



REPUBLIC OF TÜRKİYE
ALTINBAŞ UNIVERSITY
Institute of Graduate Studies
Department of Architecture

**THE CONSCIOUS IMPACT OF FRACTAL
DIMENSION IN HOSPITAL ARCHITECTURE:
ENHANCING WARMTH AND COMFORT**

Saja Mousa Hasan HASAN

Master's Thesis

Supervisor

Asst. Prof. Dr. Can UZUN

İstanbul, 2024

**THE CONSCIOUS IMPACT OF FRACTAL DIMENSION IN
HOSPITAL ARCHITECTURE: ENHANCING WARMTH AND
COMFORT**

Saja Mousa Hasan HASAN

Department of Architecture

Master's Thesis

ALTINBAŞ UNIVERSITY

2024

The thesis titled THE CONSCIOUS IMPACT OF FRACTAL DIMENSION IN HOSPITAL ARCHITECTURE: ENHANCING WARMTH AND COMFORT prepared by SAJA MOUSA HASAN HASAN and submitted on 03/04/2024 has been **accepted unanimously** for the degree of Master of Architecture.

Asst. Prof. Dr. Can UZUN

Supervisor

Thesis Defences Committee Members:

Asst. Prof. Dr. Can UZUN

Department of
Architecture,

Altınbaş University

Asst. Prof. Dr. Erine ONBAY

Department of Interior
Architecture and
Environmental Design,

Altınbaş University

Asst. Prof. Dr. Alireza
KHARAZMI NEZHAD

Department of
Architecture,

Niğantaşı University

I hereby declare that this thesis meets all format and submission requirements for a Master's thesis.

I hereby declare that all information/data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Saja Mousa HASAN

Signature



DEDICATION

I extend my sincere thanks to my esteemed professors who spent their precious time expressing my ideas, caring for me, and delivering me. I offer my heartfelt gratitude to all those who supported me, whether with effort, words, feelings, or looks. I extend my sincere thanks to my friends and colleagues at work because they have the biggest role in supporting me financially, morally, and spiritually the inhabitants of my heart. I express my heartfelt appreciation for the strong foundation that has nurtured me. My family. I extend my sincere thanks to my support in life and my wings, my brothers. I extend my sincere thanks to the reason for the happiness of my heart, my nephews.

And I dedicate all this humble effort to those whose rights I have never fulfilled, no matter how hard I strive, the origin of my existence, my hope in life, my tender heart, my teacher in life (my mother and my father)

Finally, I bow down in gratitude for the grace of my Lord, who drew the path for me with His care.

Thank you all.

ABSTRACT

THE CONSCIOUS IMPACT OF FRACTAL DIMENSION IN HOSPITAL ARCHITECTURE: ENHANCING WARMTH AND COMFORT

HASAN, Saja Mousa Hasan

M.Sc., Department of Architecture, Altınbaş University,

Supervisor: Asst. Prof. Dr. Can UZUN

Date: 04/2024

Pages: 99

The master's thesis titled "The conscious impact of fractal dimension in Hospital architecture: enhancing warmth and comfort " delves into the transformative potential of integrating fractal geometry within the architectural framework of hospitals. Drawing from mathematical principles, fractal geometry blends with architectural design through self-similarity and complexity, to culminating in visually harmonious environments finely attuned to human sensibilities. This innovative approach aims to mitigate stress by leveraging the physiological responses evoked through exposure to fractal patterns. The admixing of fractal elements engenders an atmosphere of serenity that profoundly impacts patients, visitors, and healthcare professionals alike. Furthermore, the application of fractal geometry manifests as enhanced spatial efficiency the intricate layout of hospital facilities, thereby accommodating future expansions and the dynamic demands of evolving healthcare landscapes. The main endeavour of the study investigates the extent to which the fractal dimension influences the design of healthcare facilities and the perception of comfort and warmth in them. A pivotal aspect of the research delves into the perceptions of patients and visitors, allowing for empirical analysis of the tangible effects that emerge through the incorporation of fractal aesthetics. Its effect extends to cognitive comfort and physiological well-being. The culmination of the study is to provide evidence-based design recommendations that exploit the potential of fractal geometry to create ideal comfortable and warm environments. In the context of implementing the research agenda, an integrated research approach was adopted, consisting of qualitative and quantitative methodologies. This complex interaction is demonstrated through a variety of research tools, such as case

studies, field surveys, and computational analysis focusing on fractal dimensional analysis., which is done through specialized software tools such as ImageJ and OpenAI, provides a deeper understanding of the complex self-similarity inherent in architectural designs. In summary, my master's thesis titled “The Conscious Influence of Fractal Dimension in Hospital Architecture: Enhancing Warmth and Comfort” emphasizes a transformative approach in healthcare architecture. With a blend of historical context, critical literature, methodological ingenuity, and empirical insights into the untapped potential of fractal geometry, heralding an era in which hospital design extends beyond utilitarianism to embrace functional aesthetics around comfort and warmth, spatial optimization, and overall well-being. This study not only highlights a promising path for architectural innovation, but also advances the discourse on human-centred healthcare environments.

Keywords: Fractal Geometry, Hospital Facilities, Patient Recovery, Healing Architecture, Biophilic Fractal Designs.

TABLE OF CONTENTS

	<u>Pages</u>
ABSTRACT	vi
LIST OF TABLES.....	xi
LIST OF FIGURES.....	xii
LIST OF CHARTS.....	xiii
ABBREVIATIONS.....	xvi
LIST OF SYMBOLS.....	xvii
1. INTRODUCTION	1
1.1 FRACTAL DEFINITION.....	3
1.2 THESIS STATEMENT	4
1.3 RESEARCH OBJECTIVES	5
2. GENERAL INFORMATION.....	6
2.1 FRACTAL	6
2.2 FRACTAL PROPERTIES.....	6
2.2.1 Self-Similarity.....	7
2.2.2 Fractal Dimension.....	9
2.2.2.1 The fractal dimension according to the hausdorff-besicovitch method	12
2.2.2.2 Self-similarity dimension	13
2.2.2.3 Box-counting dimension	13
2.2.2.4 Measured dimension (d).....	15
2.2.3 Infinity.....	17
2.3 APPLICATIONS OF FRACTAL GEOMETRY IN ARCHITECTURE DESIGN .	17
2.4 PERCEPTION	21
2.4.1 Perception Definition	21

2.4.2 Types Of Perception	22
2.4.3 The Perception Process	22
2.4.4 Sensory Perception And Patterns	23
2.5 HOSPITALS AND HEALTHCARE DESIGN	24
2.5.1 Evolution Of Health Architecture Overview	25
3. RESEARCH METHODOLOGY.....	28
3.1 STUDY DESIGN	28
3.2 LITERATURE REVIEW	28
3.3 CASE STUDY	28
3.4 SAMPLING STRATEGY	29
3.5 PARTICIPANTS	29
3.6 ETHICAL CONSIDERATIONS.....	30
3.7 DATA COLLECTION	30
3.8 DATA ANALYSIS.....	30
4. SELECTED PROJECTS FOR CASE STUDY TESTING	31
4.1 CASE STUDY-VICTORIA HEART HOSPITAL.....	33
4.2 CASE STUDY-JACOBS MEDICAL CENTRE AT UC SAN DIEGO HEALTH..	38
4.3 CASE STUDY-FRIENDSHIP HOSPITAL SHYAMNAGAR	42
5. RESULT	44
5.1 THE VICTORIAN HEART HOSPITAL RESULTS.....	46
5.1.1 Image of the Patient's Room (Fractal Dimension: 1.7937).....	48
5.1.2 Image of Waiting Area (Fractal Dimension: 1.7967)	49
5.2 THE JACOBS MEDICAL CENTER RESULTS.....	50
5.2.1 Fractal Dimension of the Patient's Room Image (1.7271).....	51
5.2.2 Fractal Dimension of the Waiting Area Image (1.498)	53

5.3 FRIENDSHIP HOSPITAL RESULTS.....	53
5.3.1 Image of the Patient's Room (Fractal Dimension: 1.6674).....	54
5.3.2 Fractal Dimension of the Waiting Area (Fractal Dimension: 1.7717).....	56
5.4 QUESTIONNAIRE	57
5.4.1 Age Relationship.....	57
5.4.2 The Relationship between Participants' Preference And Fractal Dimension	58
5.4.3 Analyzing the Relationship Between the Fractal Dimension Preferred by Questionnaire Participants and Their Feelings of Comfort	61
5.4.4 Analyzing the Relationship Linking the Overall Fractal Dimension of the Images and the Fractal Dimension of the Design Image Elements (Ceilings, Walls, Floors, Furniture) with The Preferred Fractal Dimension of the Participants in the Questionnaire	62
6. CONCLUSION	64
REFERENCES	66
APPENDIX A.....	75

LIST OF TABLES

	<u>Pages</u>
Table 2.1: Measured Lengths of the Coast of Britain.....	16
Table 5.1: The Relationship between the Level of Complexity of The Fractal Dimension and Comfort.....	63



LIST OF FIGURES

	<u>Pages</u>
Figure 2.1: Fractal Basics Stage.	8
Figure 2.2 : Self-Similarity Basic Steps in Sierpinski Gasket.	8
Figure 2.3: Self-Similarity Basic Steps.	8
Figure 2.4: Traditional Dimensions.	9
Figure 2.5: Object with One Dimension Divide To 3 Segments.	10
Figure 2.6: Peano Curve.	11
Figure 2.7: Illustrates the Determination Of The Fractal Dimension D For A Line, A Square, And A Cube.	14
Figure 2.8: Image (A): (N)The Number of Boxes for Image=5 (1/D) The Size of The Grid Box =0.0095 Image (B): (N)The Number of Boxes for Image=200 (1/D) The Size of The Grid Box =0.3788.	15
Figure 2.9: Show How the Box-Counting Method Finds the Fractal Dimension for A Side of the "Muqarnas" Which Is an Important Element of Architectural and Decorative Art of Islamic Architecture.	15
Figure 2.10: The Extent of Variation in The Measured Length of Britain's Coast at Each Length.	16
Figure 2.11: The Existence of The Golden Ratio , And Self-Similarity in The Pyramids of Giza Construction.	17
Figure 2.12: The Tiered Pylons of Egyptian Temples.	18
Figure 2.13: Fractal Patterns in Repetition Carvings of Indian Temples.	18
Figure 2.14: Suzhou Gardens China.	19
Figure 2.15: The Forbidden City in Beijing.	19
Figure 2.16: (A) The Eden Project Biomes in the UK, (B) The Lideta Mercato in Addis Ababa,	20

Figure 2.17: Model of "Nightingale Ward"	26
Figure 4.1: Victoria Heart Hospital	33
Figure 4.2: The Circular Garden and Design of Radial Geometry.....	34
Figure 4.3: Borrow an Idea of the Historical Botanic Garden in Padua, Italy.	35
Figure 4.4: The Perforated Screen Façade Covered with Weathering Steel	35
Figure 4.5: Three Level of Victorian.....	36
Figure 4.6: Jacobs Medical Centre at UC San Diego Health	38
Figure 4.7: Location of Jacobs Medical Centre at UC San Diego Health.....	39
Figure 4.8: The Garden Hospital Patients, Loved Ones, And Staff Members All Have Access to Calming Views of Nature and The Outdoors from Practically Every Ward and Floor of The Hospital.	39
Figure 4.9: The Process of Forming Dynamic Shape.....	40
Figure 4.10: Site Plan Of The Jacobs Medical Centre(<i>Landezine, N.D.</i>)	41
Figure 4.11: Friendship Hospital Shyamnagar (RIBA, n.d.).....	42
Figure 4.12: Location of Friendship Hospital Shyamnagar, Upazila, Bangladesh (John Hill, 2022).....	42
Figure 5.1: Pictures of test samples of Victorian Heart Hospital of Patient room.	46
Figure 5.2: Chart of Victorian Heart Hospital Patient Room Results of Fractal Dimension	46
Figure 5.3: Pictures of test samples of Victorian Heart Hospital of Waiting Area	48
Figure 5.4: Chart of Victorian Heart Hospital-Waiting Area.....	49
Figure 5.5: Pictures of test samples of Jacobs Medical Centre of Patient Room	50
Figure 5.6: Chart of Jacobs Medical Centre - Patient Room Results of Fractal Dimension	50
Figure 5.8: Chart of Jacobs Medical Centre – Waiting Area Results of Fractal Dimension	52
Figure 5.7: Pictures of test samples of Jacobs Medical Centre of Waiting Area	52

Figure 5.9: Pictures of test samples of Friendship Hospital of Patient Room	53
Figure 5.10: Chart of Friendship Hospital - Patient Room Results of Fractal Dimension..	54
Figure 5.11: Pictures of Test Samples of Friendship Hospital of Waiting Area.	55
Figure 5.12: Chart of friendship Hospital-Waiting Area Results of Fractal Dimension.....	56
Figure A.1: Project Charts :(Site, Ground, Level5, Level 7 Plans with West Section and Elevation of The Victorian Heart Hospital Project.	75
Figure A.2: Floor Plans Of The Jacobs Medical Centre (Archdaily, N.D.-A).....	76
Figure A.3: Architectural Treatments of Rainwater and Wind Flow & Natural Ventilation and Sun Radiation Direction in Friendship Hospital Shyamnagar, Upazila, Bangladesh(John Hill, 2022).....	76
Figure A.4: Friendship Hospital (A) Perspective-Section (B) Section B-B (C) Section A- A(John Hill, 2022).....	76
Figure A.6: Friendship Hospital (A) and (B) Zoning and Access Control (John Hill, 2022).	76
Figure A.5: Friendship Hospital-Elevations(John Hill, 2022)	76
Figure A.7: Plans of Friendship Hospital (A) First Floor Plan (B) Second Floor Plan (C) Geometry of Courtyards (Archdaily, N.D.-B).....	76

LIST OF CHARTS

	<u>Pages</u>
Chart 3.1: Participants' Percentage	29
Chart 5.1: The Relationship between the Fractal Dimension Levels of Patient Room –	47
Chart 5.2: The Relationship Between the Fractal Dimension Levels of Waiting Area Elements –	49
Chart 5.3: The Relationship Between the Fractal Dimension Levels of Patient Room Elements –	51
Chart 5.4: The Relationship between the Fractal Dimension Levels of Waiting Area Elements	52
Chart 5.5: The Relationship Between the Fractal Dimension Levels of Waiting Area Elements –	54
Chart 5.6: The Relationship between the Fractal Dimension Levels of Waiting Area Elements –	56
Chart 5.7: The Relationship of Participants in Survey	57
Chart 5.8: The Relationship between Participants' Preference and Fractal Dimension.....	58
Chart 5.9: The Relationship between Participants' Preference and Fractal Dimension of Patient Room	59
Chart 5.10: The Relationship between Participants' Preference and Fractal Dimension of Waiting Area.....	60

ABBREVIATIONS

HVAC	:	Heating, Ventilation and Air Conditioning
EBD	:	Evidence-based Design
AIA	:	Australian Institute of Architects
ALSO	:	The Average length of stay
ESD	:	Environmentally Sustainable Design
VHH	:	Victorian Heart Hospital
UCSD	:	University of California, San Diego
TDMA	:	Time Division Multiple Access
FracLac	:	Fractal Lacunarity
NIH	:	The National Institutes of Health in the United States
RIBA	:	Royal Institute of British Architects

LIST OF SYMBOLS

D_s	:	The Self-Similarity Dimension
d	:	The Measured Dimension
DB	:	The Box Calculation Dimension
N	:	Replicas Of The Shape Itself
r	:	The Measurement Factor
U	:	The Measured Length
S	:	The Length Of Measuring Unit
d	:	Slope , And The Measuring Dimension
\bar{P}	:	The Mean Of The Preference Ratings
\bar{C}	:	The Mean Of The Hypothetical Comfort Levels
$cov(P,C)$:	The Covariance Between Preference Ratings And Hypothetical Comfort Levels
σP	:	The Standard Deviation Of Preference Ratings
σC	:	The Standard Deviation Of Hypothetical Comfort Levels.
r	:	The Pearson Correlation Coefficient (R)
O	:	The Overall Fractal Dimension
C	:	The Ceiling Fractal Dimension
F	:	The Floor Fractal Dimension
W	:	The Wall Fractal Dimension
T	:	The Furniture Fractal Dimension
P	:	The Participants' Preferred Fractal Dimension

1. INTRODUCTION

Fractals are a field that is exciting in its self-similarity and mysterious in its complexity, and to conscious its effect, it must be contained in a physical medium, such a hospital. In this thesis, we will shed light on the relationship that brings together all this data and the recipient. This study acknowledges We recognize the profound implications of fractals in the field of hospital design, where the fusion of aesthetics and function is crucial. By understanding fractals and their inherent structure, we aim to explore how integrating them within hospital environments can create a warm, comfortable environment that absorbs feelings of anxiety and stress, contributes to patients' reassurance and well-being. This research seeks to illustrate the importance of engaging fractals as a guiding principle in the design and creation of friendly and welcoming therapeutic spaces, patient-centric.

We must draw attention to the importance of the perception process in the user's awareness of the fractals integrated into the design of hospital elements, as this process plays an important role in interpreting the stimulus (fractals) to the recipient based on his awareness of external things and their characteristics and how the data of the stimulus is transmitted through the physical medium (the hospital) to the recipient's sensory organs. Then emotional side that chooses to feel comfortable or stressed.

When thinking about hospitals Float feelings of anxiety and stress. Although hospitals are a haven for recovery, for some they trigger a feeling of anxiety that can escalate into a pronounced fear known as Nosocomephobia (Fear of Hospitals) – Nosocomephobia is an intense fear of hospitals. A type of anxiety disorder that can cause panic attacks. Contributes to unreceiving adequate medical care. Nosocomephobia may be related to fears, such as germs, disease, blood, or needles.

