.14 Results of BIM tool A professionals in Task-3

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AP1	101	6,283	35868,78	39	1	24	5	18
AP2	239	0,87	86536,35	70	2	85	27	16
AP3	49	1,401	16208,41	15	0	12	3	9
AP4	136	3,398	32262,57	23	1	19	8	12
AP5	119	9,681	28635,54	26	0	14	3	10

Table C.15 Results of BIM tool B intermediate level students in Task-3

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BS1	59	3,661	25563,27	34	0	3	13	6
BS2	139	4,52	39544,21	37	0	4	17	6
BS3	104	6,628	31223,54	36	0	15	12	9
BS4	173	2,669	52314,97	48	0	14	8	4
BS5	158	3,258	47960,61	55	0	1	10	13

Table C.16 Results of BIM tool A intermediate level students in Task-3

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AS1	331	1,646	124192,84	120	8	24	9	3
AS2	330	1,996	110164,47	102	8	32	0	18
AS3	331	1,389	87460,84	90	2	30	0	6
AS4	229	6,79	65980,47	65	0	14	0	15
AS5	335	1,785	131372,39	121	2	55	1	10

Table C.17 Results of BIM tool B beginner level students in Task-3

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BB1	139	3,356	38161,86	34	1	1	11	5
BB2	108	4,997	29321,17	30	0	10	20	6
BB3	117	9,705	18440,37	24	0	5	3	6
BB4	214	2,973	107015,32	66	1	6	13	12
BB5	141	4,585	32106,65	34	0	6	20	6

Table C.18 Results of BIM tool A beginner level students in Task-3

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AB1	250	6,66	50463,19	58	0	16	0	6
AB2	200	2,675	57700,61	55	0	9	0	9
AB3	234	10,044	104579,59	75	0	9	0	3
AB4	187	4,593	48718,2	59	1	12	5	11
AB5	215	2,976	49680,39	70	7	10	0	10

Table C.19 Results of BIM tool B professionals in Task-4

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP1	74	5,280	18060,51	18	0	6	11	6
BP2	65	1,460	31495,53	32	0	2	7	6
BP3	118	13,933	33311,04	34	0	10	8	9
BP4	69	3,871	23006,69	23	0	3	5	13
BP5	63	3,625	13176,01	18	0	11	6	6

Table C.20 Results of BIM tool A professionals in Task-4

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AP1	76	6,544	22909,57	17	0	12	2	10
AP2	140	0,687	72445,82	66	1	32	6	7
AP3	55	1,95	27774,49	21	0	3	0	12
AP4	57	1,079	19667,15	15	1	4	1	6
AP5	89	11,454	16470,84	21	2	10	2	9

Table C.21 Results of BIM tool B intermediate level students in Task-4

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BS1	39	1,555	15640,97	22	0	2	4	7
BS2	72	4,973	18274,94	18	0	4	5	4
BS3	56	3,39	21511,87	23	0	11	7	6
BS4	71	3,432	31451,87	20	0	13	6	5
BS5	94	6,167	31324,38	40	0	2	10	4

Table C.22 Results of BIM tool A intermediate level students in Task-4

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AS1	247	5,162	83362,52	89	3	13	5	5
AS2	123	1,223	40401,34	44	1	11	1	12
AS3	120	3,089	23044,39	24	0	5	0	6
AS4	158	2,586	44554,58	58	0	7	0	12
AS5	80	2,325	34636,91	27	0	6	0	6

Table C.23 Results of BIM tool B beginner level students in Task-4

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BB1	53	1,004	15562,11	15	0	3	6	3
BB2	54	2,643	20731,25	23	0	4	9	6
BB3	80	7,748	13725,19	26	0	5	4	6
BB4	115	10,635	54416,48	32	1	1	8	6
BB5	92	2,416	21781,84	31	0	5	18	5

Table C.24 Results of BIM tool A beginner level students in Task-4

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AB1	111	5,522	26066,25	33	0	10	0	6
AB2	74	7,062	38106,67	26	0	5	0	5
AB3	195	1,096	76549,98	74	0	19	0	5
AB4	100	1,834	38209,55	42	0	10	0	6
AB5	156	1,791	49496,27	60	2	13	0	12

Table C.25 Results of BIM tool B professionals in Task-5

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP1	34	10,734	13728,68	11	0	0	0	0
BP2	24	0,869	11727,36	9	0	0	0	0
BP3	46	9,663	22598,99	11	0	5	6	0
BP4	22	4,4	17100,26	9	0	2	0	0
BP5	98	9,134	48175,39	46	0	20	0	6

Table C.26 Results of BIM tool A professionals in Task-5

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AP1	44	4,438	23759,01	13	0	8	3	0
AP2	39	3,433	21720,51	15	0	8	0	6
AP3	31	2,801	11630,12	9	0	9	1	6
AP4	31	10,987	7775,55	2	0	4	0	6
AP5	19	1,975	8114,72	6	0	4	0	6

Table C.27 Results of BIM tool B intermediate level students in Task-5

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BS1	16	2,376	10366,41	8	0	0	0	0
BS2	33	4,103	12554,75	9	0	0	0	0
BS3	29	8,635	12278,77	10	0	0	0	0
BS4	28	5,478	9470,51	7	0	2	0	0
BS5	25	5,737	15024,58	7	0	0	0	0

Table C.28 Results of BIM tool A intermediate level students in Task-5

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AS1	221	5,526	52526,84	86	0	35	3	23
AS2	71	1,246	31630,34	21	0	7	0	9
AS3	53	8,495	22156,95	12	0	4	0	0
AS4	60	5,53	30011,56	15	0	0	0	0
AS5	29	9,546	11767,92	3	0	3	0	6

Table C.29 Results of BIM tool B beginner level students in Task-5

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BB1	56	3,872	17762,78	12	0	0	0	0
BB2	41	0,345	12658,16	8	1	4	0	3
BB3	48	14,092	19303,71	9	0	0	0	0
BB4	36	5,148	24427,85	11	0	1	0	0
BB5	54	5,595	10533,15	9	1	2	0	0

Table C.30 Results of BIM tool A beginner level students in Task-5

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AB1	74	6,483	19115,72	26	1	2	0	6
AB2	67	18,046	23146,97	13	1	2	0	0
AB3	60	0,865	18874,59	14	0	7	0	6
AB4	21	1,18	11154,88	7	0	2	0	0
AB5	35	10,956	9588,24	4	0	2	0	0

Table C.31 Results of BIM tool B professionals in Task-6

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BP1	112	3,175	30981,22	39	0	8	25	3
BP2	122	3,463	31024,69	56	0	8	16	4
BP3	127	0,88	32335,96	43	3	16	48	5
BP4	98	2,384	38073,69	53	1	2	10	2
BP5	124	4,077	25851,42	41	0	10	15	7

Table C.32 Results of BIM tool A professionals in Task-6

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AP1	204	20,723	63288,52	115	1	22	8	23
AP2	161	2,391	33274,69	58	1	10	7	7
AP3	80	6,153	42575,26	32	1	14	0	9
AP4	280	4,947	94358,09	68	3	20	11	3
AP5	183	0,855	41997,12	64	1	18	16	3

Table C.33 Results of BIM tool B intermediate level students in Task-6

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BS1	83	1,425	24191,41	61	0	2	21	10
BS2	135	6,11	24857,08	43	0	4	20	4
BS3	146	1,811	32200,34	57	0	27	25	5
BS4	218	2,186	45223,56	63	0	39	70	4
BS5	148	1,827	28872,05	58	0	8	19	4

Table C.34 Results of BIM tool A intermediate level students in Task-6

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AS1	276	0,907	52487,63	107	0	46	25	7
AS2	124	0,39	31383,13	39	0	4	8	3
AS3	196	1,39	43022,65	66	1	38	35	5
AS4	142	1,895	24513,71	49	0	2	1	2
AS5	170	4,208	55858,81	58	0	9	6	3

Table C.35 Results of BIM tool B beginner level students in Task-6

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
BB1	208	1,02	35952,56	73	1	7	78	4
BB2	124	1,436	38080,84	82	0	4	19	4
BB3	189	1,172	23113,64	65	1	2	11	4
BB4	276	2,491	54640,49	113	1	14	25	4
BB5	174	7,112	22752,53	45	0	78	48	4

Table C.36 Results of BIM tool A beginner level students in Task-6

USER	TIME		DISTANCE	MOUSE		KEYSTROKES		
	Total	First click	(Pixel)	Left Click	Right Click	Operational	Letter	Number
AB1	184	2,968	39101,79	68	4	16	0	3
AB2	161	2,949	34734,5	63	0	5	2	2
AB3	134	0,125	47279,52	60	0	0	8	2
AB4	127	1,384	26130,65	41	1	8	5	2
AB5	186	4,174	27542,9	63	0	4	1	4