These anxieties are compounded by the relentless barrage of sights, smells, and sounds unique to hospitals, creating a sensory overload that overwhelms the senses. However, a paradigm shifts in hospital architecture driven by the principles of fractal geometry. Fractals have the potential to transform environments into visually captivating and harmonious spaces. By tapping into the innate preferences of the human mind, fractal-based designs can soothe frayed nerves and promote a sense of tranquillity, laying the foundation for a new era in hospital architecture.

Research has shown that exposure to fractal patterns induces a positive physiological response, including reduced heart rate, lowered blood pressure, and increased relaxation. By incorporating fractal elements such as fractal art, fractal-inspired building structures, and fractal patterns in interior design, hospitals can create a soothing and therapeutic atmosphere that positively impacts patients, visitors, and even healthcare professionals (Hägerhäll et al., 2015). The visually complex yet harmonious nature of fractal patterns provides a sense of visual interest, diverting attention from pain and anxiety, ultimately fostering a healing environment.

Fractal geometry also offers practical benefits for hospital design by enhancing spatial efficiency and way-finding (R. P. Taylor, 2021). Hospitals are often vast and intricate complexes, and finding one's way through them can be daunting and time-consuming. By utilizing fractal-inspired layouts, where smaller components mimic the overall structure, patients and staff can easily navigate the complex hospital environment. Fractal-inspired floor plans and architectural designs provide intuitive wayfinding cues, reducing confusion and stress for both patients and staff members. Furthermore, the self-similarity of fractals can optimize the use of space by allowing for modular and adaptable designs that can accommodate future expansions and changing healthcare needs. Moreover, the incorporation of fractal geometry in hospital design extends beyond the physical environment. It also extends to the digital realm, where fractal algorithms can be employed in the development of cutting-edge medical technologies (Analysis, 2023). Fractal-based imaging techniques, for instance, enable the visualization of intricate details within the human body, enhancing diagnostic accuracy and facilitating minimally invasive procedures. By harnessing the power of fractal geometry, hospitals can push the boundaries of medical advancements, revolutionizing diagnostics, treatment, and patient care. In conclusion, the integration of fractal geometry in hospital design has emerged as a transformative approach, revolutionizing the healthcare environment. By incorporating self-similarity, visually captivating patterns, and spatial efficiency, fractal-inspired hospital designs promote healing, reduce stress, and improve wayfinding. Furthermore, the influence of fractal geometry extends beyond the physical environment, revolutionizing medical technologies and enhancing patient care. As hospitals strive to provide patient-centric, efficient, and visually appealing spaces, fractal geometry stands as a powerful tool that shapes the future

of healthcare architecture.

1.1 FRACTAL DEFINITION

Fractal geometry is a field that bridges mathematical complexity and aesthetic innovation. Referring to his famous work "Les Objets Fractals. Forme, Hasard et Dimension", Mandelbrot first the term "Fractals" are geometric shapes or patterns that repeat themselves at different scales, and one of the key properties of a fractal is self-similarity (The Fractal Foundation, 2013)(Matsko, 2016). This self-similarity is achieved through the process of iteration, where a given operation is repeated over and over again on smaller or larger scales, resulting in a self-similar structure. Regarding the fractal dimension, Mandelbrot pointed out in the same book: that the Euclidean space set becomes fractal if its topological dimension is smaller than its Hausdorff dimension and vice versa (Balka et al., 2015; Iturriaga & Jovanovich, 2012). In architecture, the concept of fractal architecture involves applying these principles to design and construct buildings and structures (Vrdoljak & Miletić, 2019). Architects can create unique and innovative edifices by incorporating self-similar elements while striking a balance between orderly arrangements and chaotic dynamics(Mayackaya et al., 2021). This approach allows architects to express the universe's complexity. It's worth noting that fractal principles, such as self-similarity and repetition, have deep historical roots, finding application in Indian Hindu temple architecture, which reflects the universe's self-similar nature as expounded in Hindu philosophy(Viswanathan & Ambasta, 2023).

Research and Insights on Fractal Geometry in Architecture Extensive research has explored the application of fractal geometry in architectural design. For instance, the paper "Fractal Geometry as Design Aid" delves into the intricacies of incorporating fractal geometry into architectural compositions. It emphasizes the importance of a deeper mathematical understanding, expressing the intricate nature of fractals in architecture. The paper picks out the concept of "curdling" as a method to create complex layouts, employing random fractal elements to provide a canvas for individual interpretations of order. Furthermore, this research discusses the use of fractal geometry in music, uncovering underlying fractal characteristics in various musical forms. Range analysis is employed to measure the fractal dimension of architectural elements, revealing how different orderings can yield diverse fractal measurements. This approach potentially explains the allure of complex rhythms in

vernacular design, showcasing the multifaceted nature of fractal geometry's influence on architectural composition (Bovill, 2000).

Fractal Geometry's Potential Impact on Well-being Intriguingly, fractal geometry extends its influence beyond architectural aesthetics. Studies like "Fractal Fluency: An Intimate Relationship Between the Brain and Processing of Fractal Stimuli" emphasize the role of fractals, particularly midrange complexity fractals, on human perception and well-being. Midrange complexity fractals ($D = 1.3-1.5$) are found to have unique effects on the visual system and neurophysiological responses. They facilitate visual searches, enhance attention and pattern recognition, and induce an aesthetic experience. Importantly, exposure to mid-D fractals is associated with a reduction in physiological stress levels, offering potential benefits in addressing stress-related illnesses. The parallels between this research and the application of fractal geometry in architecture suggest that integrating midrange complexity fractals into architectural design may create spaces that not only engage viewers visually, but also promote well-being. Such spaces may elicit specific emotional and cognitive responses, aligning with the desire to create architecture that contributes to both aesthetic delight and human well-being. The confluence of scientific research and architectural design form a promising avenue for innovation in the field, where mathematical complexity and aesthetic appeal converge to shape our built environments and enhance our lives (R. Taylor & Spehar, 2016) (Trivedi, 1993), (Dhrubajyoti Sardar & S. Y. Kulkarni, 2015).

1.2 THESIS STATEMENT

Fractal geometry represents a branch of mathematics that studies self-similar patterns at different levels (Bayrak & Kirci, 2020). It has been applied in various fields, including architecture, where it can help measure and understand the complexity and diversity of the built environment (Joye, 2011) and (Vaughan & Ostwald, 2021).

Hospitals represent one of the healthcare facilities that provide treatment for patients as well as medical education and training for students, researchers and others (Lopes & Betrouni, 2009). As healthcare facilities, they face the constant challenge of balancing the needs of patients, staff and learners, and complying with safety and quality standards (Calkins, 2013). Some principles of hospital design and planning suggest that the design should be considered for future expansion, improving core functions, and involving caregivers in the design

process (Garg & Dewan, 2022) and (Jiang & Verderber, 2017).

Hospitals often fail to incorporate elements that help promote well-being and relieving stress are factors that greatly influence patient outcomes. Given previous studies that indicated a correlation between fractals and reducing physiological stress, this study raises the question: “Is incorporating fractals into hospital design could enhance user comfort And reassurance by Fractal Dimension” Which seeks to discover fractals, known for their ability to enhance spatial experiences and reduce stress (Fractal Fluency) (R. Taylor & Spehar, 2016),The experience of using fractal geometry can have a positive impact on the comfort of users in hospitals, based on the hypothesis that “the fractal dimension used in hospital design can play an important role in reducing stress and providing comfort that users perceive.”

1.3 RESEARCH OBJECTIVES

The research examines the impact of the use of fractal geometry in the design of healthcare facilities and its role on the user experience, through how Fractal Dimensions relates to user comfort, and reassurance. Taking into account fractal patterns and their Dimensions Important in internal architecture of hospitals. It aims to evaluate how users and patients view hospital facilities that make use of fractal design ideas. The ultimate goal is to provide guidance and design suggestions for successfully integrating fractals into educational medical facilities while improving the hospital environment using architectural design by employing fractal geometry as an aesthetic, comfort, and reassurance factor that users perceive.

2. GENERAL INFORMATION

2.1 FRACTAL

Shapes in nature draw attention to their diversity and the accuracy of their composition, and we have always looked at them with admiration and inability to absorb them and understand their formation, but at the present time part of this inability has been removed through fractal geometry, which began to describe and interpret these shapes.

The study of both chaos theory, and complexity theory, which has been a central focus of architecture, paved the way for the birth of fractal geometry, Euclidean geometry describes plane and solid figures on the basis of axioms and theorems employed by the Greek mathematician Euclid (c. 300 BC), and fractal geometry describes the complex and irregular patterns that can be found in nature. And representing “a mathematical approach that describes the way space is filled by figures or objects.”(Vaughan & Ostwald, 2018). Fractional geometry adopts the study of fractals. Which is defined in the dictionary as Irregular curves or shapes for which any suitably chosen part is similar in shape to a given larger or smaller part when magnified or reduced to the same size(*Dictionary*, n.d.). Geometrically, Fractals are never-ending, infinitely complex patterns or shapes that are self-similar across different scales. They are created by repeating a simple process over and over in an ongoing loop. The overall fractal figure contains portions that seem identical to each other at different magnification levels, and the figure covers more space than its topological bounds (Voss, 1988). Carl Bovill sees in his book “Fractal Geometry in Architecture and Design”, P.176 that “Fractals, in general, have a beginning, but they do not have an ending”(Bovill, 1996).

2.2 FRACTAL PROPERTIES

Fractal geometry, which represents a branch of mathematics developed in the late 20th century, has revolutionized our understanding of the intricate and irregular patterns in nature, art, and science. Unlike the traditional Euclidean geometry of smooth shapes and perfect symmetry, fractal geometry explores the fascinating world of self-similarity and complexity. In this introduction, we will explore the fundamental properties of fractal geometry,

including self-similarity patterns, fractal dimensions, and applications across architecture fields.

2.2.1 Self-Similarity

Fractals exhibit self-similarity; Self-similarity is a property in which an object contains smaller copies or patterns of itself at different scales. A fractal object is self-similar if it undergoes a transformation and has modified dimensions of the structure by the same scaling factor. That means the relative proportions of the shape's sides and internal angles of it remain the same. The new shape may be smaller, larger, translated, or rotated. This property is ubiquitous in the natural world as described by Mandelbrot, (Wolfgang E. Lorenz, 2003). Therefore, Fractals produced by self-similar transformations are 'true' fractals. Self-similarity appears in objects as diverse as leaves, mountain ranges, clouds, and galaxies. If a transformation applies to an object unequally, then the transformation is referred to as a self-affine transformation. Because the internal angles of the shape or the relative proportions of the shape's sides do not remain the same, so these curves are not exactly self-similar. For example, parts of a "natural" fern or a snowflake are not exactly a copy of the whole, but nevertheless, the parts look very much like the whole - this is called a statistical self-similarity because on average parts look equal (Bovill, 1996). This is worth noting there are two types of self-similarity in fractals: Exact self-similarity that lies in fractals resulting from mathematical operations that repeat a single pattern of itself and by that fractals are identical at any level when magnification. While the approximate or statistical self-similarity, patterns reoccur in it but some parts of it can have the same structure and distribution, but do not have exact replicas with magnification. Like the shapes found in nature. Oppenheimer used the term "fractal" instead of self-similarity and affirmed: "The geometric notion of self-similarity became a paradigm for structure in the natural world. Nowhere is this principle more evident than in the world of botany" (Smith, 1984).

In the Fractal Basics A fractal represents a method for elucidating how figures or objects occupy and fill space but cannot apply the concept of fractals to all objects unless they pass through several steps, first, Initiator Which means the basic shape. Second, Generator: Collection of copies of the initiator figure arranged proportionally and to clarify this, the

Sierpinski gasket, is a good example.

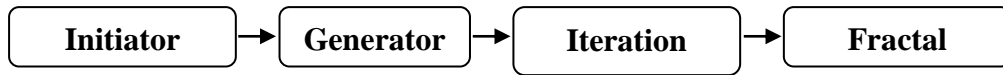


Figure 2.1: Fractal Basics Stage.

To make the iterated fractal, use the initiator and generator displayed:

Sierpinski gasket: We start with an isosceles triangle (the initial shape), and to make multiple copies, the midpoints of each side are connected to each other. The result is three triangles with an inverted triangle. The inverted triangle is removed and thus the (generator) is formed. At each stage, apply the Generation Rule by substituting each instance of the initiator with a scaled version of the generator, making any required rotations... Then the process is repeated on the other triangles and the iteration process continues to get after that the Sierpinski gasket (Fig 2.2).

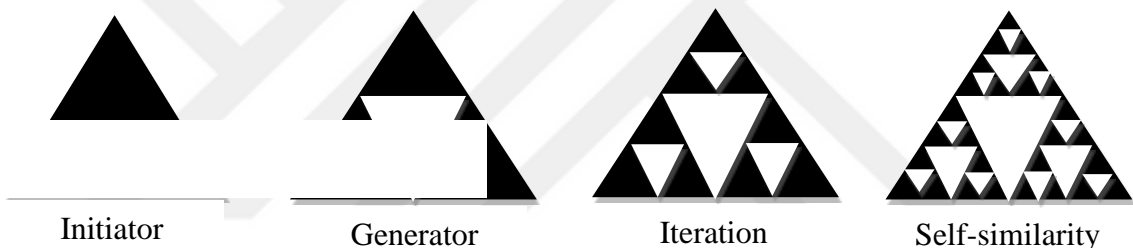


Figure 2.2 : Self-Similarity Basic Steps in Sierpinski Gasket.

Koch curve: The initial shape is a line segment, and to get a generator We segment the line into three equal parts and then substitute the middle part with two identical copies of itself, arranging them to form an isosceles triangle and to make multiple copies, the straight segments are replaced by "the generator shape". This process continues in iteration, to get finally the Helge von Koch curve, which was first explored in 1904 (Fig 2.3).

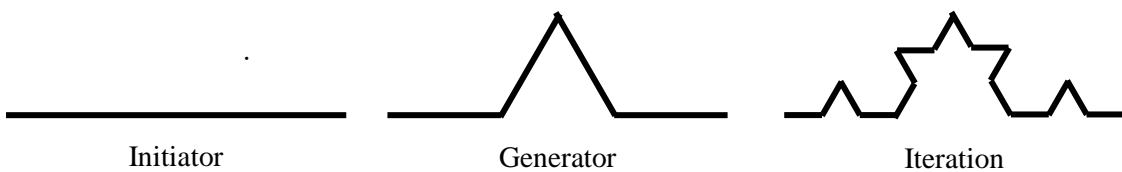


Figure 2.3: Self-Similarity Basic Steps.

2.2.2 Fractal Dimension

The geometry reveals the physical characteristics of the object and through that, determines the perception of the recipient, i.e. how an object is being perceived and understood. And by, perception, mankind started using dimensions but intuitively. Ostwald and Vaughan state (Vaughan & Ostwald, 2018) "Dimension is physically tangible, and it has a practical material and scale limits, meaning it cannot be infinitely divided or enlarged." This argument clarifies the way a dimension is understood. For the analysis of such dimensions, Bridgman in (1931) explains, "The principal use of dimensional analysis is to deduce from a study of the dimensions of the variables in any physical system certain limitations on the form of any possible relationship between those variables" (Bridgman, 1922) (Sonin, 2001).

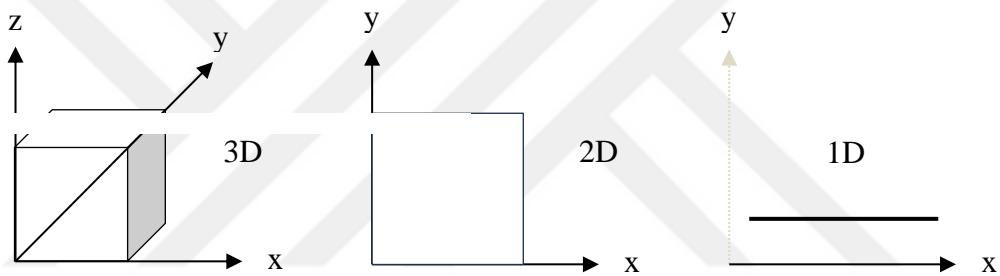


Figure 2.4: Traditional Dimensions.

In some ways, fractals constitute a rebellion against calculus since mathematics considers surfaces to be smooth and idealized, but fractals regard them as rough. Furthermore, the notion that fully self-similar forms are fractal forms contradicts the pragmatic nature of it, which represents nature itself, which is not entirely self-similar. The idea of fractal dimension represents the central of the fractal concept. The fractal dimension is a mathematical measure of the degree of the roughness of the fractal texture, and its value is greater than the topological dimension, in fractal geometry, the concept of "fractal dimension" is used to quantify the "roughness" or "complexity" of objects or patterns that exhibit self-similarity at different scales. So fractal dimension provides a measure of how a fractal object fills space, or how its complexity changes with respect to changes in scale, many ways in Geometry to specify the fractional dimension:

Ds: The self-similarity dimension for calculating dimensions of mathematically generated repeating patterns.

d: The measured dimension,

DB: the box calculation dimension for determining the ratios of a fractal's area or volume.

First, How Calculating Traditional dimensions (Wahl et al., n.d.)