C.2 Heat maps

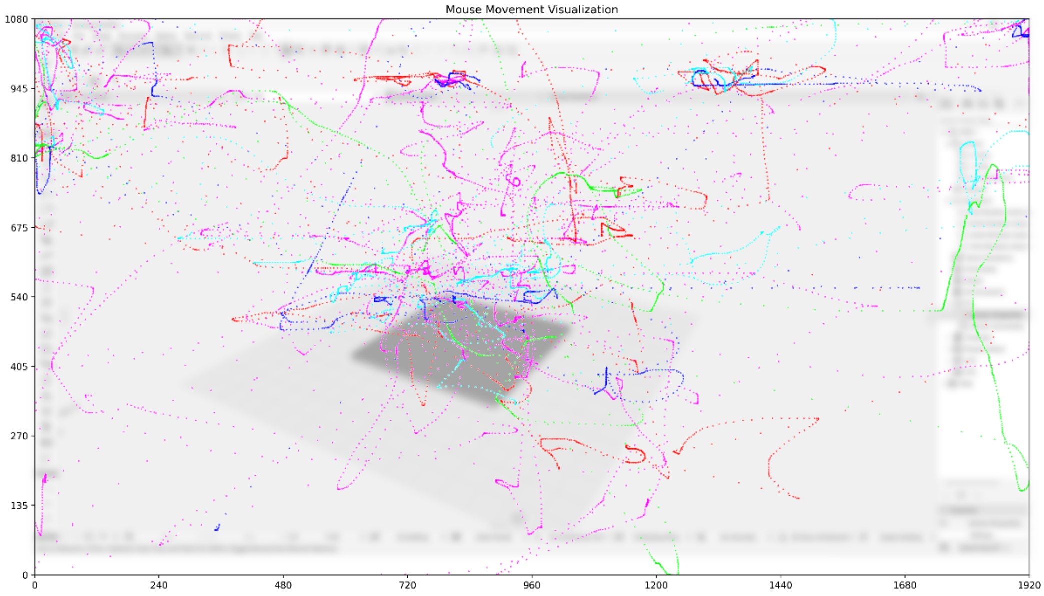

Figure C.1. Superimposed heat map of BIM tool A professionals for Task-1

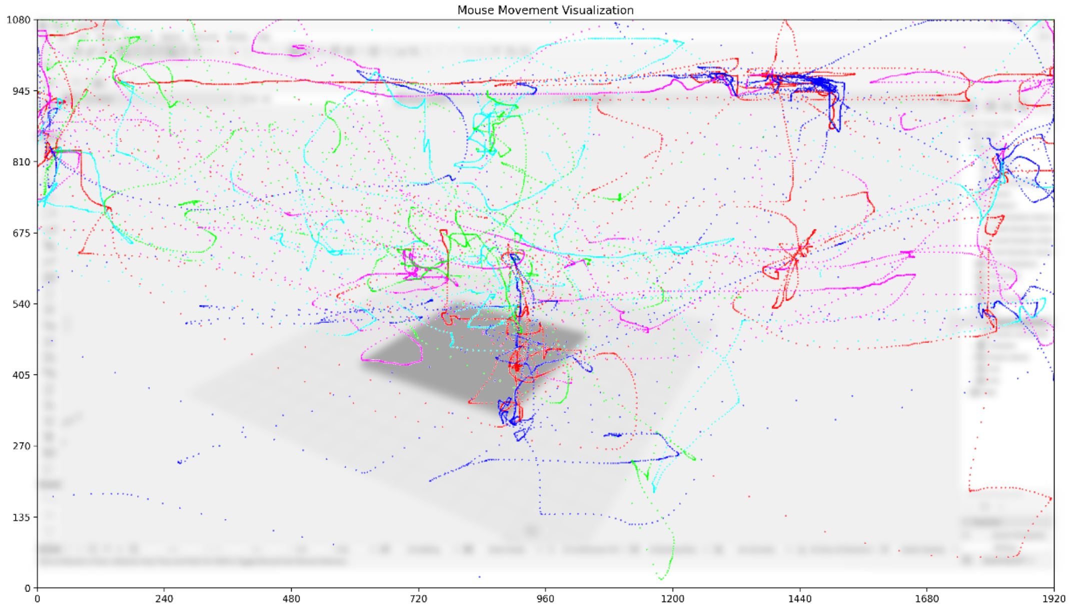

Figure C.2. Superimposed heat map of BIM tool A intermediate level students for Task-1

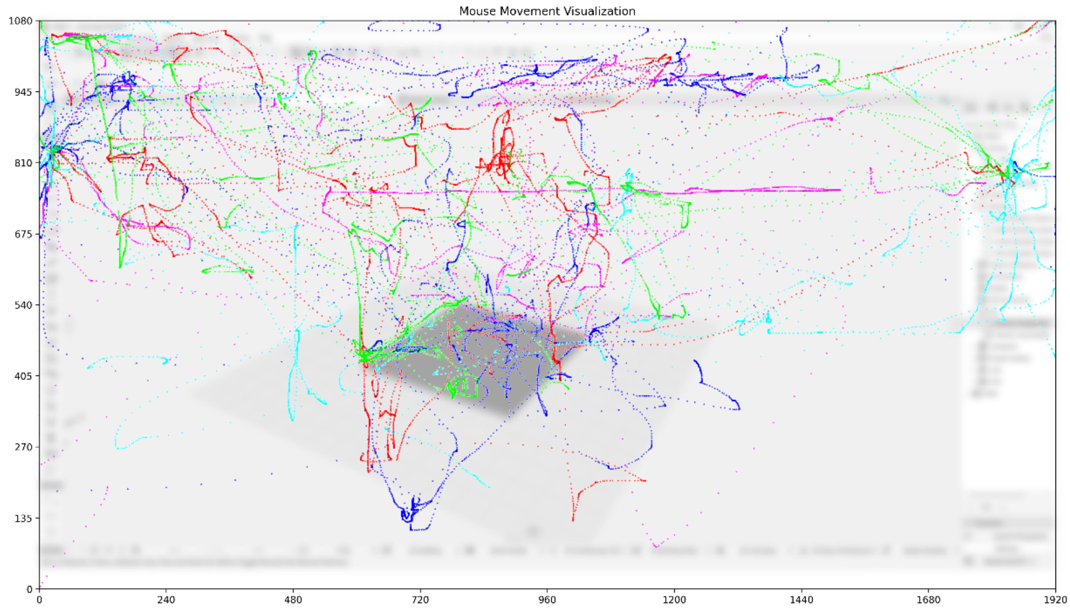

Figure C.3. Superimposed heat map of BIM tool A beginner level students for Task-1

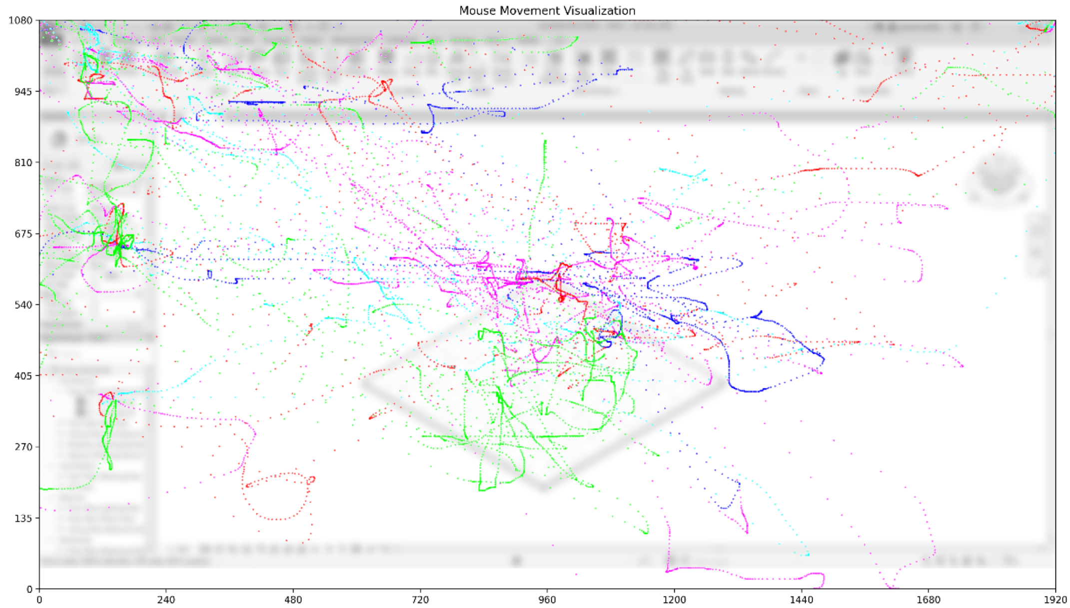

Figure C.4. Superimposed heat map of BIM tool B professionals for Task-1

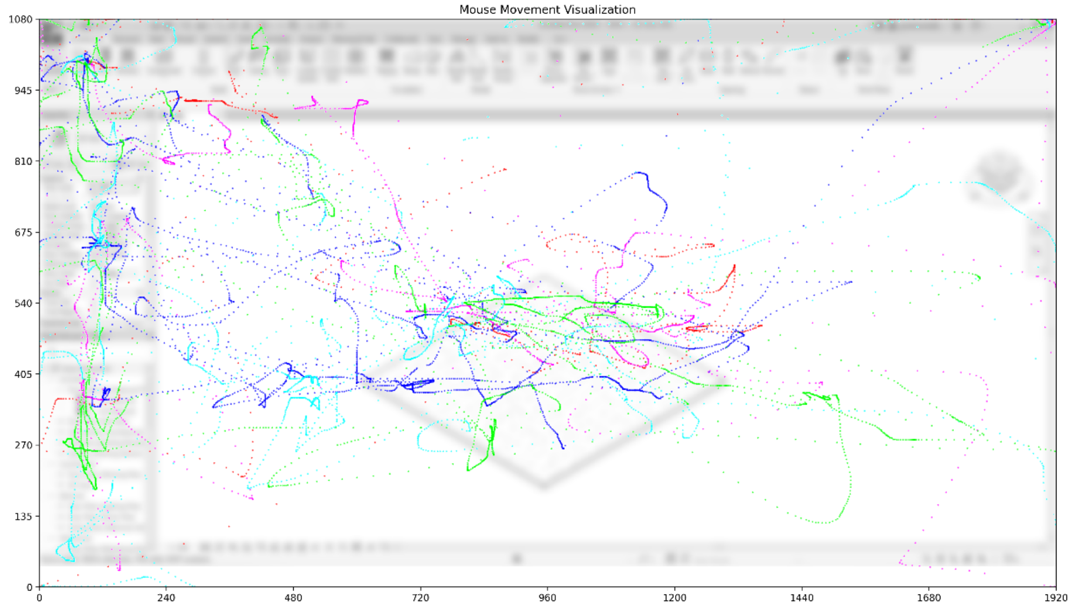

Figure C.5. Superimposed heat map of BIM tool B intermediate level students for Task-1

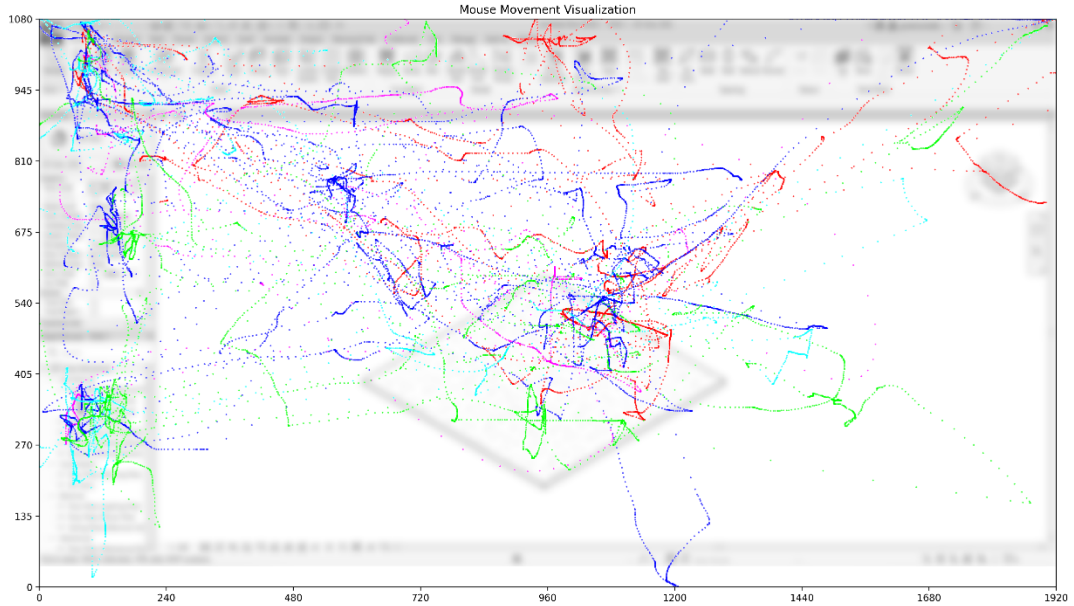

Figure C.6. Superimposed heat map of BIM tool B beginner level students for Task-1

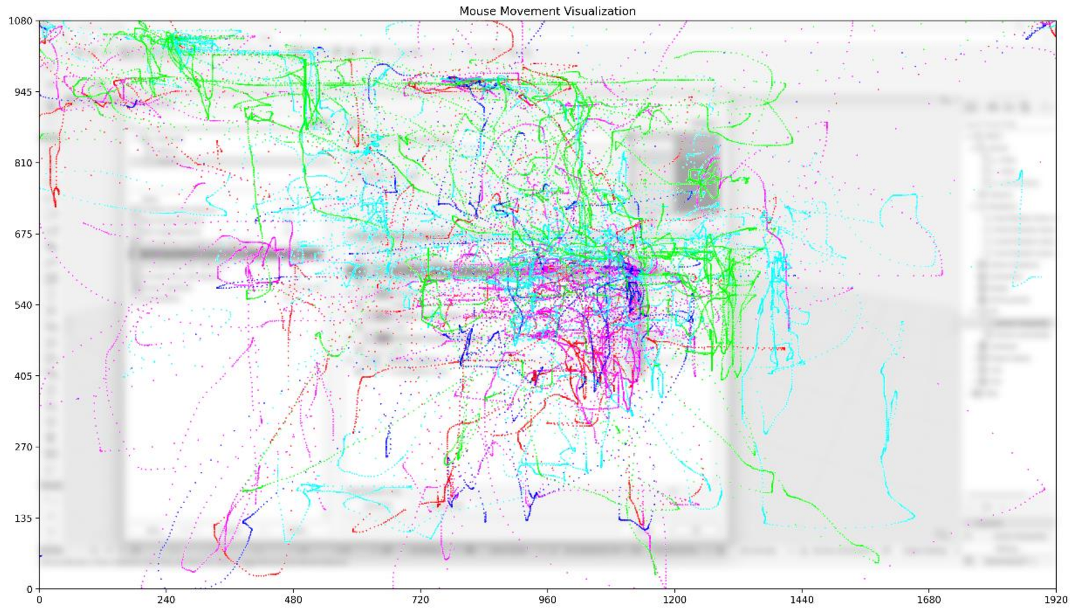

Figure C.7. Superimposed heat map of BIM tool A professionals for Task-2

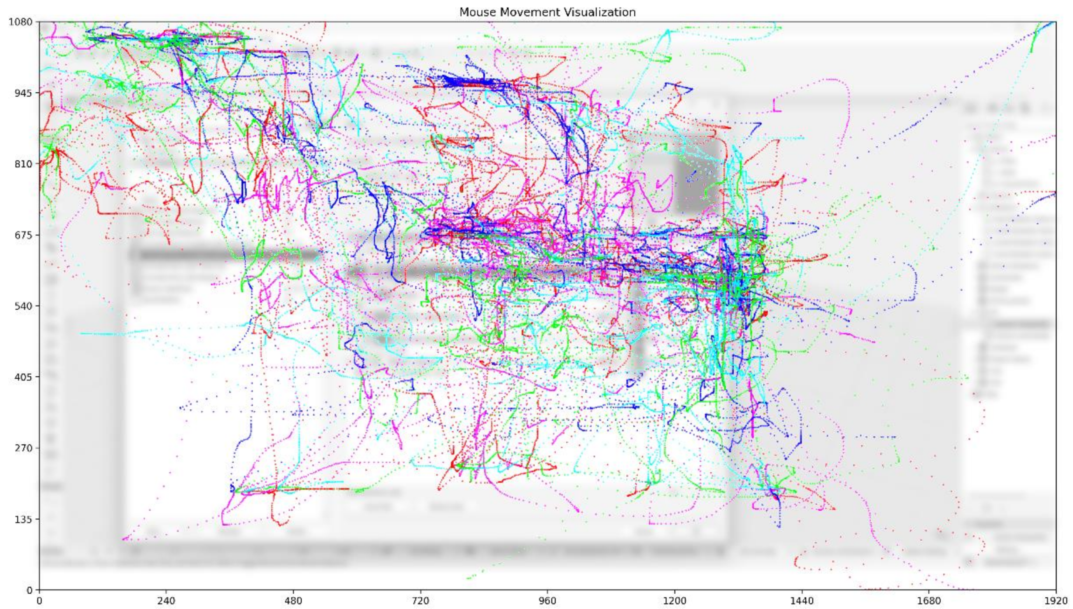

Figure C.8. Superimposed heat map of BIM tool A intermediate level students for Task-2

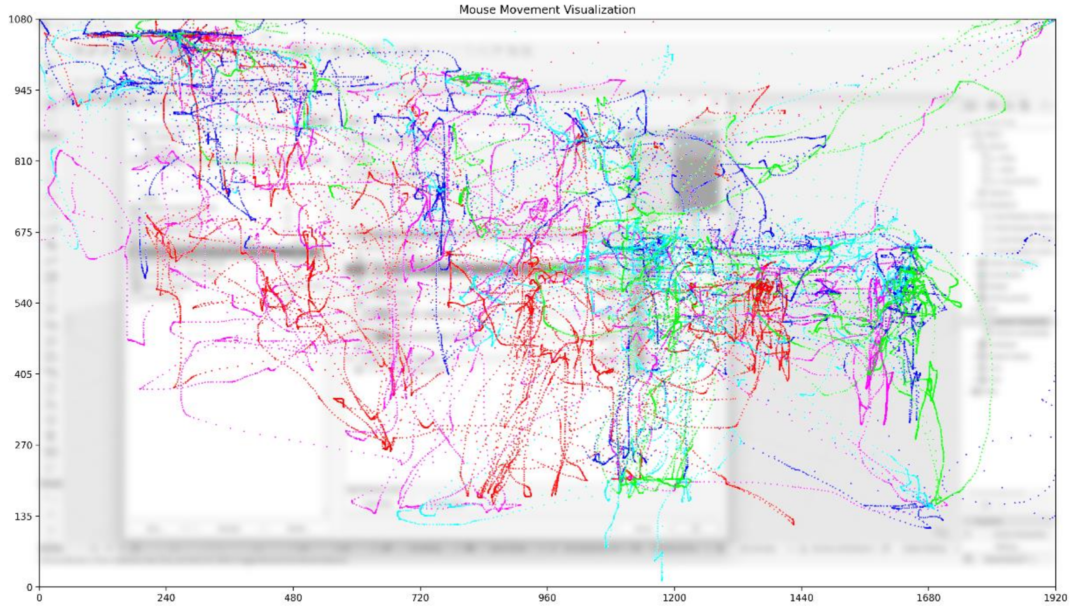

Figure C.9. Superimposed heat map of BIM tool A beginner level students for Task-2

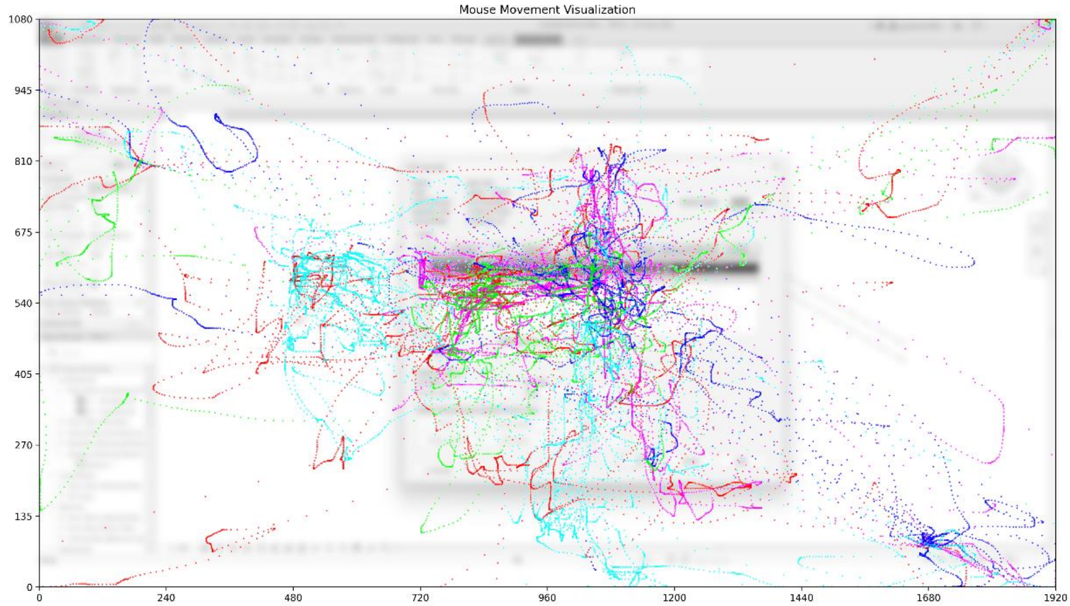

Figure C.10. Superimposed heat map of BIM tool B professionals for Task-2

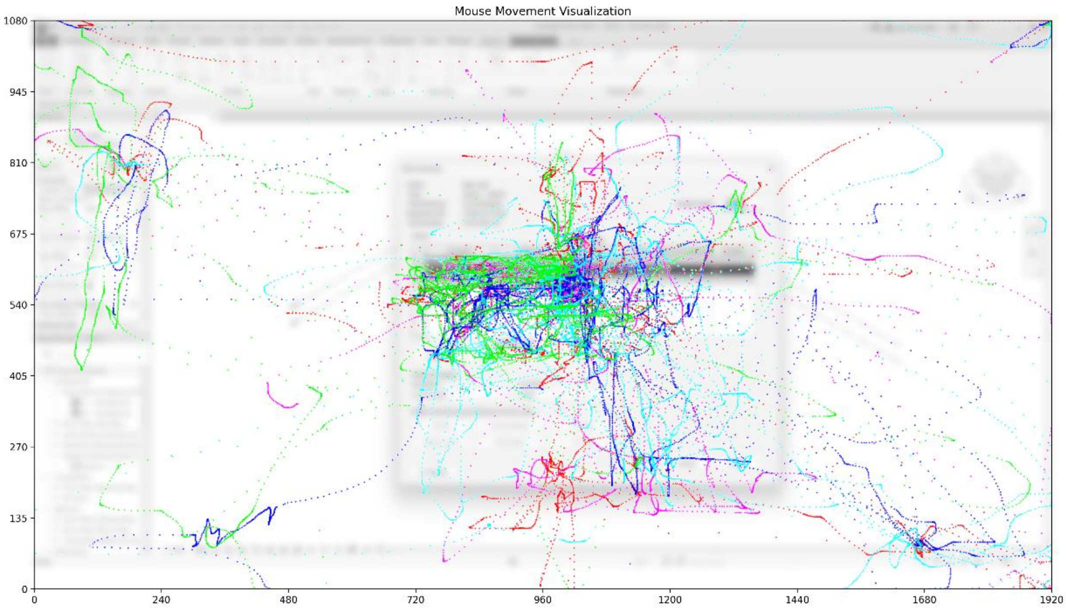

Figure C.11. Superimposed heat map of BIM tool B intermediate level students for Task-2