General Rule for Traditional Dimensions:

“The growth rate of the length of a curve is related to the length and size of the tool (unit) used to measure it”(Bovill, 1996), and this relationship leads to the mathematical formula used to find the dimensions of traditional (Euclidean) shapes. To clarify this, a straight line with a dimension (D) is used that divides it into a certain number (N) of equal segments with a specific measurement factor (r): magnification factor that must be applied to obtain the original figure (Fig2.5). These variables can be used in writing the mathematical formula to find the dimension (D):

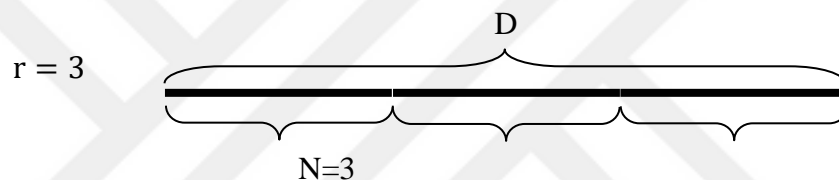


Figure 2.5: Object with One Dimension Divide To 3 Segments.

$$r^D = N \tag{2.1}$$

to prove that Euclidean geometry, like lines and squares and cubes, are self-similar, by applying the relation on the line example:

Where: $r=3$ $N=3$ $D=?$

$$3^D = 3^1 \quad D = 1 \text{ the dimension of line}$$

When applying Logarithm to this relationship:

$$D = \frac{\log N}{\log r} \tag{2.2}$$

$$D = \frac{\log 3}{\log 3} \quad D = 1$$

So based on self-similarity and the scaling factor (No Title, n.d.), one can apply this formula

in calculating the dimensions of fractal geometry but must apply Logarithm on both ends of this relationship to find the Fractal dimension for a fractal figure like the Von Koch Curve (snowflake):

Scaling factor reducing to $r = 3$

Replicas of the shape itself are $N = 4$.To find D:

$$3^D = 4 \quad \log 3^D = \log 4 \quad \frac{D}{\log 3} = \frac{\log 4}{\log 3} \quad D = \frac{\log 4}{\log 3} = 1.26 \quad \text{fractal dimension}$$

Benoit Mandelbrot, known as the father of fractals, described "fractal dimension as a way to measure the space-filling ability of a pattern". Mandelbrot also believes that there is another dimension between traditional dimensions (1, 2, and 3), which he called the fractal dimension. And that the relationship is direct between the roughness of the body and its fractal dimension, as the higher it increases, the greater the fractal dimension of the body. Mandelbrot showed that this roughness (fractal dimension) can be accurately measured using fractal geometry(Mandelbrot, 1983a).

While Carl Bovill saw that The fractal dimension serves as a mathematical gauge of the level of intricacy in the observed texture. and that It quantifies the degree to which a structure surpasses its fundamental dimension to occupy the succeeding dimension. Examples of such curves include the Koch, Minkowski, and Peano curves. They represent transition curves starting from a one-dimensional line that then encloses a space (such as the Koch curve),

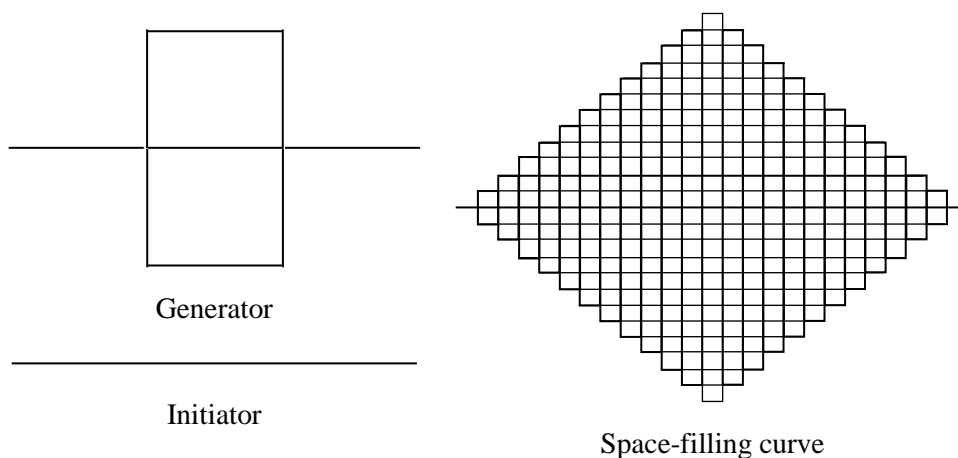


Figure 2.6: Peano Curve.

and then fills an entire two-dimensional plane (such as the Peano curve) (Fig 2.6) So, The fractal dimension serves as a metric for how far the structure goes beyond the base dimension to fill in the next dimension."(Bovill, 1996) .

Another definition by Ostwald, M.J. and Vaughan, J., "The fractal dimension is a mathematical assessment of the inherent complexity level within an image or object." (Ostwald & Vaughan, 2016).

Every iteration in the creation of a fractal curve contributes additional length to the curve, and if this process continues infinitely, the resulting fractal curve will possess an infinite length (Bovill, 1996).

The mathematician Georg Cantor has explained that identifying dimensions (the fractal dimension) with coordinate numbers is a "treacherous" notion, and modern mathematics prefers to emphasize the topological aspect of dimension. Determining the plane shape requires two coordinates (X, Y) in order to define any point on it. This idea is correct with the fractional dimensions because the Cartesian coordinate system (x, y, z) does not include a fractional dimension (Mandelbrot, 1983a).

2.2.2.1 The fractal dimension according to the hausdorff-besicovitch method

Mathematicians Felix Hausdorff and Abram Besicovitch changed the game in math by realizing the necessity for a more accurate way to measure dimensions. Usually, (points=0 D, lines=1D, planes=2D, and volumes=3D). But Hausdorff and Besicovitch note that some curves didn't fit the traditional method because they have an "in-between" dimensions. So traditional methods couldn't catch these complexities, so in 1918 Hausdorff introduced the Hausdorff dimension, later developed by Besicovitch.

Originally, Hausdorff dimension used to measure roughness, but turned into a tool for understanding fractal dimensions (complexity) in architectural forms. This method, particularly suitable for analyzing the self-similarity property of architectural elements (Stiny, 1981), is a valuable tool to measures the "roughness" or "complexity" of a set or curve within architectural forms. And determining and quantifying the space-filling capacity of fractal curves or shapes and provides insights into the level of complexity in design. Additionally, the technique offers valuable assessments of visual appeal, structural stability, and spatial organization in architectural.

The Hausdorff-Besicovitch Dimension method estimates the fractal dimension by analyzing the relationship between scale and measurements. Here are two methods:

2.2.2.2 Self-similarity dimension

The fractal dimension of self-similarity is used to measure the complexity of a fractal form (Ed & Moellering, 2014), because Fractals are geometric shapes that exhibit self-similarity at different scale levels (Betti, 2023), meaning that they contain smaller copies of themselves within their structure. The Hausdorff dimension compares and estimates the number of copies that cover the fractal form (Duvall et al., 2000).

In the study of fractals, the dimension is related to the concept of measurement or unit in mathematical relationship. Measurement depends on the number of copies into which the original formation is divided and the Magnification factor, and this rule valid for both fractal and non-fractal structures. Since the dimensions of (length=1D, area=2D, and volume=3D), if divided into smaller parts, are equal according to a certain scaling ratio. The mathematical formula of (Hausdorff-Besicovitch) can be applied to finding the dimension of self-similarity (Bovill, 1996):

This method is based on the principle that when you divide an object into smaller parts, the number of self-similar parts is related to Scale or magnification factor. Mathematically, this relationship is expressed as:(Bovill, 1996):

$$D_s = \frac{\log(N)}{\log\left(\frac{1}{r}\right)} \quad (2.3)$$

N: the number of self-similar objects (Tgmdev, 2012).

r: the scale of division.

D: the fractal dimension.

2.2.2.3 Box-counting dimension

The box-counting method stands as one of the simplest and most widely employed approaches for measuring the fractal dimension in Architecture (Gurung, 2018). It involves dividing the architectural form into a grid of boxes with a constant size, and then counting the boxes that intersect with the shape. By repeating this process with boxes of grid varying sizes, an association can be defined between the size of the boxes and the count of boxes,

allowing for the estimation of the fractal dimension. The box-counting method is applicable to both 2D and 3D architectural forms show in (Fig2.7) (Gurung, 2018).

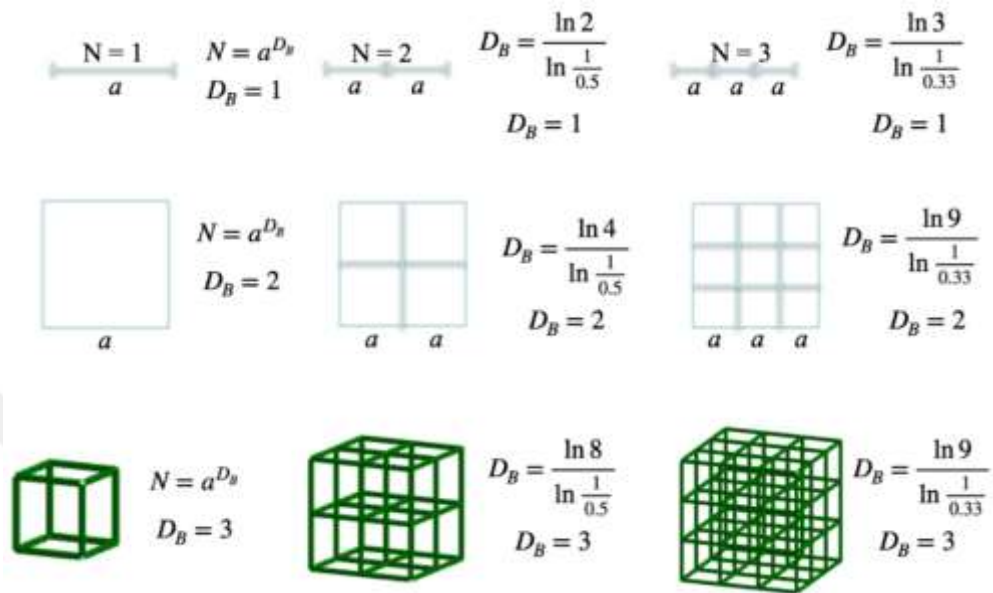


Figure 2.7: Illustrates the Determination Of The Fractal Dimension D For A Line, A Square, And A Cube.

$$D = \frac{\log(N)}{\log(\frac{1}{d})} \quad (2.4)$$

$$D = \frac{(\log N_2 - \log N_1)}{(\log \frac{1}{d_2} - \log \frac{1}{d_1})} \quad (2.5)$$

N : The number of boxes covered by the fractal curve is determined,

d : The size of the grid box is noted.

D : The fractal dimension

The box-counting method is a way of measuring the fractal dimension of an image or a pattern. Fractal dimension is a number that describes how complex or irregular a shape is. The higher the fractal dimension, the more detail and self-similarity the shape.

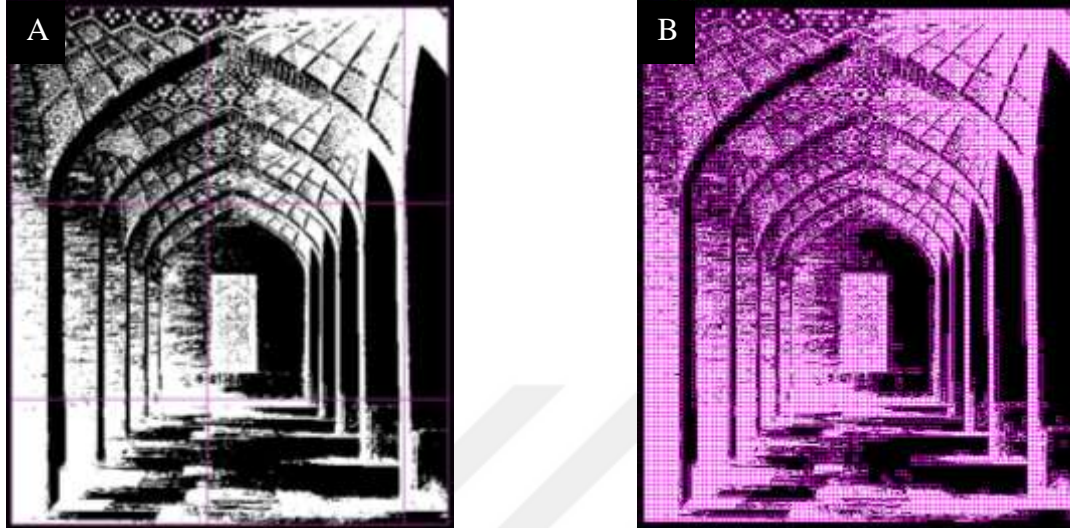


Figure 2.8: Image (A): (N)The Number of Boxes for Image=5 (1/D) The Size of The Grid Box =0.0095
Image (B): (N)The Number of Boxes for Image=200 (1/D) The Size of The Grid Box =0.3788.

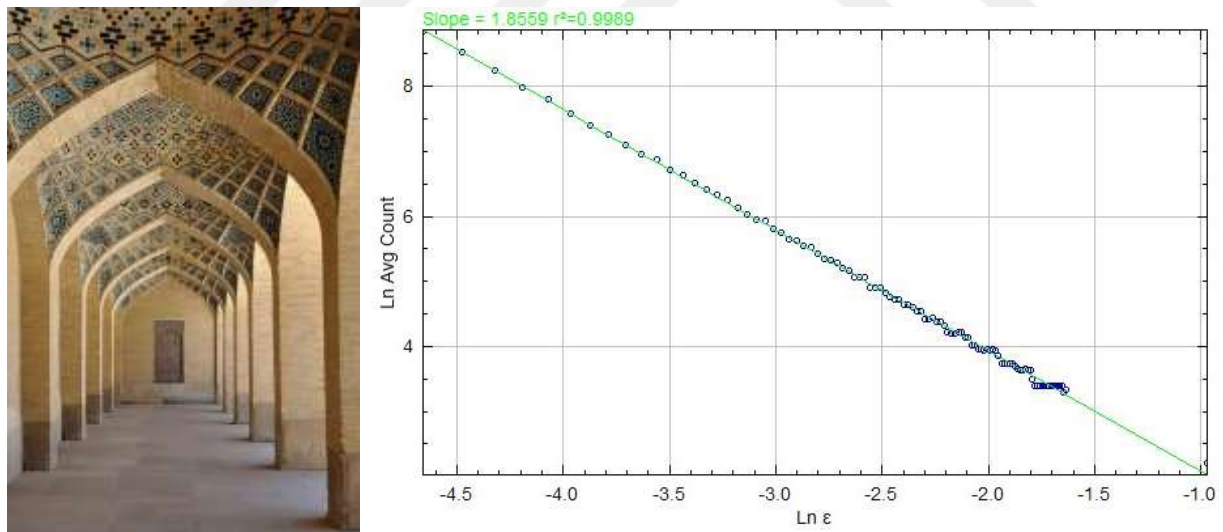


Figure 2.9: Show How the Box-Counting Method Finds the Fractal Dimension for A Side of the "Muqarnas" Which Is an Important Element of Architectural and Decorative Art of Islamic Architecture.

2.2.2.4 Measured dimension (d)

The measured dimension (d) is concerned with calculating the length of the boundaries of complex shapes. It has an inverse relationship with the length of the measurement unit

(instrument). The length being measured is inversely proportional to the length of the tool. It captures more and more detail as the smaller the unit of measurement, the greater the measured length with a smaller instrument and vice versa. In his renowned work "The Fractal Geometry of Nature,"(Mandelbrot, 1983b) Benoit Mandelbrot explored the connection between natural forms and fractals and posed the inquiry of measuring the length of the coastline of Britain. It is known that the coast of Britain includes many large and small bays and inlets. Hence, using a (small) measuring tool or unit of measurement will incorporate additional inlets and finer intricacies into the calculated length, causing the coastline measurement to extend continuously. Figure (2.10) illustrates a contrast in the assessed lengths of the British coastline when measured with straight instruments set at intervals of 200 miles, 100 miles, 50 miles, and 25 miles.

Table 2.1: Measured Lengths of the Coast of Britain.

Number of units	Unit length	Coastal length
7	200 miles	1400 miles
16.25	100 miles	1625 miles
40	50 miles	2000 miles
96	25 miles	2400 miles

The measured dimension is calculated by the formula:

$$u = constant \left(\frac{1}{s}\right)^d \quad (2.6)$$

Where: u: the measured length, s: the length of the measuring unit, d: slope and the measuring dimension.

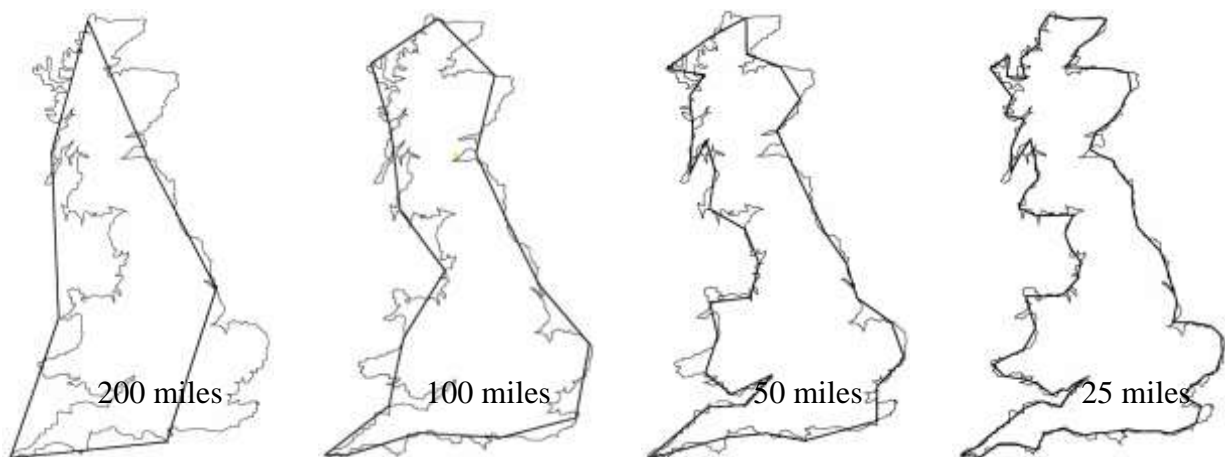


Figure 2.10: The Extent of Variation in The Measured Length of Britain's Coast at Each Length (200 Miles, 100 Miles, 50 Miles, 25 Miles) of A Unit of Measure [4].