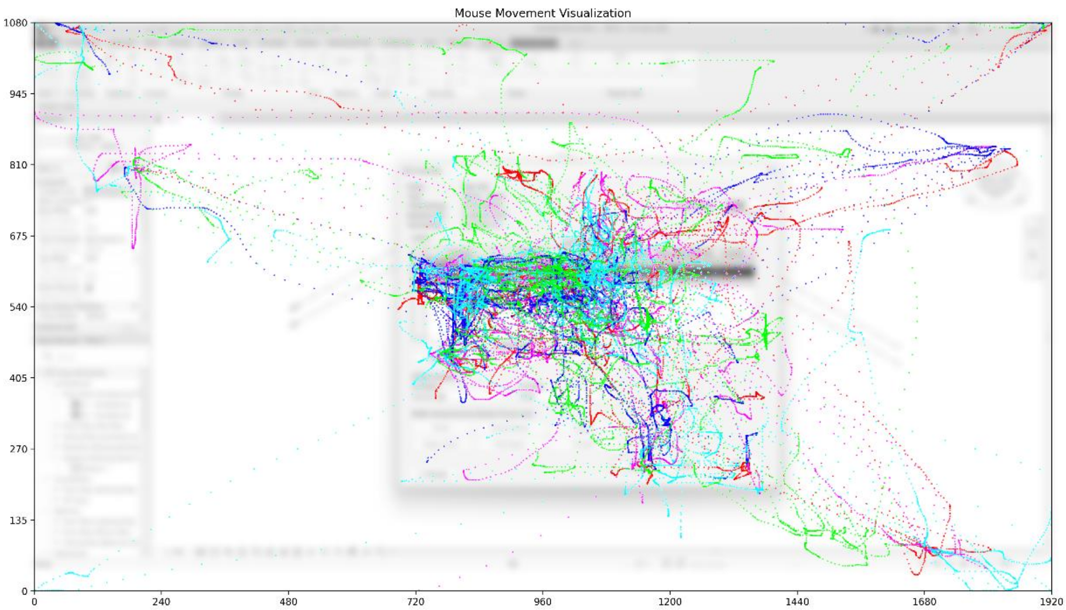

Figure C.12. Superimposed heat map of BIM tool B beginner level students for Task-2

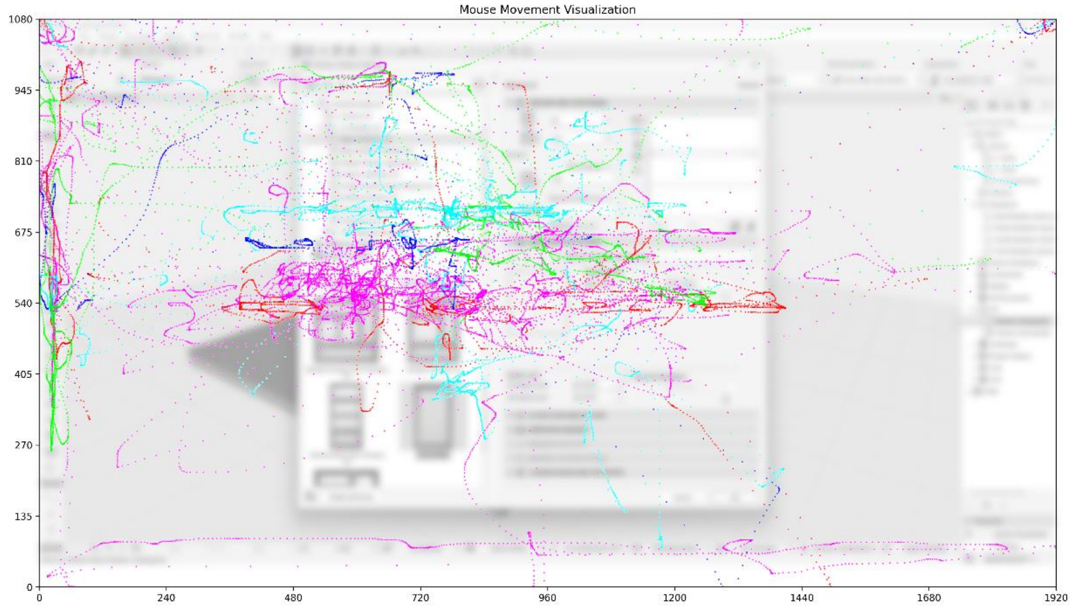

Figure C.13. Superimposed heat map of BIM tool A professionals for Task-3

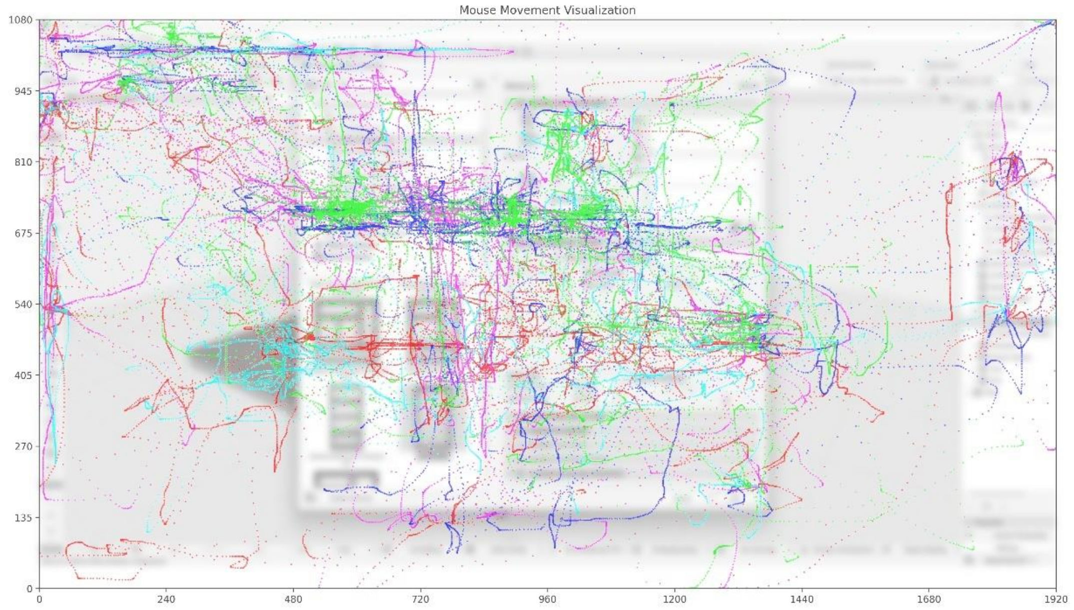

Figure C.14. Superimposed heat map of BIM tool A intermediate level students for Task-3

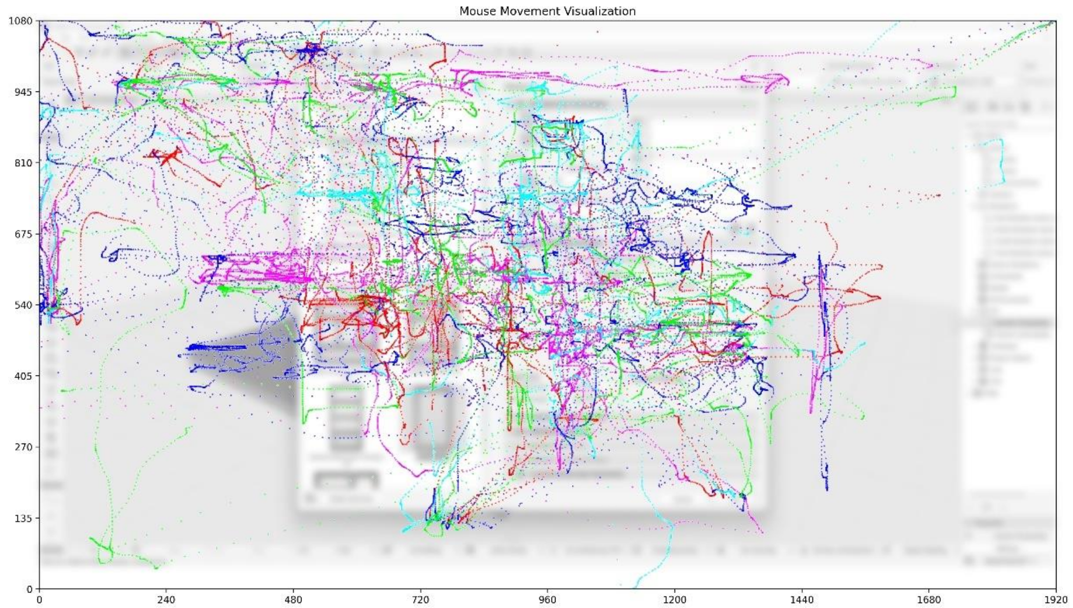

Figure C.15. Superimposed heat map of BIM tool A beginner level students for Task-3