2.2.3 Infinity

Infinity is one of the captivating aspects of fractals. It plays a significant role in fractal geometry, which deals with complex, self-replicating geometric patterns. Fractals are distinguished by their self-replicating patterns across various scales, meaning that as you zoom in on a fractal, you see similar patterns repeating over and over again. This self-similarity often leads to intricate structures and shapes that can extend infinitely in terms of complexity and detail. Fractals are characterized by self-similarity, meaning that patterns repeat at different scales.

2.3 APPLICATIONS OF FRACTAL GEOMETRY IN ARCHITECTURE DESIGN

The philosophy of fractal geometry, which focuses on how objects or shapes fill space, has found applications in architectural design throughout history. Egyptian, Indian, and Chinese civilizations, while not explicitly aware of fractal geometry, incorporated self-replicating patterns and principles into their architectural designs.



Figure 2.11: The Existence of The Golden Ratio , And Self-Similarity in The Pyramids of Giza.

Scientists who studied the Pyramids of Giza (Fig 2.11) found signs of the existence of the golden ratio (Ramirez et al., 2018), and self-similarity in their construction even if it was not intended (Fig 2.11-2.12), reflecting fractal concepts, and the tiered pylons of Egyptian temples create a sense of repetition and hierarchy.



Figure 2.12: The Tiered Pylons of Egyptian Temples.

Similarly, Indian temples (Dutta & Adane, 2014) feature intricate and repetitive carvings mirroring fractal-like patterns (Fig 2.13).



Figure 2.13: Fractal Patterns in Repetition Carvings of Indian Temples.

The Traditional Chinese Gardens (Peng, 1986) (Fig 2.14) and Forbidden City in Beijing (Zhang et al., 2023) (Fig 2.15) incorporate hierarchical layouts and repeated architectural patterns reminiscent of fractals.



Figure 2.14: Suzhou Gardens China.



Figure 2.15: The Forbidden City in Beijing.

In contemporary architecture, fractal design continues to inspire innovative and visually impactful structures. Examples include the Eden Project Biomes in the UK, inspired by fractal geometry for efficient use of materials and space, and the Lideta Mercato in Addis Ababa, Ethiopia, which integrates fractal motifs from traditional Ethiopian women's attire. The Lotus Temple in New Delhi is another modern architectural marvel inspired by fractal principles, showcasing the enduring influence of fractal geometry in architecture design (Fig 2.16).



Figure 2.16: (A) The Eden Project Biomes in the UK, (B) The Lideta Mercato in Addis Ababa, (C) The Lotus Temple in New Delhi.

Despite the great difference in design style, period and surrounding environment, all examples still arouse interest with their beauty and distinctive patterns. One of the main reasons why these buildings are beautiful is that our brains process the sensory information we receive from our senses and associate it with patterns used evolutionarily in nature. However, because pattern recognition and perception occur at a subconscious level. Most of us do not realize the psychological, neurological and physiological basis behind this feeling of beauty.

The Nature rich in fractal patterns, that have recursive self-similar components on levels of different sizes. Perceptual experience is influenced by the surroundings, including the built environment that houses these natural patterns (Robles et al., 2021). To understand the reason behind it, you must learn about the concept of human perception.

2.4 PERCEPTION

Norman reports in *The Psychology of Everyday Things* that humans do not always behave clumsily and do not always err, but are much more likely to when things they use are badly perception and designed (Norman, 1988).

The collaboration between environmental psychology and architectural design has yielded profound insights into human perception and behavior within built environments, particularly in healthcare settings. So what is perception (Bonnes et al., 2009).

Interest in perception dates back to the time of ancient Greek philosophers who were interested in how people know the world and gain understanding. The word perception comes from the Latin perception-, *perceptio*, meaning "apprehension with the mind or senses." (11_ Chapter 3.Pdf, 1375).

2.4.1 Perception Definition

Perception is the set of unconscious processes we undergo to make sense of the stimuli and sensations we encounter.

In Cambridge Academic Content Dictionary Define perception as an awareness of things through the physical senses(Perception, 1995).

In contemporary psychology, perception is defined as the brain's interpretation of sensory information so as to give it meaning (Perception, n.d.), and (McCallum, 2024).

Perception relies on the cognitive functions used to process information, such as utilizing memory to recognize the faces or detect a familiar scent. By the perception process, we are able to both identify and respond to environmental stimuli. Perception includes the five senses; sight, smell, sound, taste and touch. It also includes what is known as proprioception, which is a set of senses that enable us to detect changes in body position and movement.

2.4.2 Types Of Perception

The distinction between types of perception is often made by reference to the sensory receptors. It includes visual perception, smell perception, touch perception, sound perception, and taste perception. Perceiving the environment is done using these properties (Kendra Cherry, 2023).

2.4.3 The Perception Process

The perception process consists of three sub-processes: selection, organization, and interpretation (Qiong, 2017). Components of the surrounding environment are considered stimuli. When selection, the senses pick up stimuli according to their nature (the sense of touch, the sense of sight, the sense of hearing, the sense of smell, the sense of taste), as (the characteristics of the stimuli are important because they affect the perceiver. When the perceiver interacts with the stimulus, the sensation occurs and the process of perception begins) and then they are transformed into electrical signals. It is transmitted through the nerves and regulated through neural processes to the brain. This input is then “processed” to come up with an interpretation. Opinions, feelings, are the Outcomes of the perception process, which ultimately determines people's behavior.

How does the response process work?

Feeling is one of the functions of the brain, and it is linked to two parties: the recipient and the stimulus. It has three overlapping aspects: A - Perceptual aspect (cognitive) B - The emotional side (affects and emotions) C - the dispositional aspect (action)

Attention is the process of focusing feeling on something exciting, whether this stimulus is sensory or moral. McDougall states that attention is the primary determinant of behavior.

Sensation is the psychological effect that arises directly from the stimulation of a sense organ and the impact of the sensory centers in the brain, after the availability of stimuli suitable for the sense in question and of sufficient intensity ().

Perception A psychological process based on awareness of external things, their qualities, and their relationship to what is directly related to sensory operations.

Perception is the process by which the recipient interprets sensory stimuli. Sensation records environmental stimuli, and perception interprets them and formulates them in images that the recipient can understand.

Perception is a type of response to external forms and objects, and the response aims to carry out a specific type of behavior, and this depends on the nature of the external stimulus, the emotional and emotional state of the recipient, his intellectual orientation, and his previous experiences. Perception is a (psychological - sensory - mental) activity, as it depends on the effectiveness of the sensory system and the recipient's previous experience

2.4.4 Sensory Perception And Patterns

Humans' awareness of patterns in the surrounding environment began from the earliest times, as humans began to recognize patterns as a result of the amount of information they deal with. Humans appeared to have the ability to recognize patterns hidden within their sensory perception, as patterning is a basic feature of human perception that resulted from hypothetical logic and imagination. In a simplified way, human perception went through several stages to reach what it is today. In the beginning, it began with recognizing the surrounding patterns(Logan & Tandoc, 2018). Then it developed into the stage of its creation, manipulation, and restructuring through mathematics, imagination, and hypothetical logic, all of which played a role in human culture and its establishment(Logan & Tandoc, 2018).

The environment constitutes a rich source of stimuli and a key factor in the human cognition process, which constantly needs complex techniques and methods not only to process patterns, but also to reshape and process them in new ways. Mathematical and creative thinking that recreates complex patterns and shapes results from a human being's ability to memorize those patterns he recognizes in both mind and memory simultaneously, allowing him to borrow from them and restructure them in countless ways. The ability to recognize and create patterns is key to understanding the nature of human cognition and culture, human traits, the ability to manipulate information, and modeling(Logan & Tandoc, 2018).

2.5 HOSPITALS AND HEALTHCARE DESIGN

Design is often overlooked until it fails, as Bruce Mau notes in "Massive Change." (B. Mau et al., 2004) This failure prompts us to recognize the significant impact and power of design in our lives. When it comes to hospitals, the emphasis on patient-centric design is crucial. Helles (Helles, 2022). highlights the importance of creating hospital environments that prioritize patients' physiological and psychological needs, aiming to alleviate stress and anxiety. This patient-centered approach involves various factors such as location, access, identity, and human interactions (Mohebi et al., 2018). Additionally, Wang and Wang (Wang & Wang, 2017) stress the importance of addressing both physical and psychological needs through the use of color and materials in medical space design to foster comfort and aid in quicker recovery.

Integrating fractal elements into hospital design further enhances the therapeutic environment by creating visually appealing and psychologically supportive spaces (Alhonsuo & Colley, 2019; Patterson et al., 2017). These fractal patterns align with the goal of improving safety, efficiency, and patient satisfaction in healthcare settings. By combining patient-centered design principles with fractal elements, hospitals can provide holistic and supportive environments that cater to both physical and cognitive needs.

The shift towards patient-centered care in health facility engineering places patients at the forefront of treatment and care, prioritizing their comfort and well-being (Prugsiganont & Waroonkun, 2021). This approach acknowledges that hospitals and medical centers are not just places for treatment but integral parts of the treatment process itself (Bromley, 2012). Patient satisfaction is increasingly recognized as a key quality indicator in healthcare, influencing treatment outcomes and the overall quality of care (Schoenfelder, 2012), (Epstein et al., 2010).

Architectural design in healthcare has evolved from a focus solely on physical structure and functionality to encompass aesthetic, cultural, and psychological considerations (Güner, 2018). Creating healing environments for patients is now a primary objective, with patient experiences and preferences informing design decisions (van Oel et al., 2021). Collaborative design processes involving healthcare professionals and patients themselves are advocated for, recognizing the value of patient perspectives in shaping hospital environments.

Recent studies in environmental psychology underscore the importance of humanizing architectural design in healthcare to enhance environmental quality and user well-being (Schweitzer et al., 2004). The physical environment of healthcare facilities, including structure, interior design, and outdoor spaces, plays a crucial role in establishing spatial links and influencing patient experiences (Netherland Board for Healthcare Institutions, 2008).

2.5.1 Evolution Of Health Architecture Overview

Thoughtful and elaborate design of healthcare facilities can help create a comfortable atmosphere that gives visitors a first impression of comfort and reassurance, especially patients. A well-planned hospital building can prevent the spread of disease and provide a soothing environment that enhances the well-being and reassurance of patients (A. B. Mau et al., 2019).

In the past, hospital wards were reserved for patients unable to pay for doctors' home visits, while doctors treated upper-class patients at home. Religious institutions were the ones providing care for the poor in these sections. With the increase in disease incidence, there was a need to expand patient wards, but not taking into account the role of design in such spaces contributed to creating an unhealthy environment vulnerable to the spread of diseases (Buklijaš, 2008).

Florence Nightingale (Suárez, 2020), renowned as the founder of modern nursing, significantly influenced hospital design, particularly during the Crimean War. She successfully persuaded the British government to improve hospital conditions for the Armed Forces by using statistical evidence to demonstrate the link between sanitary conditions and reduced mortality and morbidity rates. Nightingale's innovative "Nightingale Ward" (Fig 3.1) (The new hospital design system was created with ventilation in mind, which permits the Miasma to dissipate. The main idea behind hospital building was assigning patients to separate wards, known as pavilions. A pavilion was a rectangular room with many windows to allow for cross-ventilation of light and fresh air and to allow for the least number of nurses to be supervising.) design, featuring a modular layout for simplicity and affordability, emphasized better ventilation. This marked a significant departure from the previous Roman model and bad circumstances. Her efforts during the war laid the foundation for a tremendous transition in healthcare. Stephen Verderber credits ancient Egyptians, Greeks,

Middle Eastern, and Eastern cultures for pioneering the use of architecture to promote health (Adams, 2000).

Notably, Nightingale's influence extends to the present, as seen in the layout of NHS Nightingale hospitals during the Covid-19 pandemic, showcasing the enduring relevance of her principles in addressing contemporary health challenges.

After that, the Hospital Survey and Building Act, commonly known as the Hill-Burton Act, was passed in 1946 and initiated the largest healthcare facility reform. President Truman introduced this act, which authorized the use of federal grants and loans for the purpose of enhancing the physical infrastructure of hospitals. The goal of this legislation was to improve public health by funding medical facility upgrades and new buildings at public and other non-profit institutions(LaRouche, 2002).

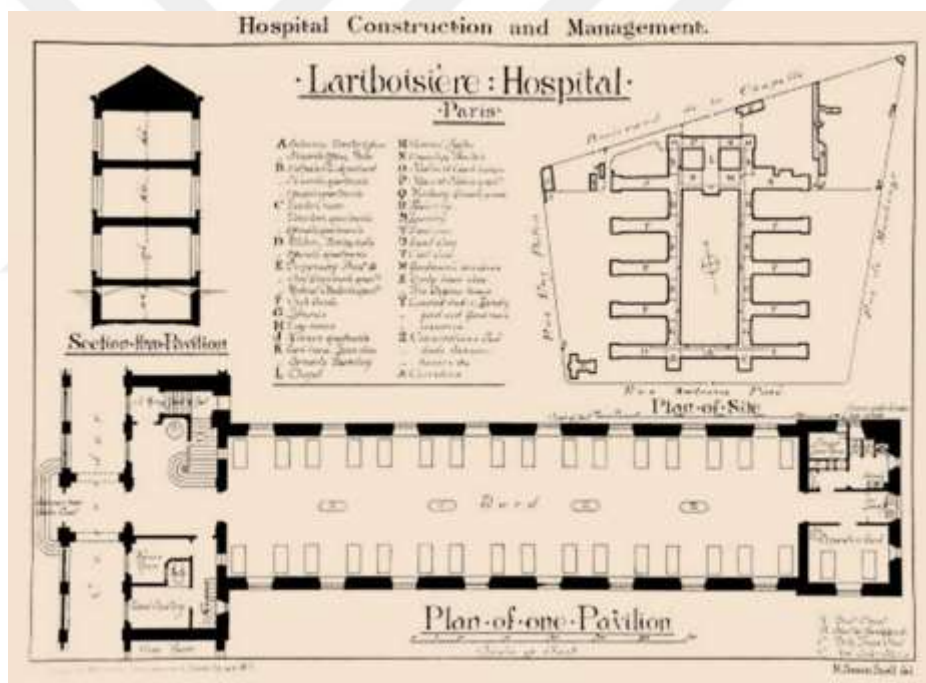


Figure 2.17: Model of "Nightingale Ward".

A dedicated architecture for the elderly arose in the 20th century. Hospitals once housed the elderly and chronically ill. "By the mid-1960s, it was a widely held assumption that regardless of cultural, political, or economic factors in a particular country, a certain percentage of the elderly population would be in need of a continuous level of healthcare services most efficiently provided within a long-term institutional setting," Verderber (Adams, 2000).

Sociologists and gerontologists advocated residential zing long-term care facilities. Hospitals are increasingly affected by hospitality.

Evidence-based design (EBD) influenced HC Health-Care architecture in the late 20th century. Evidence-based medicine, which applies scientific evidence to medical treatment, inspired EBD. Architects and designers can use scientific evidence to design. Hospitals and long-term care facilities have been the main sites of design research. Evidence-based designs speed healing, reduce pharmaceutical use, and reduce psychological suffering. Buildings, where people spend most of their time, should be comfortable. Healthcare and long-term care are undergoing a major cultural shift toward evidence-based, patient-centered care.

Big general hospitals sometimes subdivide into programs that offer specialized services, such as a number of ambulatory care facilities, specialized care facilities, and mental health institutions. These kinds of establishments are ranked according to the level of care required by their residents.

3. RESEARCH METHODOLOGY

This section describes the methodological approach adopted to investigate the conscious impact of fractal dimension on hospital architecture and its role in enhancing warmth and comfort. The research methodology is structured into several phases:

3.1 STUDY DESIGN

The research adopts a mixed approach, incorporating qualitative and quantitative techniques to comprehensively investigate the relationship between the fractal dimension in hospital architecture and its perceived impact in the eyes of hospital occupants. It adopts a case study methodology to examine realistic applications of fractal dimensions in hospital environments, and a questionnaire methodology to measure participants' awareness and understanding. The use of both case studies and questionnaire surveys allows for triangulation of data, enhancing the validity and reliability of the findings. The inclusion of quantitative analysis enables statistical inference regarding the relationship between the fractal dimension and participants' perceptions, while qualitative insights gathered via interviews and inquiries enrich the understanding of the underlying mechanisms and contextual factors to build a comprehensive conceptualization of the research areas.

3.2 LITERATURE REVIEW

Comprehensive examination of existing literature to explore the intersections between fractal geometry, human psychology and physiology, and the design of hospital architecture. Presentation and analysis of previous research in the field to establish the theoretical foundation for the study.

3.3 CASE STUDY

Three Hospitals Selected (Victorian Heart Hospital, Jacobs Medical Centre, Friendship Hospital) as a case studies Have Biophilic design as practical examples that resonate with the subject under investigation because the Fractal patterns fall in biophilic design as a classification, looking for "biophilic patterns and shapes".

3.4 SAMPLING STRATEGY

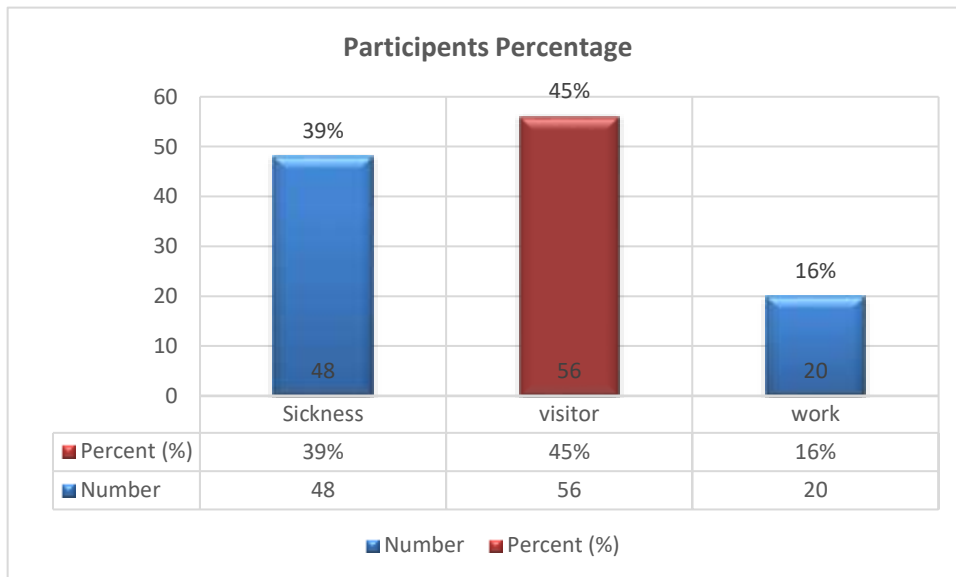
For Regarding the topic of selecting case study samples for (Victorian Heart Hospital, Jacobs Medical Center, and Friendship Hospital), two images were chosen for each case study, one for the patient room and the other for the waiting Area, from websites available to hospitals on the Internet, due to the difficulty of obtaining live and direct data despite Attempts to communicate with the relevant authorities, as I did not receive a response to my emails, in addition to the distance factor.

3.5 PARTICIPANTS

The electronic questionnaire prepared using Survey-Monkey targets a total of 124 participants from various categories and different backgrounds within the hospital environment, including sickness, workers, and visitors. Classify: (Sickness: 48 individuals, Workers: 20 individuals, Visitors: 56 individuals).

Questions are designed to assess participants' awareness of fractal concepts and to evaluate their preference and perception of hospital atmospheres.

Chart 3.1: Participants' Percentage.



3.6 ETHICAL CONSIDERATIONS

Informed consent will be obtained from all participants prior to their involvement in the survey.

Measures will be taken to ensure confidentiality and anonymity of participants' responses.

3.7 DATA COLLECTION

Interviews and Inquiries: Experienced and relevant individuals were interviewed to gather insights and perspectives.

Review of Previous Studies: Information and data from previous studies in the field were collected.

Questionnaire: An electronic questionnaire was prepared using the Survey Monkey platform, targeting 124 participants, including hospital visitors (patients, auditors, visitors), to assess their awareness of fractal concepts and evaluate their preference and perception of hospital atmospheres.

3.8 DATA ANALYSIS

Analysis of Case study Images: Two research samples for each case study (patient room and waiting area) were analyzed using the ImageJ program to calculate the fractal dimension via the box counting method. Interior design elements in the images, including fractal patterns, were analyzed using artificial intelligence (OpenAI).

Analysis of Questionnaire Data: The results of the questionnaire were analyzed using Excel and IBM SPSS Statistics to elucidate relationships, particularly examining the correlation between the fractal dimension and participants' cognitive awareness and its impact on creating a comfortable environment.

Responses from each participant category will be analyzed separately to identify any variations in awareness, preference, and perception.

Data Comparative analysis across participant categories will be performed to understand potential differences in perception and preference.

4. SELECTED PROJECTS FOR CASE STUDY TESTING

The relationship between biophilia and biophilic design and the fractal patterns

Initially, the biophilia word originates from the Greek, 'Biophilia' which meaning 'love of'. Literally means "a love of life" or living things. Humans have an innate love of nature, which is an intuitive and natural drive imprinted into our DNA.

For, the biophilia hypothesis revolves around the belief that humans are genetically predisposed to be attracted to nature.

This mean that all humans attracted Instinctively to the natural world. This idea that we are drawn to and need nature was first put forth by a man named Edward O. Wilson in his book, Biophilia, published in 1984

Biophilic design, rooted in the concept of biophilia, relates to humanity's inherent tendency to connect with nature and its profound impact on physical and mental well-being(Kellert, 2003; WILSON, 2009).

Accordingly, biophilic design integrates elements of nature into the built environment to achieve comfort, enhance productivity and overall health. This design includes many biophilic design principles, such as creating visual connections with nature, integrating natural light, water resources, indoor plants, vibrant patterns and shapes scattered in nature such as fractals, and adopting natural materials, to create a multi-sensory environmental experience and design dynamic and changing environments. Biomimicry enhances, Biophilic design, and increases the depth of connection with the environment. Experimental studies have shown that the human mind interacts with nature indirectly and this applies to the built environment which deals with shapes and surfaces that mimic nature, giving an effect similar to being in nature. The natural and built environment, with its natural shapes, fractal patterns and colors, help elicit innate responses and evoke feelings of comfort and well-being. During ancient times, the physical and biological sciences were inspired by fractal geometry to narrate symbolic historical and mythological events through geometric compositions that refer to those eras, Fractal geometry was later used to create the relationship between art and nature that serving aesthetic concerns physical health, and psychological well-being. And for that, biophilic design has been shown to positively impact cognitive function.

Fractal patterns represent a sub-principle of biophilic design that falls under the name

“biophilic patterns and shapes” (Kellert et al., 2011), characterized by self-similarity and complexity as they move across scales. Nature itself is rich in fractal structures, ranging from branching tree branches to the complex shapes of snowflakes. By incorporating fractal patterns into biophilic design, architects and designers foster feelings of connection within built environments to the natural world. Fractals evoke a feeling of harmony and relaxation, and their patterns found in nature reflect responses within humans. Its combination with architectural elements enriches the layout, material and decorative texture and enhances the aesthetics, functional structure of the space and luxury at the same time. Therefore, exploring the relationship between biophilic design and fractal patterns not only enriches our understanding of design principles, but also provides insight into how to create environments that resonate with our innate affinity for the beauty and complexity of nature.

In the context of searching for hospitals as case studies to test fractal patterns and the challenge in choosing appropriate case studies due to the limitations of hospitals specifically designed with fractal principles, the choice fell on biophilic design, as it is the most appropriate and closest choice to that. Hospitals were chosen that adopt the principle of “biophilic patterns and shapes” within biophilic design. As alternative case studies, due to their alignment with the required standards. The design nature of these selected cases, although not fractal, reflects properties that reflect the essence and effects of fractal patterns within biophilic environments. This approach allows the exploration of the relationship between biophilic design and fractal patterns, with the aim of highlighting and studying their impact on the design environment of hospitals and the perception of their classification as a welcoming and warm therapeutic environment or as a fearful and stressful environment, and thus its impact on human health and well-being.

4.1 CASE STUDY-VICTORIA HEART HOSPITAL



Figure 4.1: Victoria Heart Hospital.

The Victorian Heart Hospital (Fig 4.1) is a newly established facility and is the first state-of-the-art specialist heart hospital and the only one of its kind in Australia and the Southern Hemisphere.

Managed by Monash Health, this medical facility is located in Clayton, Victoria within the Monash Campus in close proximity to the Monash Medical Centre. The hospital offers clinical cardiology services, research initiatives and educational endeavors. It serves as a comprehensive center contributing to setting new standards in cardiovascular research (Abdel, 2023)

The project is a joint venture between Monash University and Monash Health. The project was designed by **Conrad Gargett and John Wardle Architects**, the hospital structure is as complex as the human body. The movement of people inside the hospital plays the role of blood circulation within the body, the organizational structure plays the role of the backbone, and the protection task is left to the facade of the building, which acts like the protective skin. Finally, all activities gravitate toward the heart, the center of attraction (the center of gathering). The design focuses on improving the human experience by establishing a connection between the mind and body through a multi-sensory environment. The design philosophy, is a thoughtful integration of architecture and nature in the context of a hospital setting, emphasizing a thoughtful approach to creating a healing environment. The

consideration is given to how the built environment affects the health and well-being of patients, carers, staff, researchers, students and visitors in the hospital architecture, and interior design, clinical layout and facilities layout and landscape design to create spaces that make the outdoors part of the soothing and healing environment. The hospital is envisioned as a community in itself (Stefan Mee, 2021), comprising patients, clinicians, staff, researchers, students, careers, and visitors. With recognizing that for some, the hospital is a long-term workplace, while for others, it may be a temporary stop, acknowledges the different connections people form with the facility.

To create a focal point where the different segments of society that constantly flow into the building direct and meet, a circular garden was carved into the building, representing the meeting point of the straight layout of the building with the radial geometry of the public spaces in the hospital, and together they embrace the garden. The circular garden (Figure 4.2) acts as a central element to unify the dynamic community within the hospital. This intentional design of radial geometry in public spaces is a poignant reminder of the inherent therapeutic essence of gardens and landscapes. It also provides a focal point for direction, creating a sense of cohesion and enhancing the collective experience within the hospital.

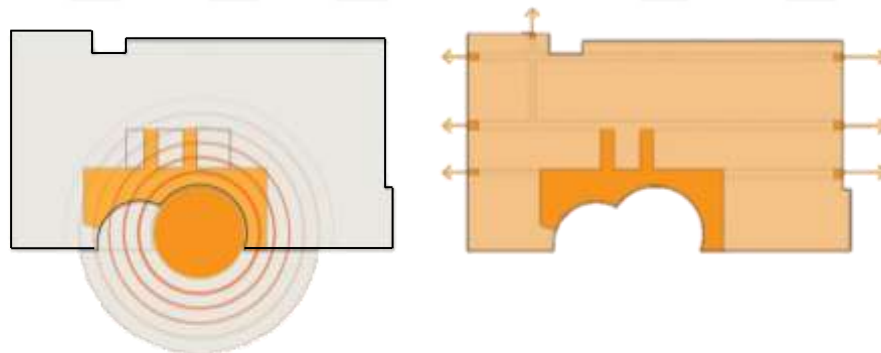


Figure 4.2: The Circular Garden and Design of Radial Geometry.



Figure 4.3: Borrow an Idea of the Historical Botanic Garden in Padua, Italy.

The Idea, drawing inspiration from the historical Botanic Garden in Padua, Italy (Fig 4.3), that highlights the healing nature of gardens and aligns with the hospital's role as a place of recovery(Stefan Mee, 2021).

The circular garden is not just an aesthetic metaphor but fulfills a functional role, providing a recreational space for rest or daily walks (Emmett, 2023). This is consistent with a holistic healthcare approach, which recognizes the role of the environment in the healing process.

The façade (Fig 4.4) is the perforated screen that Stretch to cover the lower podium levels of the Victorian Heart Hospital. Made of weathering steel, with color matures rapidly from a mid-red to a deeper burnt umber. The perforated screen Generally reduces the heat load on the Hospital building, especially the western flank façade, and minimizes glare, allowing air and natural daylight to pass through, spread, and see what is outside the building due to the density of the external holes, which reduces the proportion of shadows and brings calm inside.

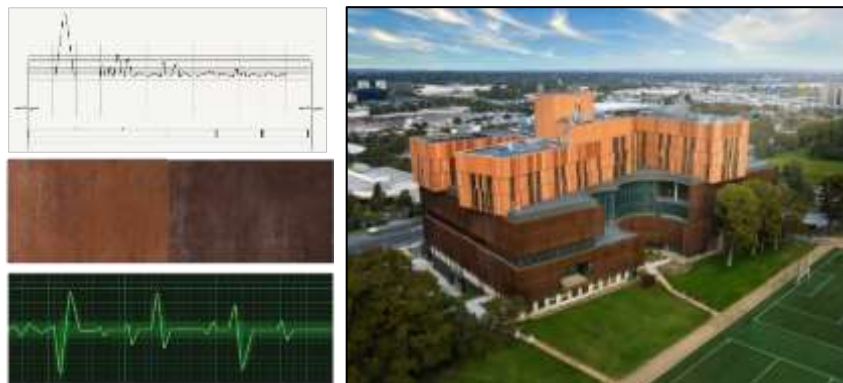


Figure 4.4: The Perforated Screen Façade Covered with Weathering Steel.

The Victorian Heart Hospital's design prioritizes a holistic approach to healthcare architecture, incorporating features guided by biophilic design principles and a salutogenic approach (which study investigates the origins of health by emphasizing factors that contribute to human well-being and overall health. In contrast to the traditional approach of studying factors that lead to disease (pathogenesis) (Antonovsky, 1979). The heavily landscaped courtyard garden at the center of the hospital aligns with biophilic principles, providing a nature-rich experience. The salutogenic approach focuses on factors promoting health and well-being, contributing to a positive environment for all occupants. with the building open to the surrounding landscape. Which was praised by Victorian Premier Daniel Andrews: “The first designs show a world-class hospital that puts the patient's needs and well-being at heart. It will save and change thousands of lives”(Team, 2018).

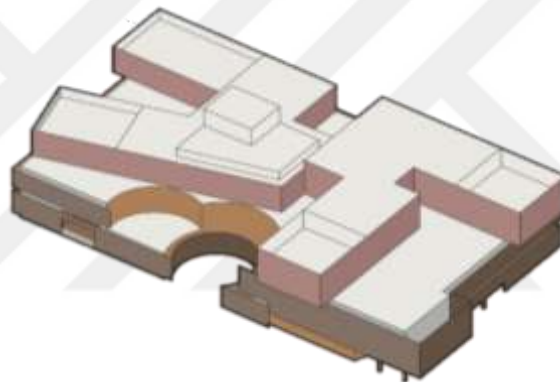


Figure 4.5: Three Level of Victorian .

The Core of Victorian Heart Hospital (VHH) (Fig 5.5) that consists of eight floors, prioritizes functionality, with a thoughtful organization into three vertical layers that correspond to varying degrees of public to private uses. These layers are seamlessly connected by a rational network of passageways, facilitating easy access to departments and outdoor spaces. At the heart of the building lies a circular garden, serving as a central focal point, while the clinical spaces, strategically positioned between this garden and the building's periphery, are intentionally designed to provide a calming environment. The integration of services and structure within these spaces is meticulously orchestrated to enhance the overall patient experience. To optimize navigation and enhance amenity, all primary routes extend to the building's façade, aiding in orientation throughout the hospital. Notably, the clinical areas are designed with the utmost consideration for tranquility, aligning with the hospital's

commitment to patient well-being.

The facility boasts three state-of-the-art operating theaters, a capacity for up to 206 beds, and the inclusion of seven cardiac catheter laboratories. This comprehensive setup ensures that the hospital is well-equipped to meet the diverse needs of its patients.

The hospital's second level features multifunctional laboratories, technology simulation rooms, collaboration spaces, training rooms, and medical study spaces, providing care to nearly 100,000 heart disease cases annually.

Victorian Heart Hospital has been carefully designed to improve the patient experience. “Upon arrival at the Victorian Heart Hospital, there is a sense of openness, with large voids and a central café, creating a feeling of a civic place rather than a hospital,” said Wardle principal Stefan Mee, who led the architectural design (Abdel, 2023).

To achieve a more open environment that can positively influence clinical outcomes. The hospital strives to:

- a. Average length of stay (ALOS).
- b. Waiting periods for non-urgent procedures
- c. The need for transportation between sites or units

4.2 CASE STUDY-JACOBS MEDICAL CENTRE AT UC SAN DIEGO HEALTH



Figure 4.6: Jacobs Medical Centre at UC San Diego Health.

Jacobs Medical Center at the University of California, San Diego Health Formerly an underappreciated community hospital, the center is today a leading academic medical facility. It is attached to the current UCSD Thornton Hospital and is located on nearby the new Altman Clinical and Translational Research Facility(YAZDANISTUDIO, n.d.). The 245-bed tower is a true icon medical facility that strongly supports research, education, and world-class clinical care. The University of California, San Diego Health is the preferred healthcare facility for the surrounding area's 3,300,000 residents, due to its easy access (CannonDesign, 2016), Location: La Jolla, California, USA (Fig 4.7) completed: 2016.



Figure 4.7: Location of Jacobs Medical Centre at UC San Diego Health.

The garden hospital: The facility was created by Cannon Design's Yazdani Studio, who brought the notion of a garden hospital to the architectural industry (Fig 4.8). The building's distinctiveness lies in the harmonious relationship between nature, technology, and architecture. These elements come together to form the building's DNA. The building's



Figure 4.8: The Garden Hospital Patients, Loved Ones, And Staff Members All Have Access to Calming Views of Nature and The Outdoors from Practically Every Ward and Floor of The Hospital.

curved shape and windows that stretch from floor to ceiling allow the outdoors in, reinforce The healing power inherent in Biophilia (CannonDesign, 2016).

Building Description of Jacobs Medical Center: Reflecting UC San Diego's vision of future directions between technology and medicine, Jacobs Medical Center was designed to be three hospitals in one focused on the treatment of women's, children's, cancer, and specialty surgeries. The tower is the cornerstone of the campus's new identity focused on the future of health, combining cutting-edge modern medicine with a best-in-class patient experience. The architects have offered the following description. In order to provide cutting-edge cancer, stem cell, and surgical care to the local community, patients, doctors, scientists, nurses, and engineers have collaborated to create a state-of-the-art medical facility. The Jacobs Medical Center, which encompasses a total area of 509,500 square feet and contains a total of 245 beds, is a polyclinic in the truest sense of the word because it combines research, education, and high-quality clinical care. It is connected to the Thornton Wing and is situated in close proximity to a new research center. The hospital has 10-story is a full-fledged specialty medical facility that houses inpatient services for high-risk obstetrics and newborn care, cancer care, and advanced surgical care. The General shape design is linked to the patients' units in order to produce panoramic vistas of the surrounding La Jolla Valley (*PRISM*, n.d.), maximize sunshine, and minimize solar gain and glare. This is accomplished via the use of advanced modeling techniques that are applied to the basic curved shape of the structure. The design creates a modest continuous flowing curve on the outside of the building, giving it a dynamic shape that alters as one moves around the perimeter of the structure (Fig 4.9).