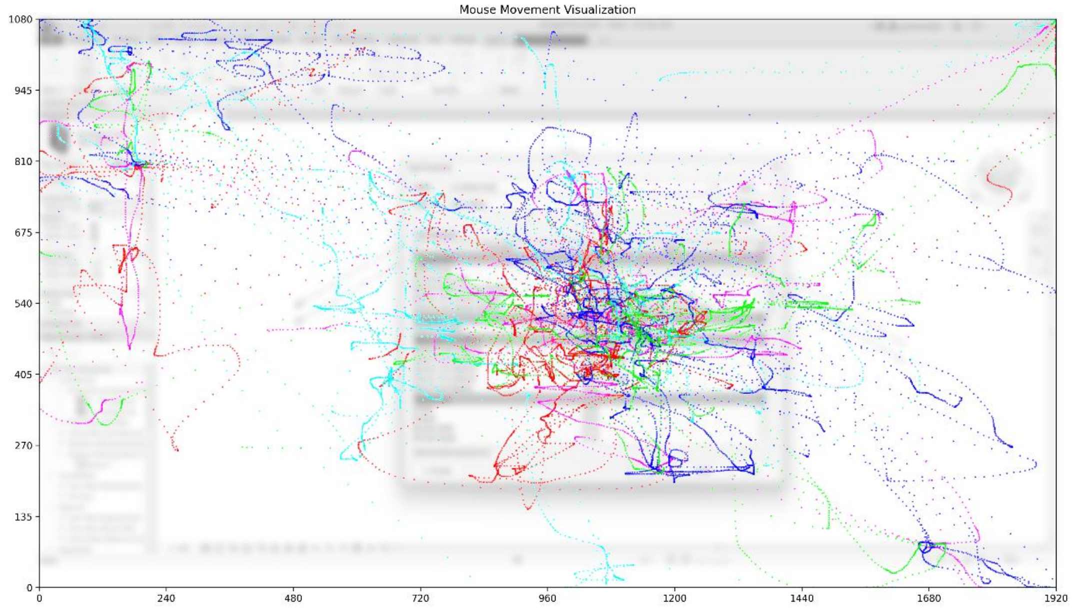

Figure C.16. Superimposed heat map of BIM tool B professionals for Task-3

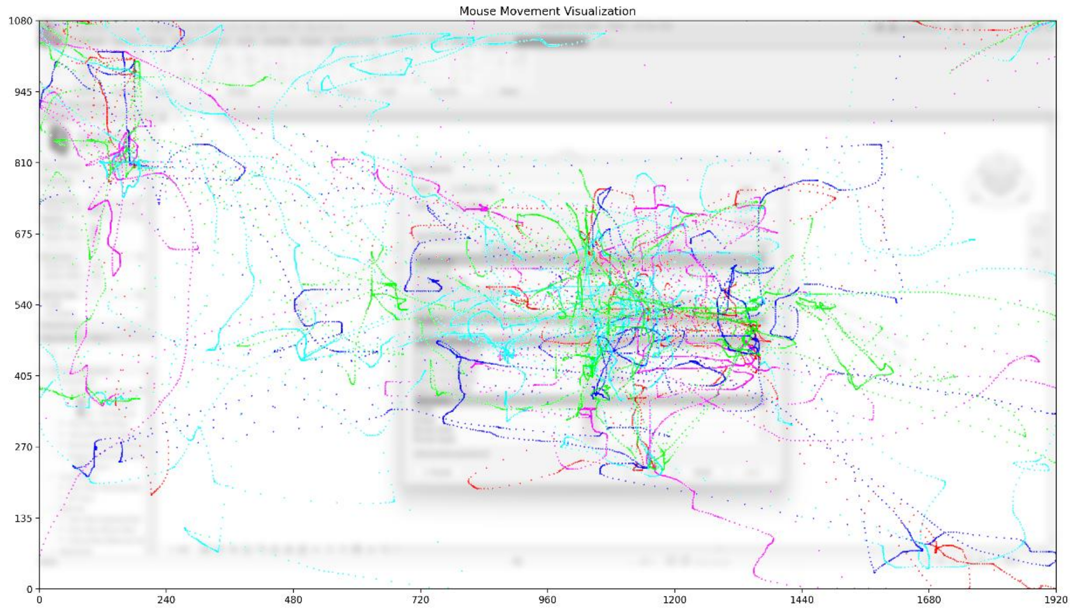

Figure C.17. Superimposed heat map of BIM tool B intermediate level students for Task-3

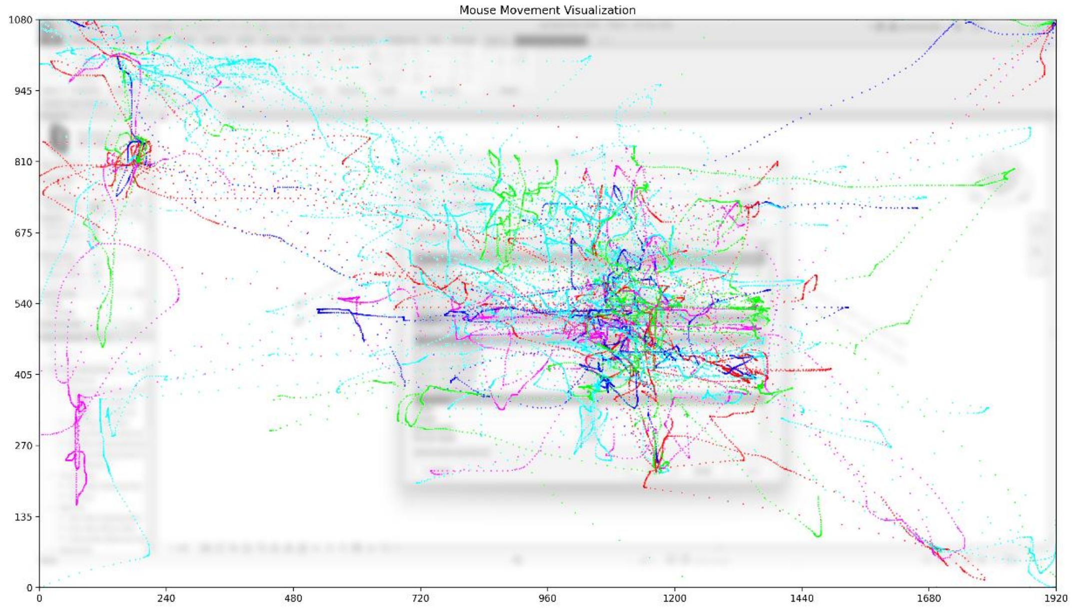

Figure C.18. Superimposed heat map of BIM tool B beginner level students for Task-3

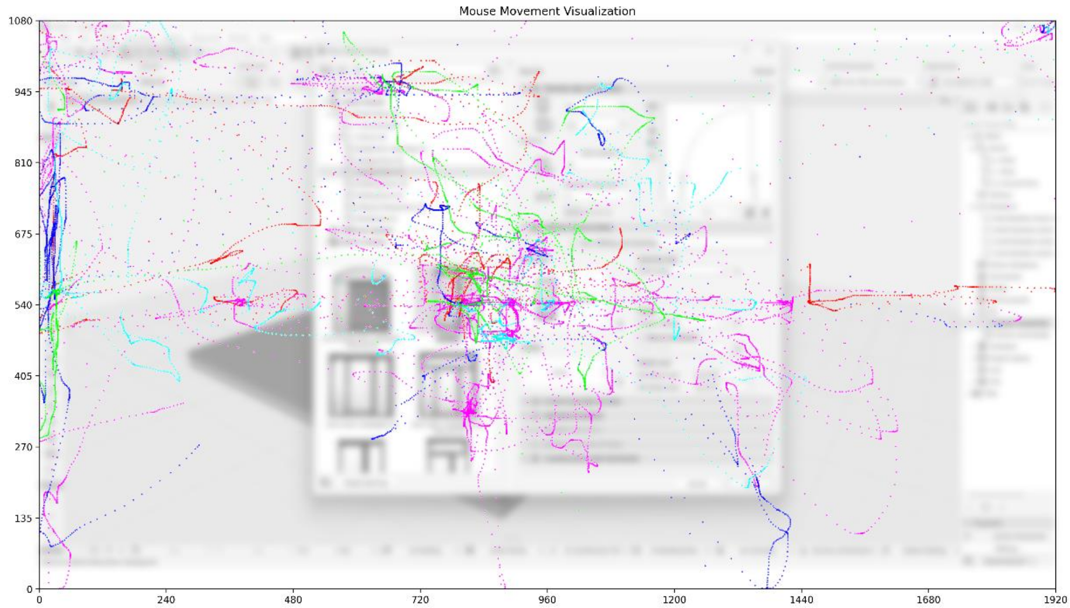

Figure C.19. Superimposed heat map of BIM tool A professionals for Task-4

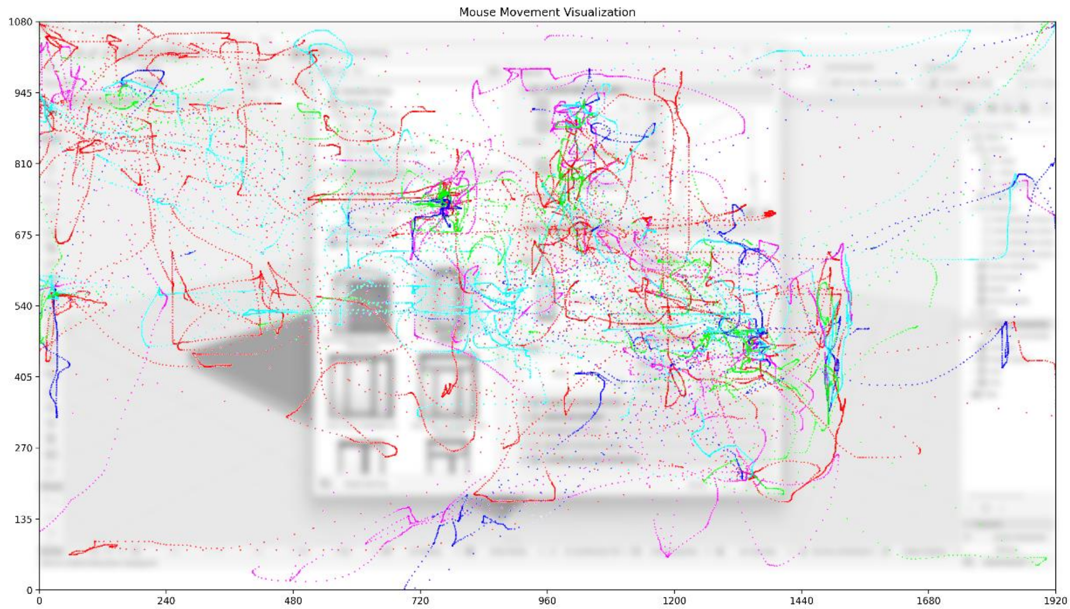

Figure C.20. Superimposed heat map of BIM tool A intermediate level students for Task-4

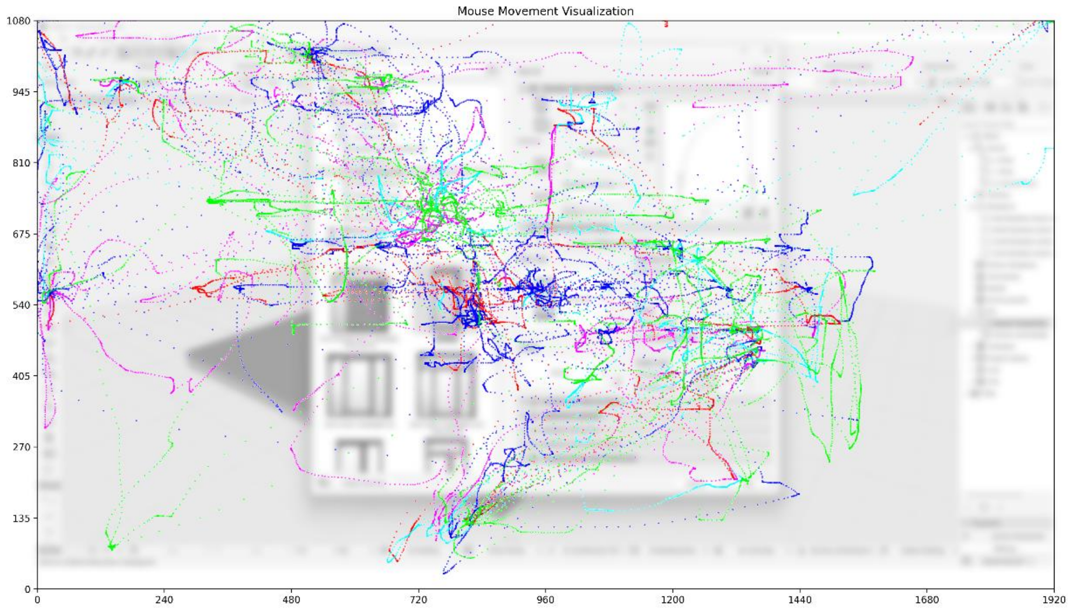

Figure C.21. Superimposed heat map of BIM tool A beginner level students for Task-4