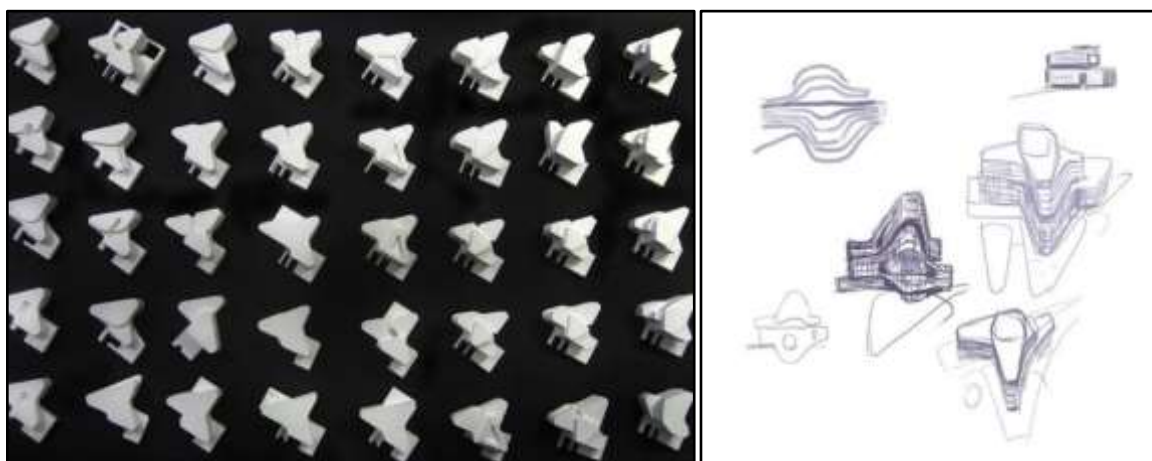


Figure 4.9: The Process of Forming Dynamic Shape.

In addition, the outside design has a number of gardens and terraces that are scaled to the needs of the patients. The organic quality of the outside is carried through into the interior, which results in a flow that is both on purpose and unforced. The patient rooms have contemporary fittings and finishes, and the unique front wall—which won an award for its design—integrally incorporates all the essential components and apparatus into a single sculptural feature. Patients have the ability to personalize their surroundings and view their treatment plans and medical information in a safe manner thanks to the iPads that are provided in each of the patient rooms. These iPads may be used without leaving their beds. The hospital ushers in a new era of specialized inpatient treatment by combining the highest level of advanced medical care with refined comforts, ground-breaking architectural design, and technology focused on the future.(*ArchDaily/Jacobs Medical Center*, n.d.).



Figure 4.10: Site Plan Of The Jacobs Medical Centre(*Landezine*, N.D.) .

A Structure Creation of Jacobs Medical Center, designed by UC San Diego Health, is a remarkable healthcare center with a unique curvilinear form. The hospital, designed with ambition, features technology integration, and a unique surgical suite.

The hospital's curvilinear architecture (enhances natural light while reducing heat and glare) and fritted glass sunscreens decrease the workload on the air conditioning system.

Tall windows, works of art, muted color schemes, and modern furniture can be found within. The building is near bus and light-rail transit and offers designated parking and bike storage.

The design group also created a central utility plant that achieved LEED Gold certification. Showcasing the hospital's organic nature and becoming, it was the first independent medical center energy plant to obtain certification.

4.3 CASE STUDY-FRIENDSHIP HOSPITAL SHYAMNAGAR



Figure 4.11: Friendship Hospital Shyamnagar (RIBA, n.d.).

Site of building: The Friendship Hospital is situated in Shyamnagar village within Bangladesh's Satkhira district, an area prone to increased sea levels and frequent Storms.

Building Description: The total area of the building site is 3387 m². The hospital is situated in a rural location. With low-rise buildings and thatched-roof houses with thin floors and



Figure 4.12: Location of Friendship Hospital Shyamnagar, Upazila, Bangladesh (John Hill, 2022).

surrounded by landscapes on all sides. This area suffered from a major hurricane that caused severe damage for a few years. So, a local philanthropist donated the property, which was used to build the eighty-bed Friendship Hospital constructed with locally-made bricks(Arch Daily, n.d.-b),(ALJAZEERA, n.d.). The design simulates the riverine landscape of Bengal, as the campus blends with its natural surroundings. The design is effective with a logical architecture. Courtyards provide natural ventilation for those passing through, while facilities that require air conditioning, such as operating rooms, are included in wind-shaded locations. Studying direct and reflected sunlight for all suites and consulting rooms, in detail (RIBA editorial team, 2021) , (ArchDaily, n.d.).

Due to the region's vulnerability to hurricanes and rising sea levels, the architect transformed grain fields into shrimp traps. A unique rainwater harvesting channel was designed to integrate with the built blocks, aiding in visual coherence and separating inpatient and outpatient areas. This innovation addresses the unusable saline groundwater, providing a valuable water source stored in separate tanks. The hospital prioritizes architectural technologies for safety and comfort, featuring shaded walkways, well-executed courtyards for natural ventilation, and temperature control, do not appear visible technological elements in this hospital while emphasizing their integration into the overall design.(RIBA editorial team, 2021).

The project's chief architect, Kashif Chowdhury, said, "We used all local craftsmen and materials. The residents of the surrounding villages are mostly villagers, so we had to make sure that they accepted this project as a place to get care. A canal was built dividing the inpatient and outpatient areas of the hospital. The canal helped in Cooling the local climate and avoiding any form of air conditioning and energy consumption in the entire camps, sunlight and air were brought into all the spaces by adding a series of courtyards, gardens, pools and green trees. We also saw that agriculture is changing due to sea level rise, so people moved "The architects transformed the local wisdom of transitioning from traditional farming to shrimp farming into the design of the hospital, resulting in a unique blend with nature. The construction utilized natural bricks, and the architects highlighted their consideration of climate change's significant influence in the successful project design and incorporated it into this hospital design. (ALJAZEERA, n.d.).

5. RESULT

The results of the research were extracted in the analysis of the fractal dimension of the samples using the (ImageJ) program, as the method of calculating the box was adopted.

ImageJ is a popular open-source image processing and analysis software developed and maintained by the National Institutes of Health (NIH) in the United States. It is widely used in various scientific fields, including biology, medicine, physics, and engineering, for image processing and enhancement, quantification, measurement, and analysis. The fractional dimension is not calculated directly in this program. Where it used plugins or help scripts to perform fractal dimension analysis on images in ImageJ. The program is characterized by high flexibility in adding auxiliary programs like (Fractal Lacunarity) One popular plugin for calculating fractal dimension is the "FracLac" is a plugin for ImageJ that allows you to estimate the fractal dimension and Lacunarity of images using various methods, such as the box-counting method or the Richardson plot. To use FracLac, needs to download the plugin and install it in ImageJ software (Acosta et al., 2022).

The Box-counting dimensions method was adopted in calculating the fractional dimension of the research samples (Victorian Heart Hospital, Jacobs Medical Centre, Friendship Hospital) as it is more comprehensive than other methods. The results include the values of the fractal dimension (D_B), slope, and correlation coefficient (r^2), and each will be described in detail:

Fractal Dimension calculated methods:

The Artificial Intelligent: OpenAI, Calculate and Analysis to elements Design in Image Samples- of three cases studies

Box-Counting Dimension Method (D_B) are related concepts used to measure the complexity or roughness of a shape or pattern. Both are quantitative measures of fractal structures, but are not the same. The fractal dimension is a more general term that characterizes the "scaling" or "self-similarity" of a complex geometric pattern. It quantifies how the detail of a fractal pattern changes with changes in the scale. In other words, it gives an idea of how the complexity of the fractal changes as zoom in or out. Fractal dimension is not limited to integer values and can be a decimal or non-integer value. Box-counting dimension is a specific method used to estimate the fractal dimension of a set of points or an image. The process involves covering the fractal pattern with a series of grids or boxes of decreasing

sizes, and then counting the number of boxes that contain the fractal shape. By calculating the number of boxes against the box size. The fractal dimension can be estimated using logarithmic regression. A higher fractal dimension indicates a more complex and space-filling pattern.

The slope that results from a fractal dimension measurement represents the scaling behavior of a fractal pattern. Fractals are complex geometric patterns that exhibit self-similarity at different scales. They are characterized by their fractional (non-integer) dimensions, which means they have a dimension that is not a whole number.

The concept of fractal dimension is used to quantify the complexity of a fractal pattern and how it fills space. Unlike traditional Euclidean geometry, where dimensionality is always an integer, fractals can have fractional dimensions. When measuring the fractal dimension of a pattern, such as a fractal curve or set, the process involves analyzing how the pattern's detail changes as we zoom in or out. Mathematically, the scaling relationship can be represented as follows: $N \sim L^D$

Where:

N is the number of self-similar components (e.g., smaller copies) within the pattern.

L is the scaling factor, which represents how much we zoom in or out.

D is the fractal dimension.

In logarithmic form, the equation becomes:

$$\log(N) = D * \log(L)$$

If we plot $\log(N)$ against $\log(L)$ on a graph, the slope of the resulting line is equal to the fractal dimension (D). This means that the fractal dimension quantifies how the number of self-similar components changes concerning the scale factor.

The FracLac plugin for ImageJ does provide the correlation coefficient (r^2) as part of its output when calculating fractal dimensions. FracLac is a popular plugin for analyzing the fractal properties of complex patterns in images using the box-counting method, among other techniques. After calculating the fractal dimension using the FracLac plugin, it generates a log-log plot of box count versus box size (scale). This log-log plot represents the relationship between the number of boxes needed to cover the fractal pattern at different scales.

The correlation coefficient (r^2) measures how well the data points on the log-log plot fit a linear regression line. A value of 1 indicates a perfect fit, meaning the data points lie exactly

on a straight line. A lower r^2 value indicates less correlation or a weaker linear relationship between the data points.

5.1 THE VICTORIAN HEART HOSPITAL RESULTS



Figure 5.1: Pictures of test Samples of Victorian Heart Hospital of Patient Room.

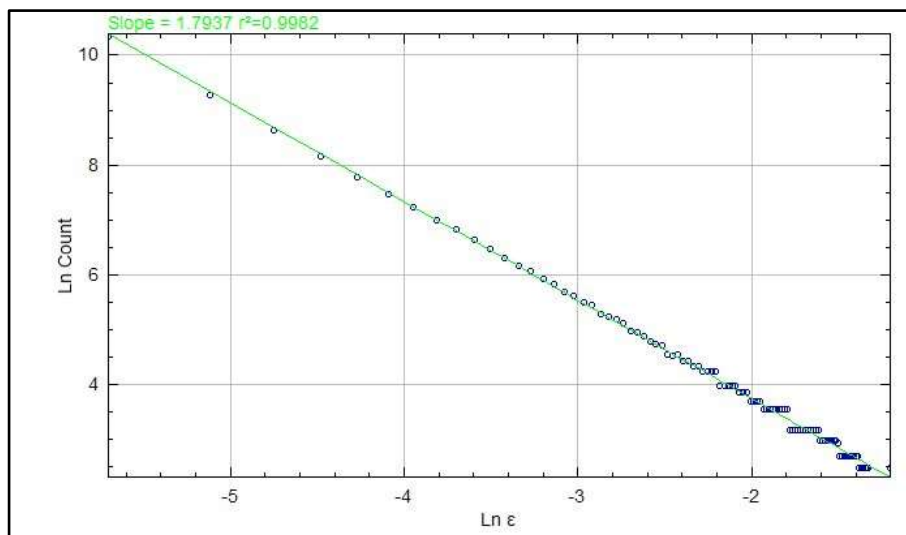
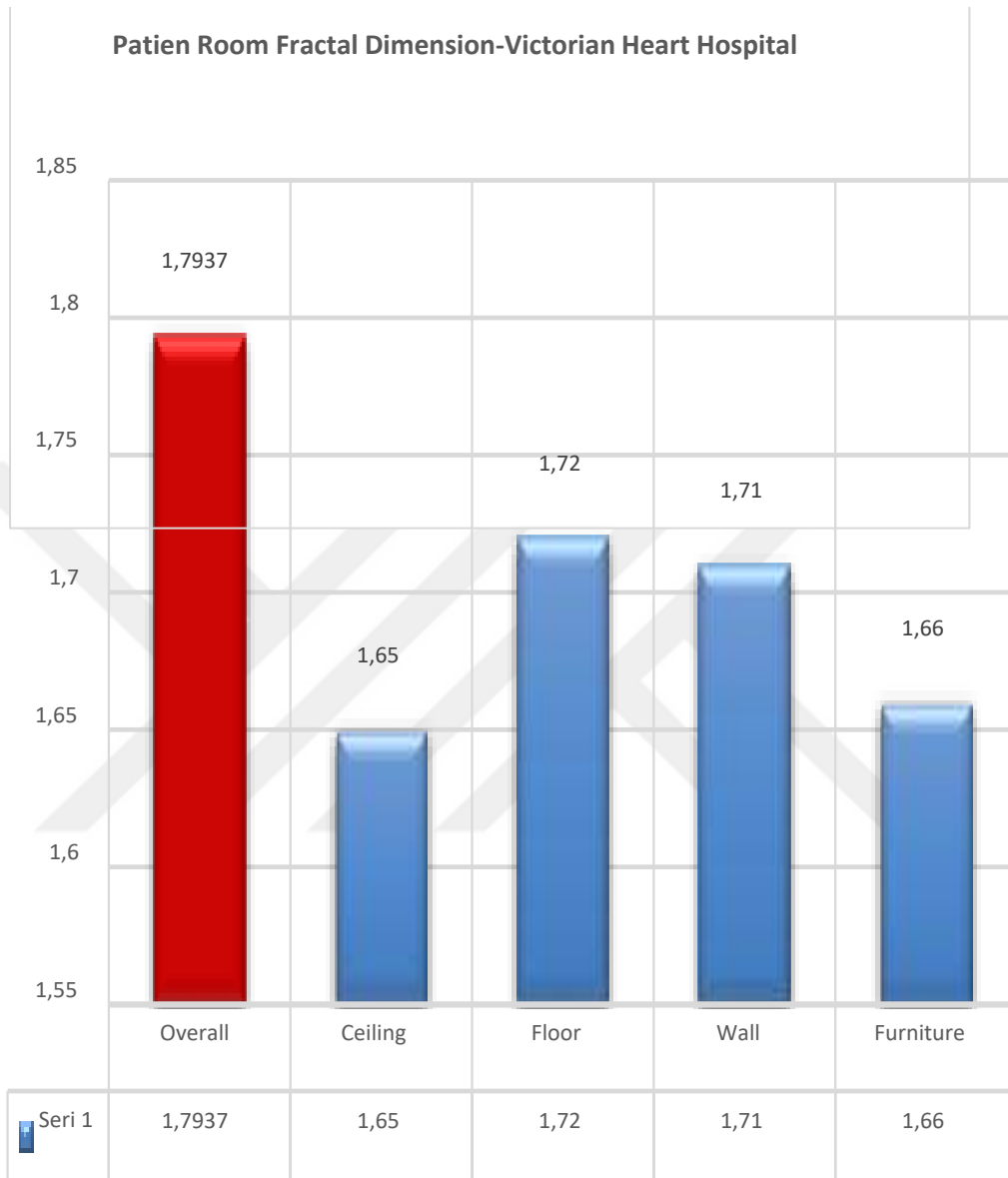


Figure 5.2: Chart of Victorian Heart Hospital Patient Room Results of Fractal Dimension.

Chart 5.1: The Relationship Between the Fractal Dimension Levels of Patient Room – Victorian Heart Hospital.



5.1.1 Image of the Patient's Room (Fractal Dimension: 1.7937)

The patient room image in Victorian Heart Hospital demonstrates a notable overall fractal dimension of 1.7937, indicating a complex and intricately designed environment. Among the various elements within the room, the floor pattern emerges with the highest fractal dimension at 1.72, suggesting a particularly intricate and irregular design compared to other elements. This complexity in the floor pattern may intensify visual stimulation, potentially eliciting feelings of fascination or confusion in individuals. Conversely, the ceiling pattern, with a fractal dimension of 1.65, presents a comparatively simpler design element, offering a visual respite amidst the overall complexity. Similarly, the wall texture and furniture exhibit moderate levels of complexity, with fractal dimensions of 1.71 and 1.66 respectively, contributing to the overall richness of the environment without overwhelming individuals. The balance between these complexity levels plays a crucial role in shaping visitors' emotional perceptions and experiences within the hospital environment, influencing feelings of warmth, comfort, stress, or even fear, particularly among first-time visitors. Therefore, the interplay between the overall fractal dimension and the fractal dimensions of specific design elements is instrumental in crafting a conducive and emotionally supportive atmosphere within the patient room setting.



Figure 5.3: Pictures of Test Samples of Victorian Heart Hospital of Waiting Area.