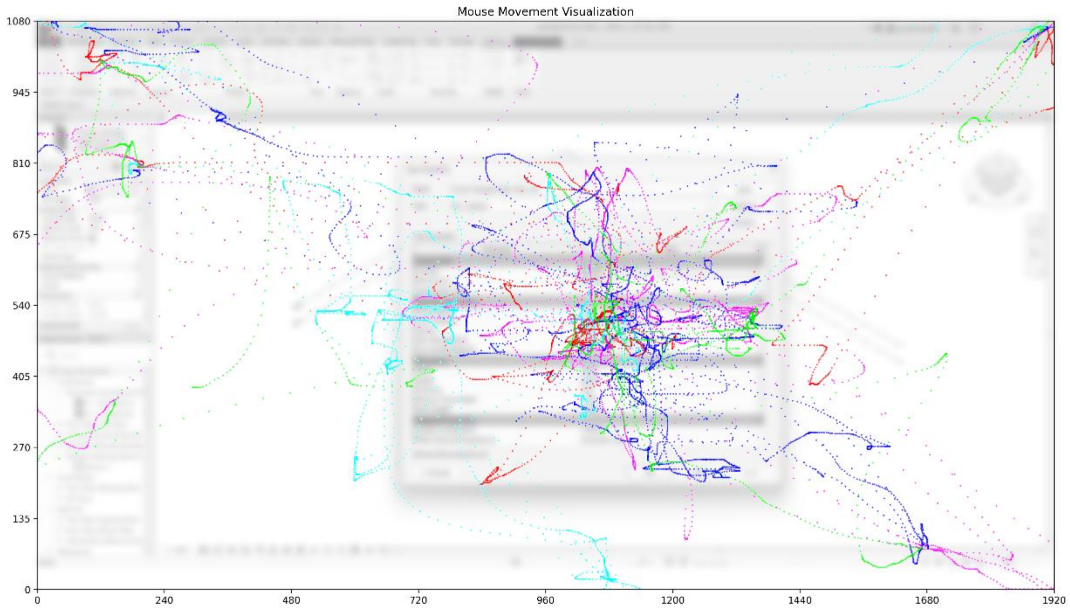

Figure C.22. Superimposed heat map of BIM tool B professionals for Task-4

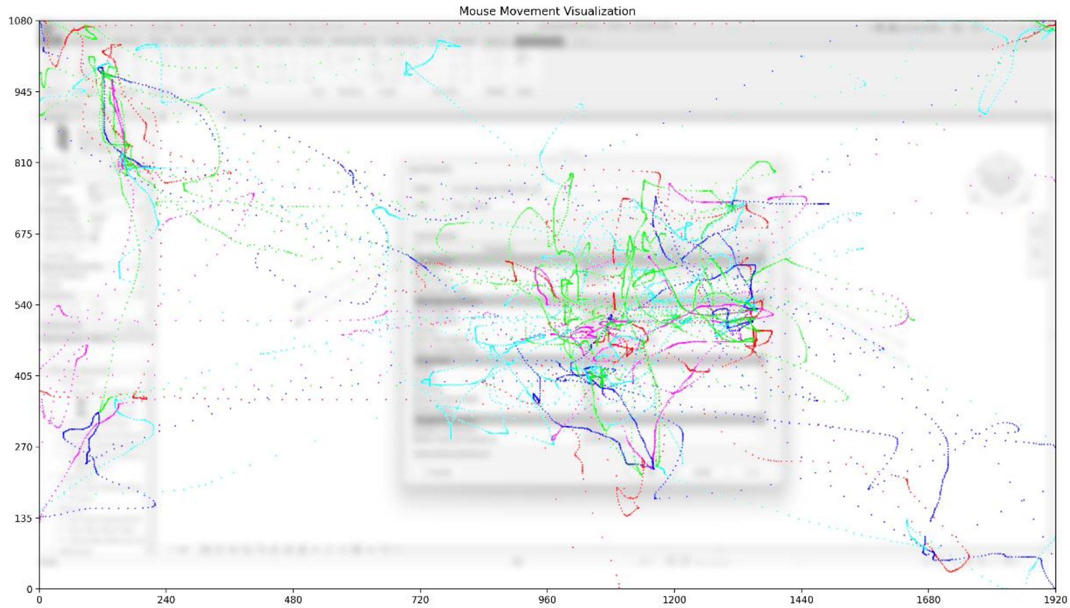

Figure C.23. Superimposed heat map of BIM tool B intermediate level students for Task-4

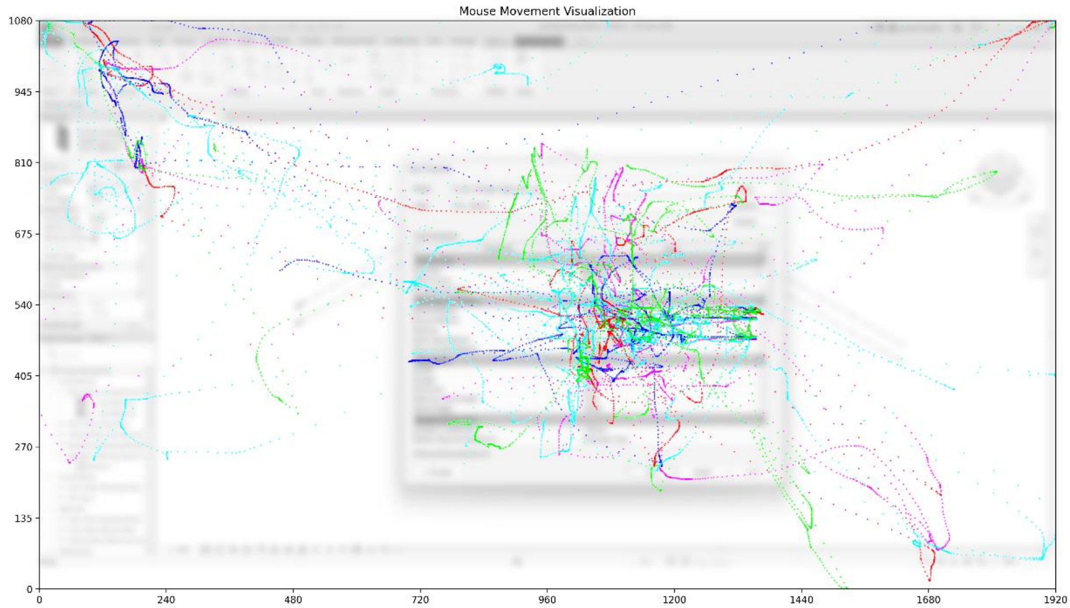

Figure C.24. Superimposed heat map of BIM tool B beginner level students for Task-4

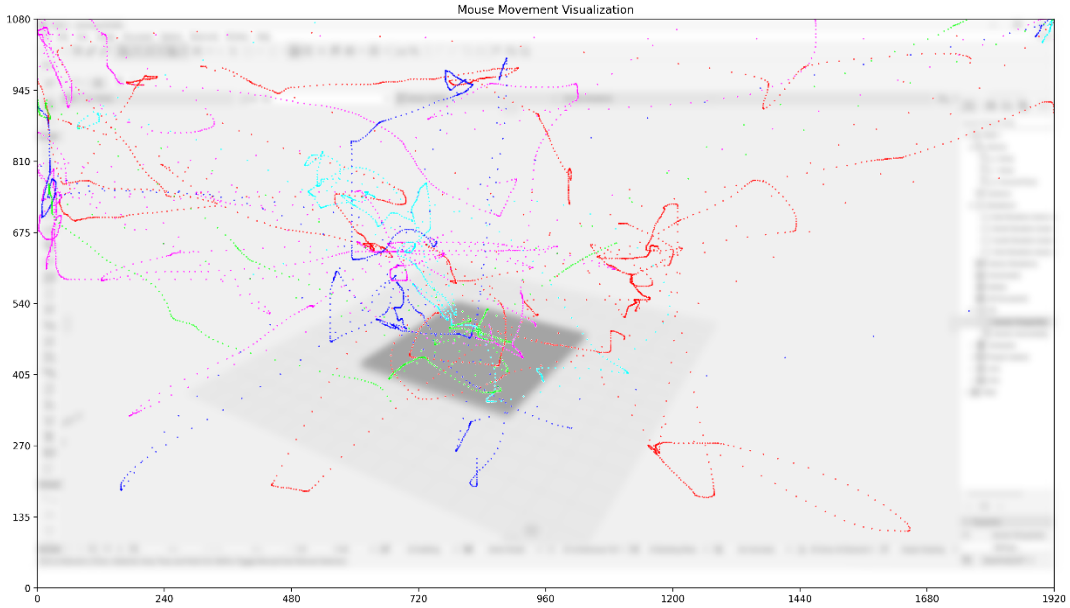

Figure C.25. Superimposed heat map of BIM tool A professionals for Task-5

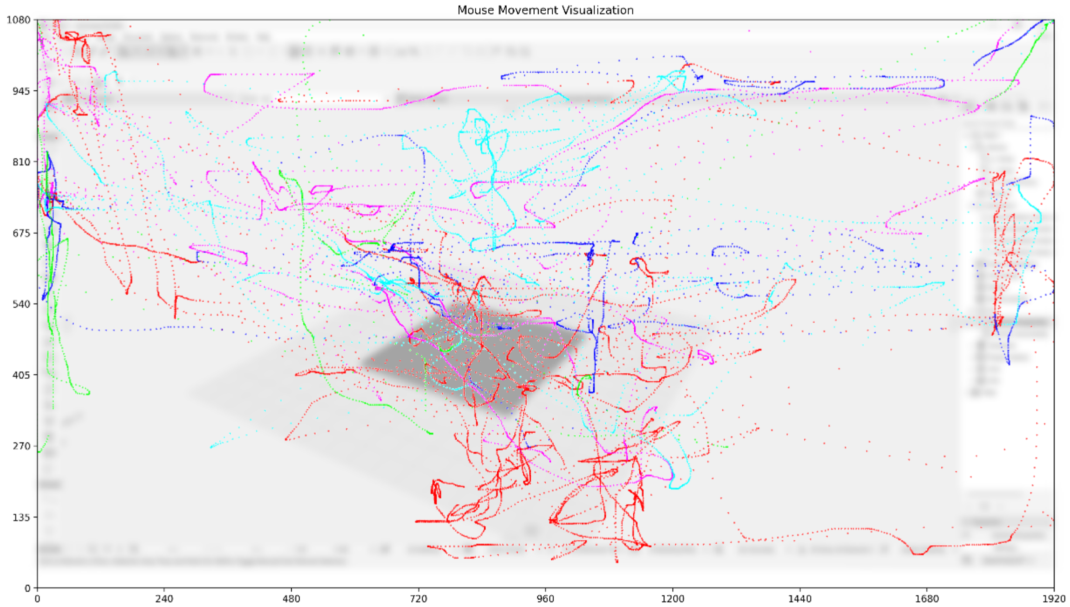

Figure C.26. Superimposed heat map of BIM tool A intermediate level students for Task-5

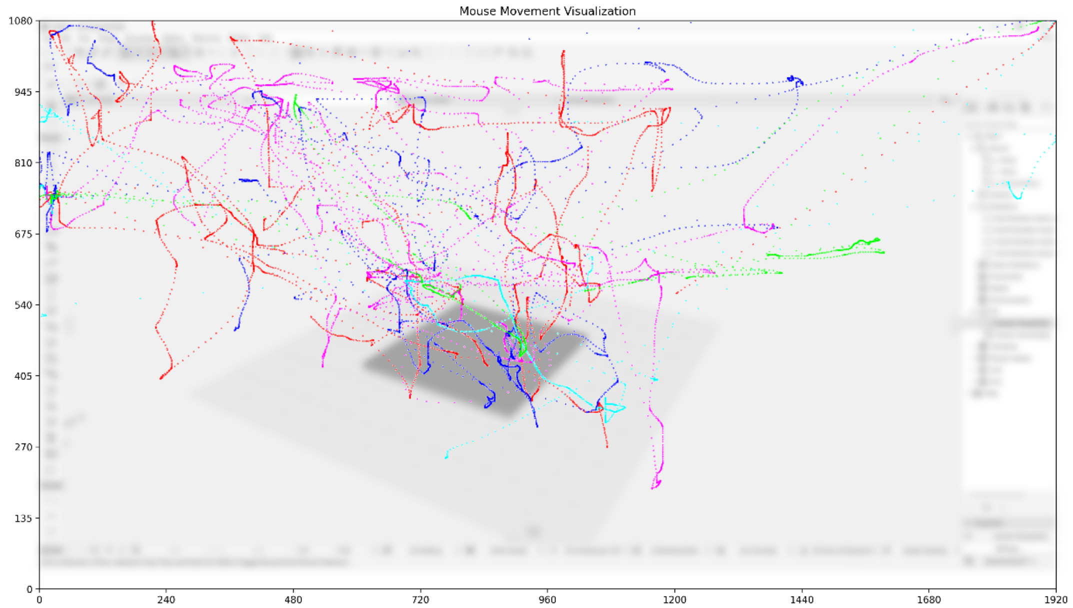

Figure C.27. Superimposed heat map of BIM tool A beginner level students for Task-5

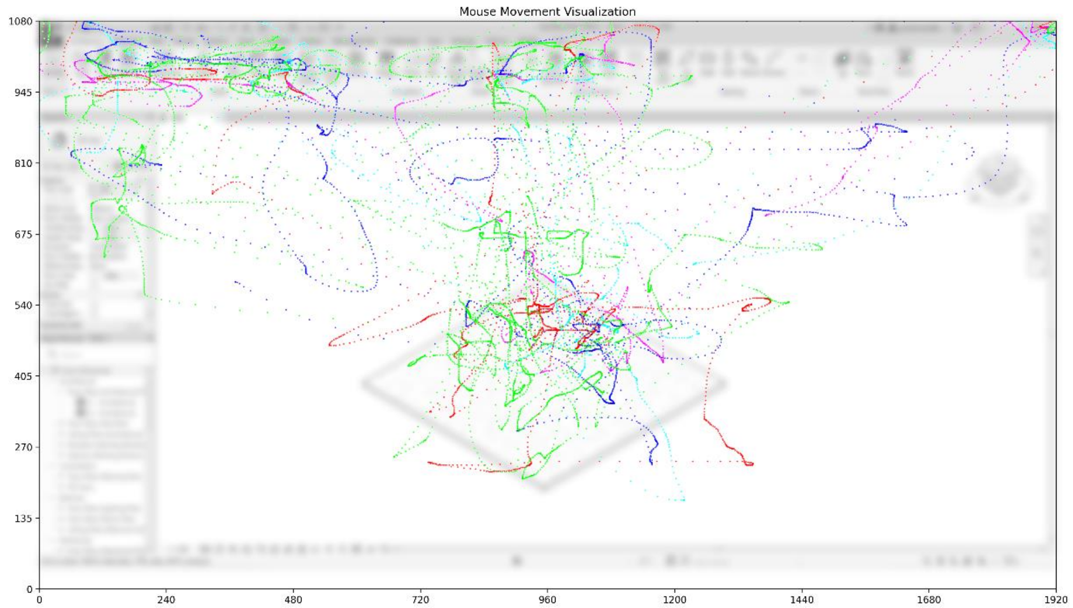

Figure C.28. Superimposed heat map of BIM tool B professionals for Task-5

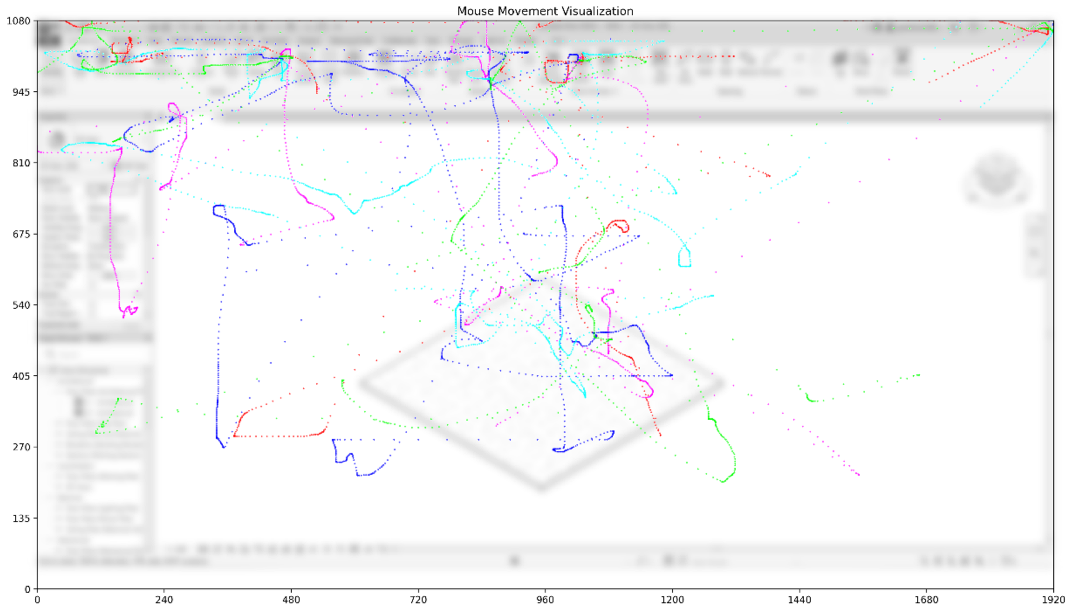

Figure C.29. Superimposed heat map of BIM tool B intermediate level students for Task-5

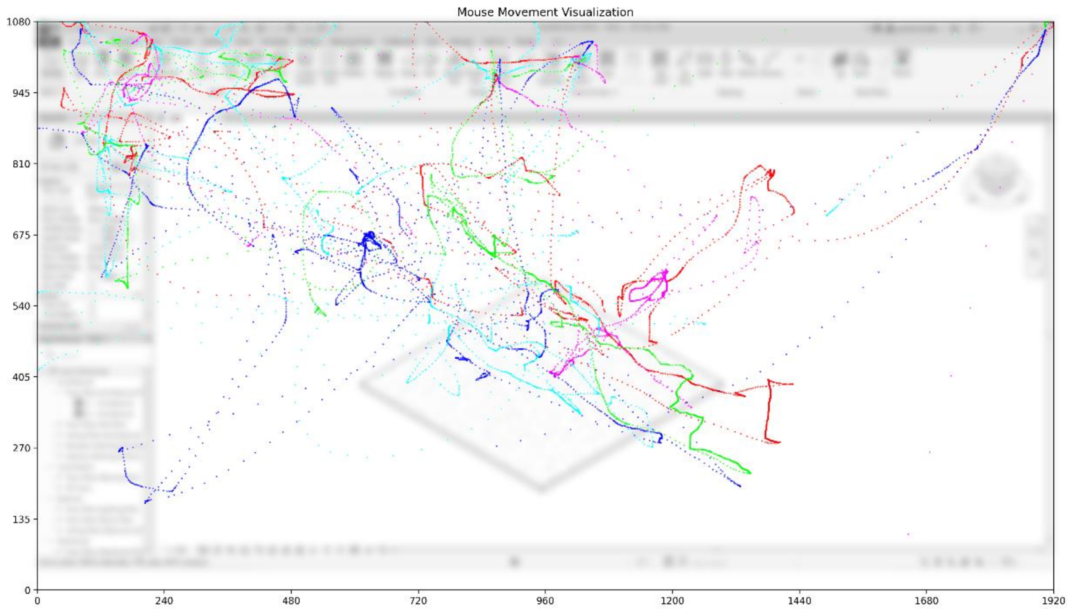

Figure C.30. Superimposed heat map of BIM tool B beginner level students for Task-5