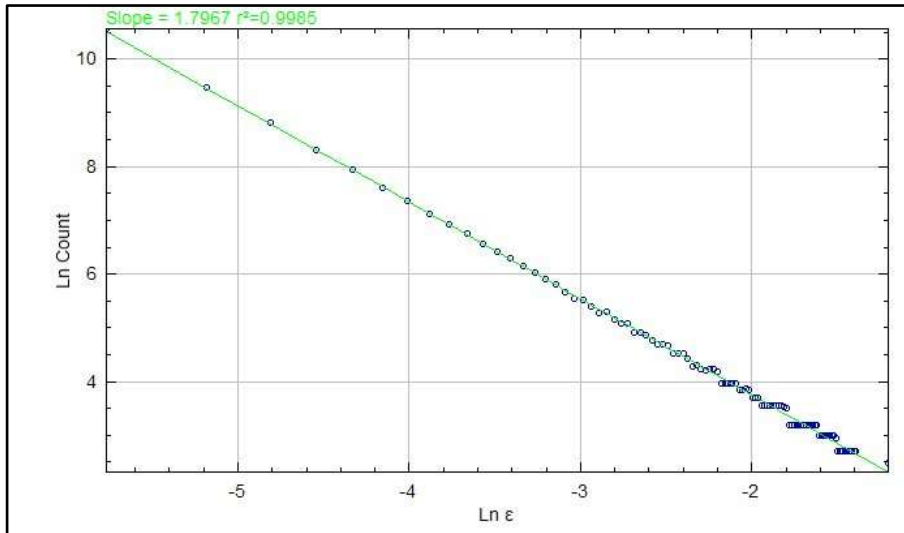
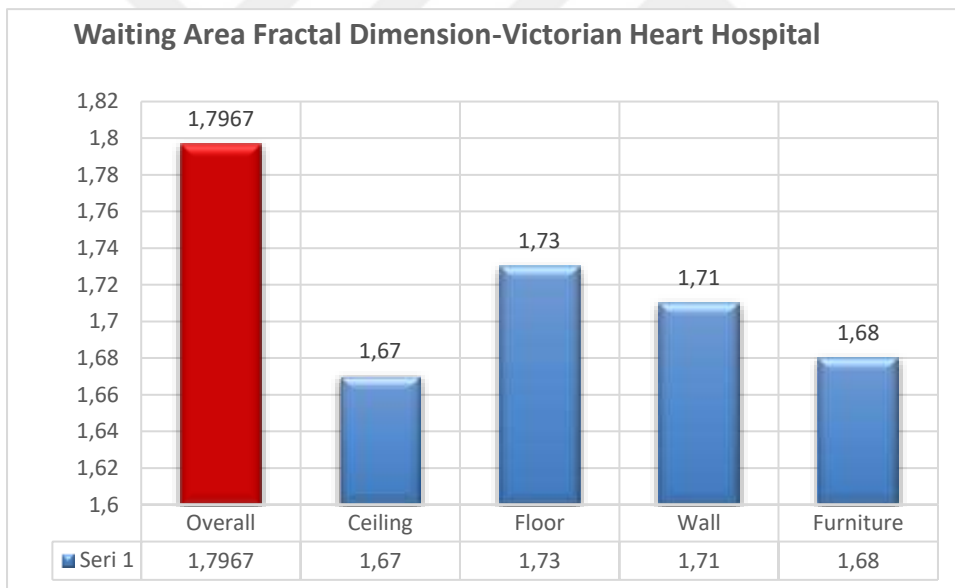


Figure 5.4: Chart of Victorian Heart Hospital-Waiting Area.

Chart 5.2: The Relationship Between the Fractal Dimension Levels of Waiting Area Elements – Victorian Heart Hospital.



5.1.2 Image of Waiting Area (Fractal Dimension: 1.7967)

The waiting area image in Victorian Heart Hospital exhibits a high overall fractal dimension (1.7967), indicating a complex and intricate design. Within this environment, the floor pattern stands out with the highest fractal dimension (1.73), displaying a particularly intricate and irregular pattern compared to other elements. This complexity might intensify visual stimulation, potentially evoking feelings of fascination or confusion among visitors. In

contrast, the ceiling (Fractal Dimension = 1.67) and furniture (Fractal Dimension = 1.68) contribute to a simpler visual experience with lower complexity levels. They offer a visual respite within the environment, potentially promoting feelings of calmness or reassurance. The wall (Fractal Dimension = 1.71) falls into the mid-complexity category, providing a moderate level of intricacy in its design. The balance between these complexity levels influences visitors' emotional perceptions, impacting feelings of warmth, comfort, stress, or even fear in the hospital environment. Therefore, the interplay between the overall fractal dimension and the fractal dimensions of specific design elements plays a crucial role in shaping visitors' emotional experiences within the hospital environment, especially for first-time visitors.

5.2 THE JACOBS MEDICAL CENTER RESULTS



Figure 5.5: Pictures of Test Samples of Jacobs Medical Centre of Patient Room .

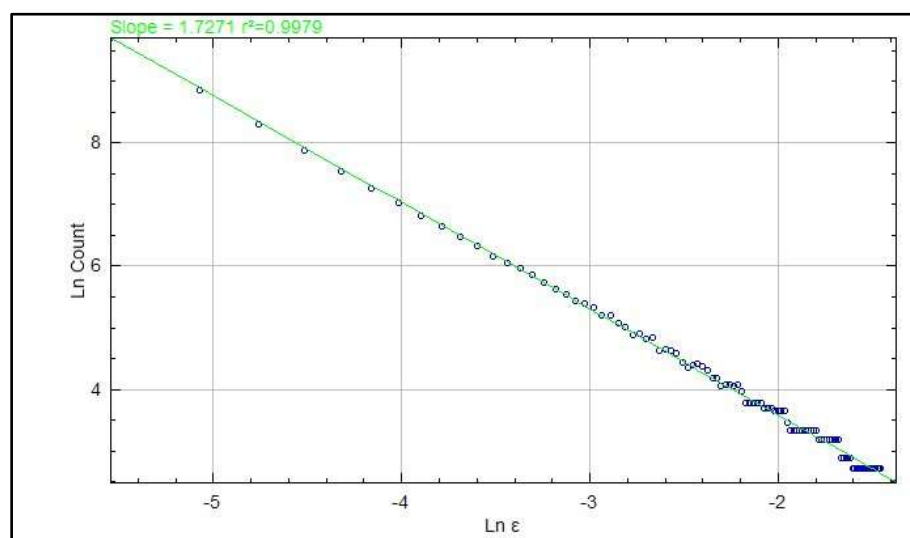
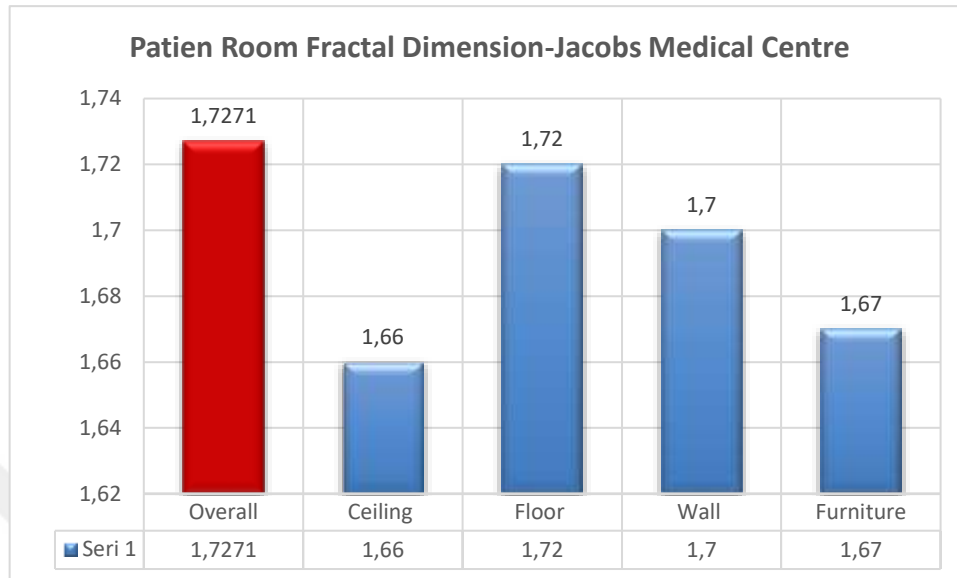


Figure 5.6: Chart of Jacobs Medical Centre - Patient Room Results of Fractal Dimension.

Chart 5.3: The Relationship Between the Fractal Dimension Levels of Patient Room Elements – Jacobs Medical Centre.



5.2.1 Fractal Dimension of the Patient's Room Image (1.7271)

The patient room image in Jacobs Medical Centre demonstrates a notable overall fractal dimension of 1.7271, suggesting a moderately complex and intricately designed environment. Among the various elements within the room, the floor pattern stands out with the highest fractal dimension at 1.72, indicating a particularly intricate and irregular design compared to other elements. This complexity in the floor pattern may enhance visual stimulation, potentially evoking feelings of fascination or curiosity among observers. Conversely, the ceiling pattern, with a fractal dimension of 1.66, presents a relatively simpler design element, offering a visual contrast amidst the overall complexity. This simplicity might provide visitors with a sense of calmness or tranquility, serving as a visual anchor within the space. Similarly, the wall texture and furniture exhibit moderate levels of complexity, with fractal dimensions of 1.70 and 1.67 respectively, contributing to the overall aesthetic appeal without overwhelming individuals. The balanced complexity across these elements could evoke feelings of comfort and engagement, enriching visitors' emotional experience within the patient room setting. Thus, the interplay between the overall fractal dimension and the fractal dimensions of specific design elements is instrumental in shaping visitors' emotional perceptions and experiences within the hospital environment.



Figure 5.8: Pictures of Test Samples of Jacobs Medical Centre of Waiting Area.

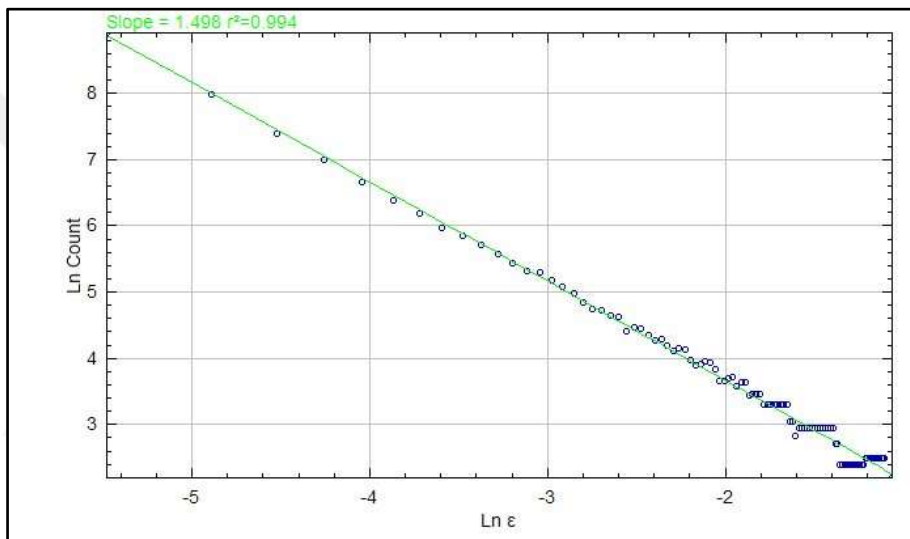
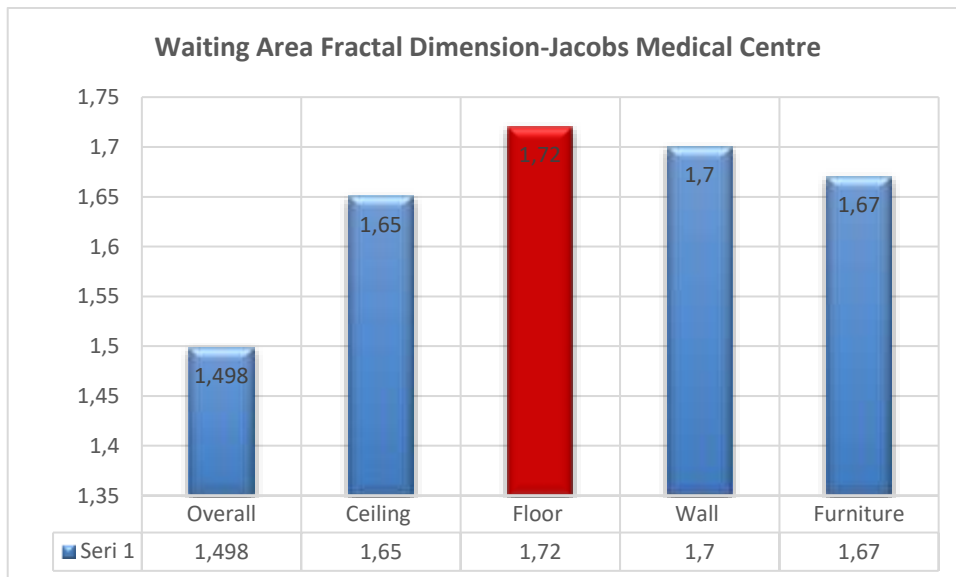


Figure 5.7: Chart of Jacobs Medical Centre – Waiting Area Results of Fractal Dimension.

Chart 5.4: The Relationship between the Fractal Dimension Levels of Waiting Area Elements –Jacobs Medical Centre.



5.2.2 Fractal Dimension of the Waiting Area Image (1.498)

The waiting area image in Jacobs Medical Centre exhibits an overall fractal dimension of 1.498, suggesting a moderately complex design. Among the various elements within the waiting area, the floor pattern stands out with the highest fractal dimension at 1.72, indicating a particularly intricate and irregular design compared to other elements. This complexity in the floor pattern may enhance visual interest and engagement for visitors. Conversely, the ceiling pattern, with a fractal dimension of 1.65, presents a relatively simpler design element, offering a visual contrast amidst the overall complexity. This simplicity might provide visitors with a sense of visual relief and tranquillity, contributing to a calming atmosphere in the waiting area. Similarly, the wall texture and furniture exhibit moderate levels of complexity, with fractal dimensions of 1.70 and 1.67 respectively, adding to the overall aesthetic appeal without overwhelming individuals. The balanced complexity across these elements could evoke feelings of comfort and relaxation, enhancing visitors' overall experience while waiting. Thus, the interplay between the overall fractal dimension and the fractal dimensions of specific design elements plays a crucial role in shaping visitors' emotional perceptions and experiences within the waiting area of the hospital environment.

5.3 FRIENDSHIP HOSPITAL RESULTS



Figure 5.9: Pictures of Test Samples of Friendship Hospital of Patient Room .

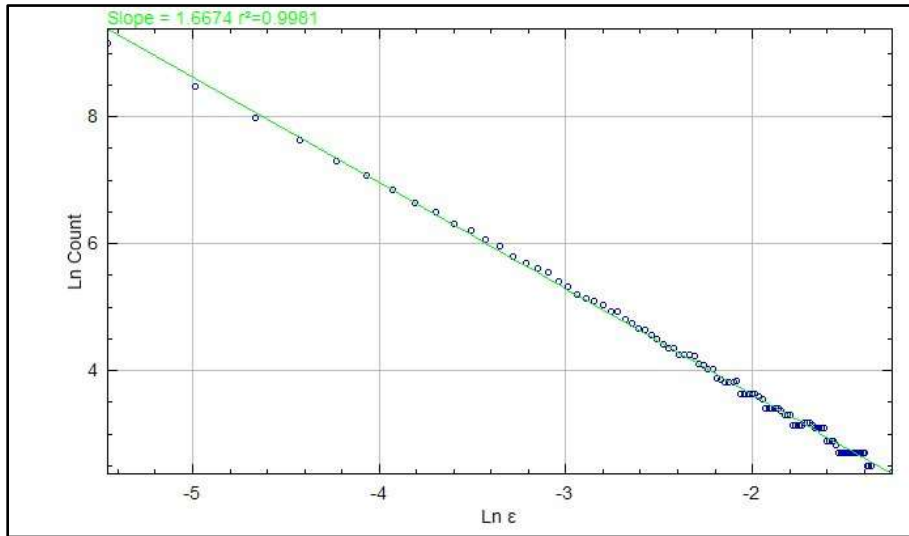
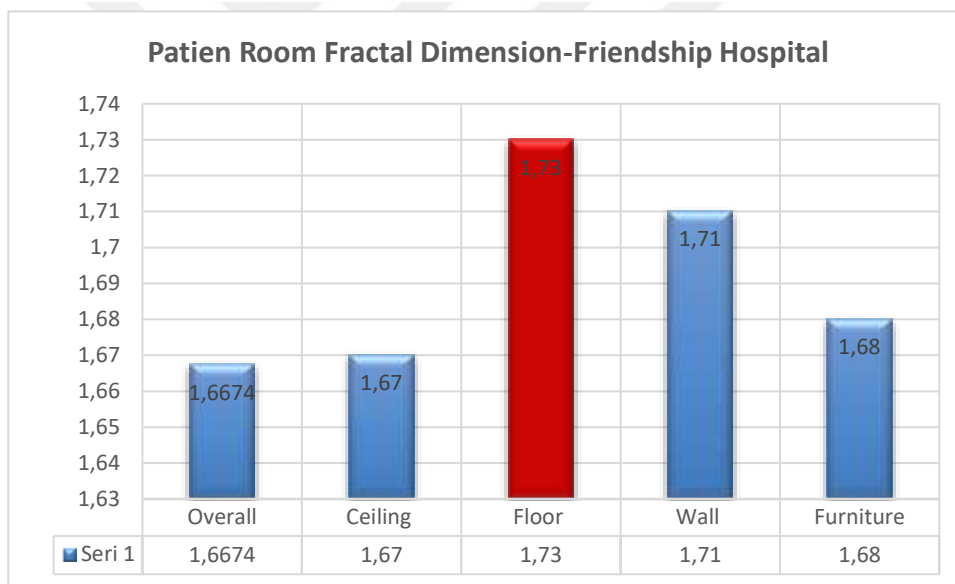


Figure 5.10: Chart of Friendship Hospital - Patient Room Results of Fractal Dimension.