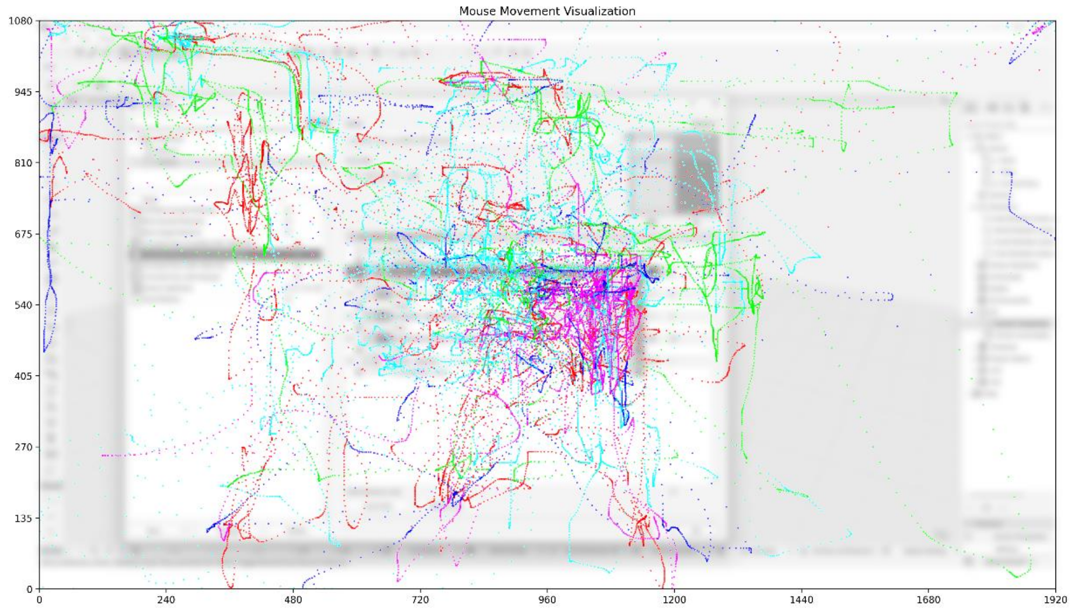

Figure C.31. Superimposed heat map of BIM tool A professionals for Task-6

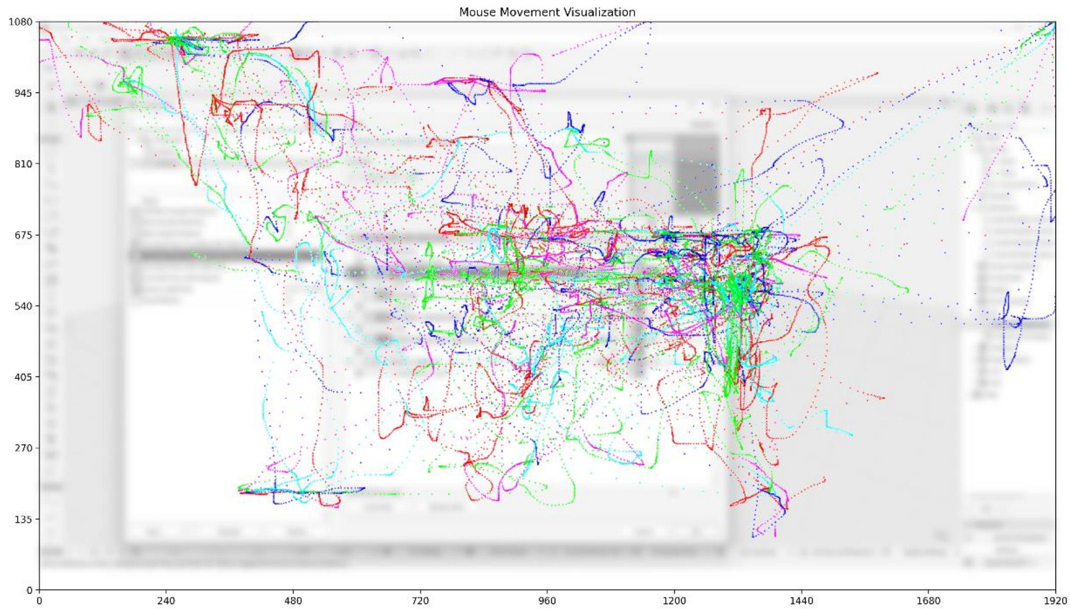

Figure C.32. Superimposed heat map of BIM tool A intermediate level students for Task-6

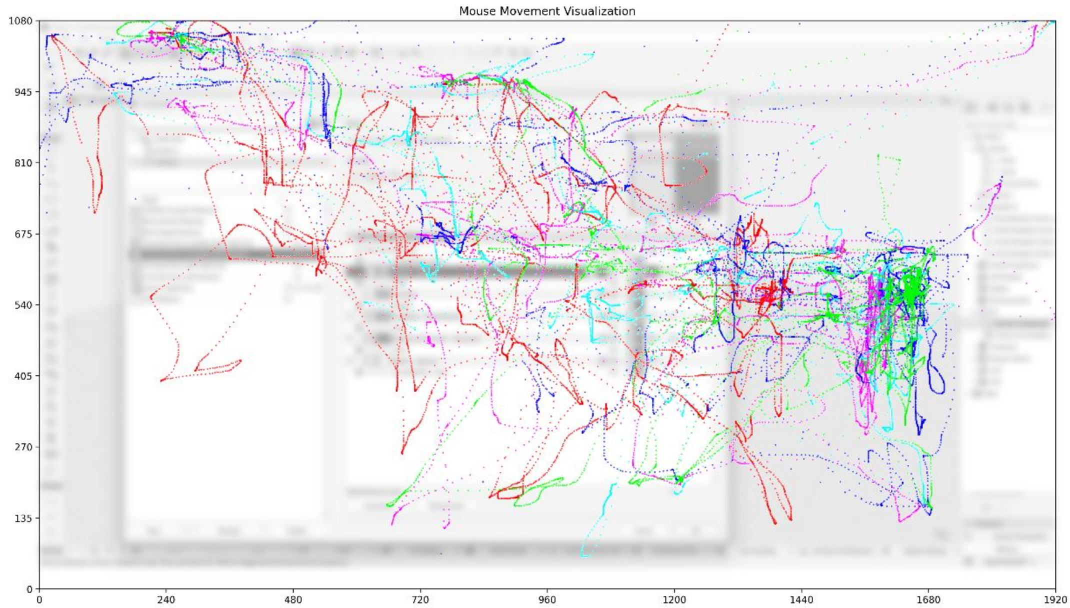

Figure C.33. Superimposed heat map of BIM tool A beginner level students for Task-6

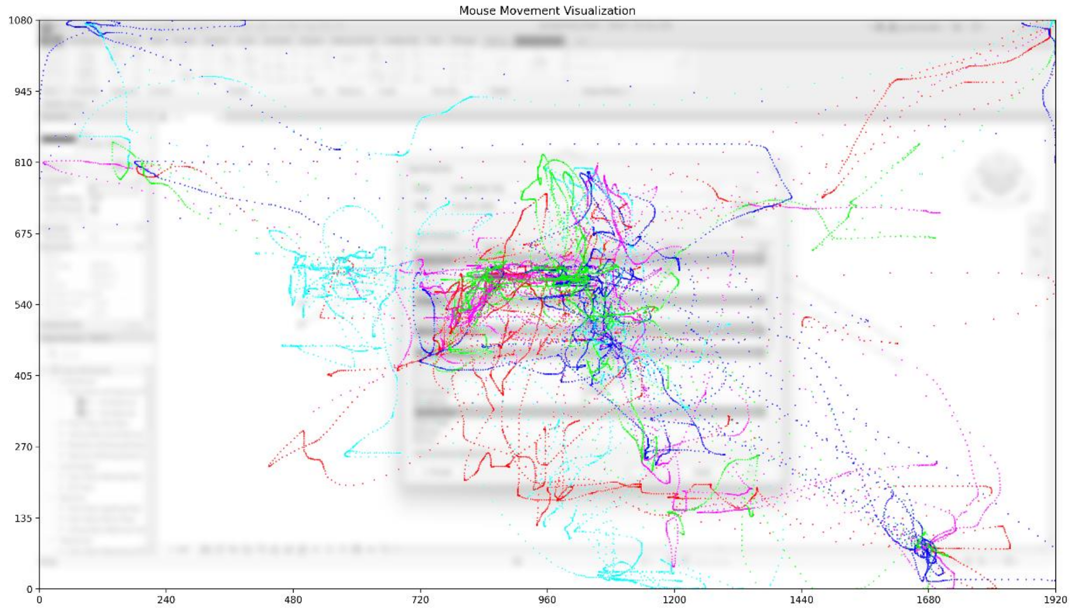

Figure C.34. Superimposed heat map of BIM tool B professionals for Task-6

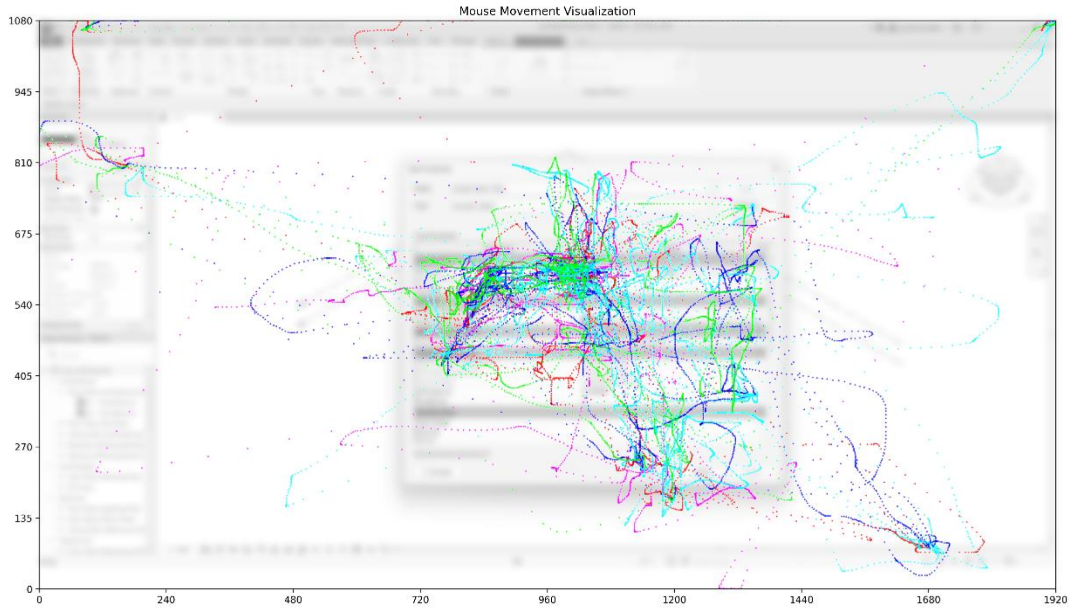

Figure C.35. Superimposed heat map of BIM tool B intermediate level students for Task-6

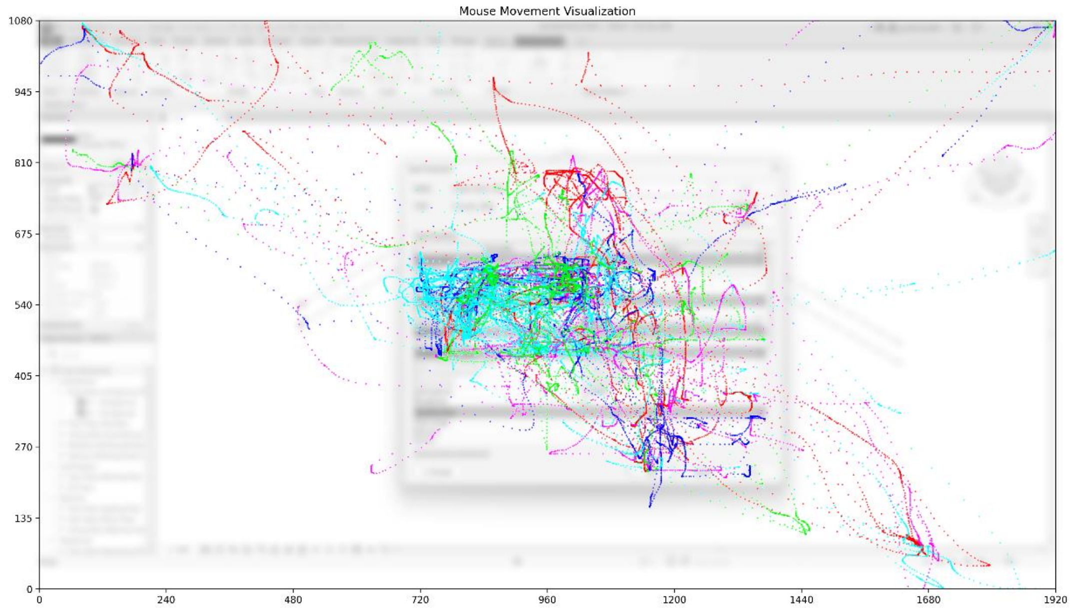

Figure C.36. Superimposed heat map of BIM tool B beginner level students for Task-6