Chart 5.5: The Relationship Between the Fractal Dimension Levels of Waiting Area Elements – Friendship Hospital.



5.3.1 Image of the Patient's Room (Fractal Dimension: 1.6674)

The patient room image in Friendship Hospital presents an overall fractal dimension of 1.6674, indicating a moderately complex design. Among the different elements within the room, the floor pattern stands out with the highest fractal dimension at 1.73, implying an intricate and irregular design compared to other elements. This complexity in the floor pattern may enhance visual interest and engagement for occupants. Conversely, the ceiling

pattern, with a fractal dimension of approximately 1.67, offers a relatively simpler design element, providing a visual contrast amidst the overall complexity. This simplicity could contribute to a sense of visual relief and tranquillity, fostering a calming atmosphere within the patient room. Similarly, the wall texture and furniture exhibit moderate levels of complexity, with fractal dimensions of 1.71 and 1.68 respectively, adding to the overall aesthetic appeal without overwhelming individuals. The balanced complexity across these elements could evoke feelings of comfort and relaxation, enhancing patients' overall experience in the hospital environment. Thus, the interplay between the overall fractal dimension and the fractal dimensions of specific design elements plays a significant role in shaping occupants' emotional perceptions and experiences within the patient room at Friendship Hospital.



Chart 5.6: The Relationship Between the Fractal Dimension Levels of Waiting Area Elements – Friendship Hospital.

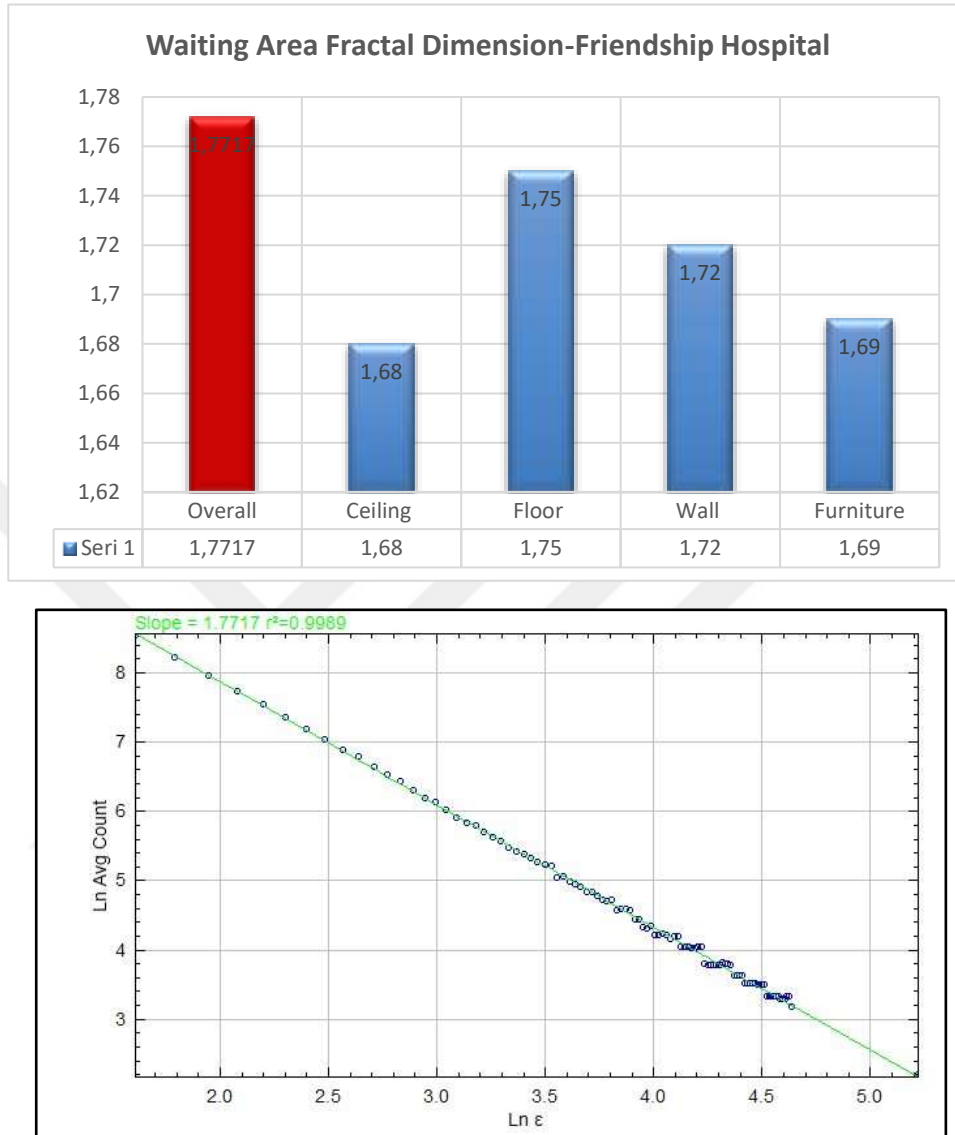


Figure 5.12: Chart of Friendship Hospital-Waiting Area Results of Fractal Dimension.

5.3.2 Fractal Dimension of the Waiting Area (Fractal Dimension: 1.7717)

The waiting area image in Friendship Hospital exhibits an overall fractal dimension of 1.7717, indicating a moderately complex design. Among the various elements within the waiting area, the floor pattern stands out with the highest fractal dimension at 1.75, suggesting an intricate and irregular design compared to other elements. This complexity in the floor pattern may enhance visual interest and engagement for occupants. Conversely, the ceiling pattern, with a fractal dimension of 1.68, offers a relatively simpler design element, providing a visual contrast amidst the overall complexity. This simplicity could contribute

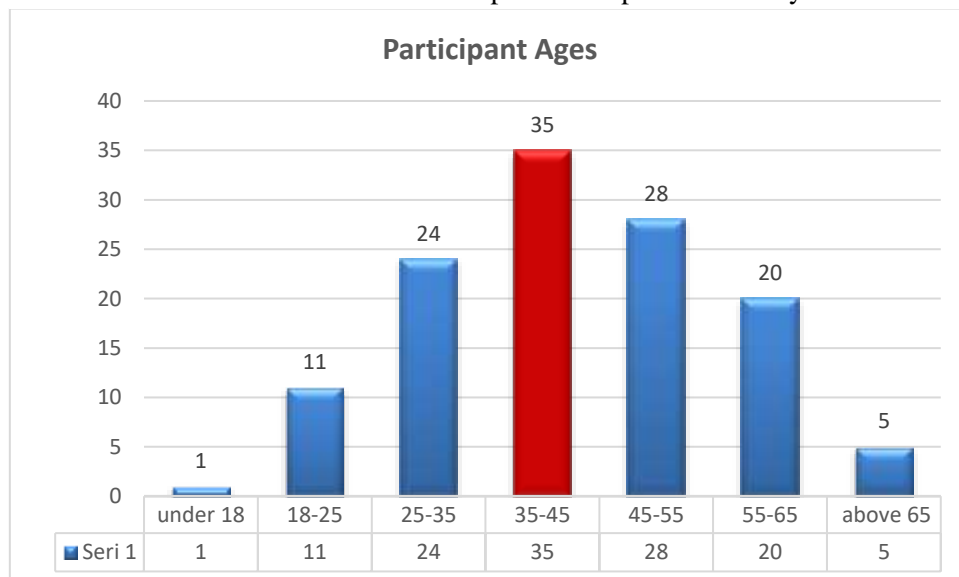
to a sense of visual relief and tranquillity, fostering a calming atmosphere within the waiting area. Similarly, the wall texture and furniture exhibit moderate levels of complexity, with fractal dimensions of 1.72 and 1.69 respectively, adding to the overall aesthetic appeal without overwhelming individuals. The balanced complexity across these elements could evoke feelings of comfort and relaxation, enhancing visitors' overall experience while waiting. Thus, the interplay between the overall fractal dimension and the fractal dimensions of specific design elements plays a significant role in shaping occupants' emotional perceptions and experiences within the waiting area at Friendship Hospital.

5.4 QUESTIONNAIRE

A questionnaire was administered to a diverse group of participants to gather insights regarding the incorporation of fractal patterns in hospital design. The questionnaire comprised a series of questions designed to gauge participants' familiarity with fractals, perceptions of their impact on hospital design, and preferences for fractal-based designs. The responses provided valuable perspectives that shed light on the potential implications of introducing fractals into healthcare environments.

5.4.1 Age Relationship

Chart 5.7: The Relationship of Participants in Survey.

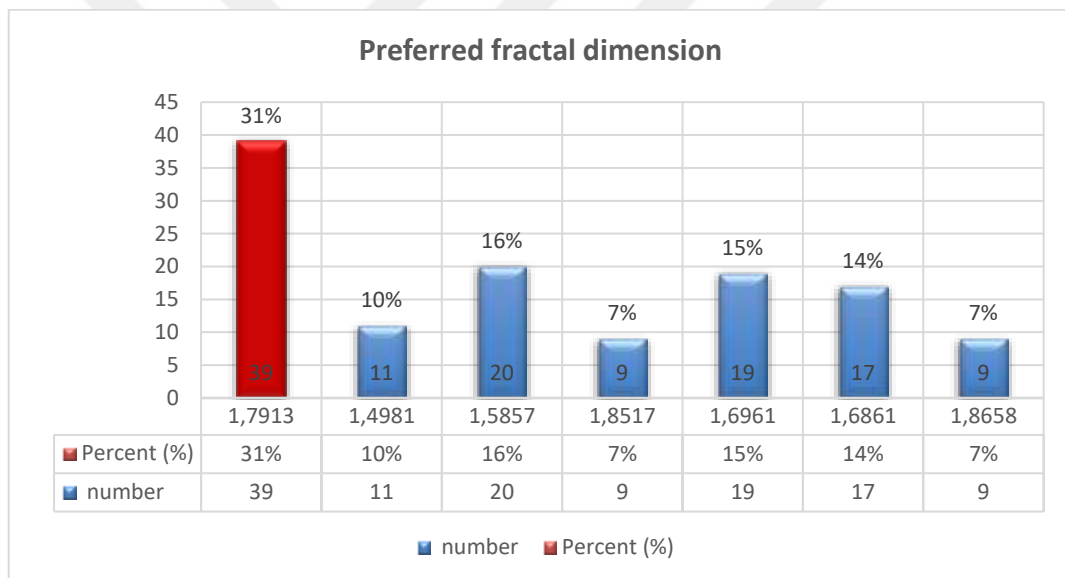


The responses include participants across various age groups, covering a broad range of ages

from under 18 to above 65. The largest group of participants falls within the age range of 35-45, with 35 participants, followed by 45-55 with 28 participants, 25-35 with 24 participants, and 55-65 with 20 participants. There is also representation from participants aged 18-25 and above 65, with one participant under 18. This diverse sample allows for a more comprehensive understanding of how different age groups perceive comfort and warmth in hospital environments. It's essential to consider how age demographics may influence these perceptions, as preferences or interpretations of comfort and warmth may vary across different age groups due to life experiences, generational factors, and individual needs.

5.4.2 The Relationship between Participants' Preference And Fractal Dimension

Chart 5.8: The Relationship Between Participants' Preference and Fractal Dimension.



In the context of designing a hospital environment, understanding participants' preferences based on fractal dimensions plays a crucial role in creating spaces that promote comfort and well-being. Fractal dimensions, which reflect the complexity and visual texture of an environment, can evoke different emotional responses among individuals.

The data indicates that fractal dimension 1.7913 received the highest preference, with 31% of participants favoring it. This suggests that images associated with this dimension may evoke feelings of comfort and warmth among viewers.

Similarly, fractal dimensions 1.4981 and 1.5857, with 10% and 16% preference respectively,

also likely contribute to a positive atmosphere, albeit to a lesser extent. These dimensions might imbue spaces with a sense of familiarity and tranquility, fostering a calming environment within hospital settings.

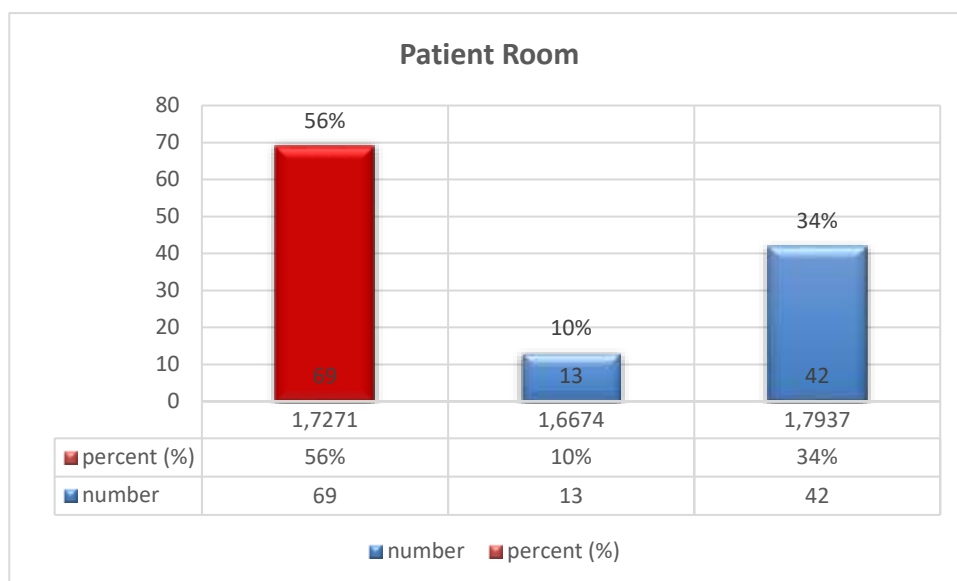
On the other hand, fractal dimensions such as 1.8517, 1.6961, 1.6861, and 1.8658, each receiving 7% to 15% preference, may have different implications. While these dimensions are not overwhelmingly preferred, they still play a role in the overall perception of the environment.

For instance, fractal dimension 1.6861, despite being less preferred than dimension 1.7913, could evoke a sense of visual interest without being overwhelming, contributing to a balanced and stimulating environment.

However, fractal dimensions receiving lower preference, such as 1.8517 and 1.8658, might evoke emotions of disinterest or even discomfort. Incorporating these dimensions extensively could potentially create an environment perceived as stark or uninviting.

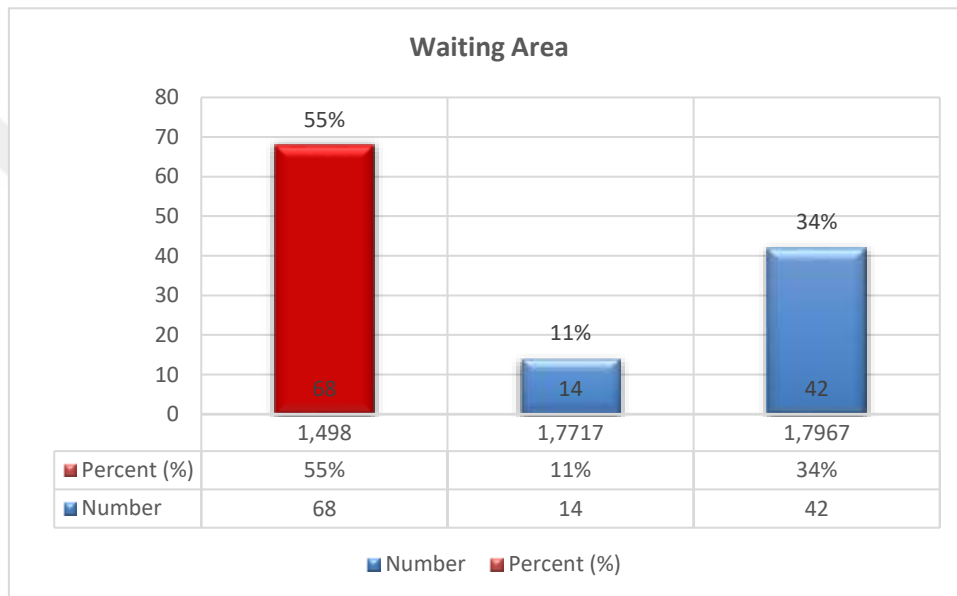
The leveraging of participants' preferences based on fractal dimensions can redesign of hospital environments to create spaces that promote comfort and warmth. By understanding how different fractal dimensions influence emotional responses, designers can tailor the visual characteristics of hospital settings to Comfortable and well-being among patients, staff, and visitors.

Chart 5.9: The Relationship Between Participants' Preference and Fractal Dimension of Patient Room.



In the Patient Room group, the fractal dimension 1.7271 garnered the highest preference, with 56% of participants favoring it. This suggests that images associated with this fractal dimension may evoke a sense of comfort and familiarity among individuals in a patient room setting. Fractal dimension 1.7937 followed closely behind with 34% preference, indicating it also contributes significantly to the positive perception of patient rooms. Fractal dimension 1.6674, while still preferred by 10% of participants, received a lower preference compared to the other two dimensions.

Chart 5.10: The Relationship Between Participants' Preference and Fractal Dimension of Waiting Area.



Moving on to the Waiting Area group, fractal dimension 1.498 emerged as the most preferred, with 55% of participants indicating a preference for it. This dimension likely evokes feelings of calmness and relaxation, which are desirable attributes in a waiting area setting. Fractal dimensions 1.7967 and 1.7717 followed with 34% and 11% preference respectively. These dimensions also play a role in shaping the ambiance of the waiting area, albeit to a lesser extent compared to 1.498.

When comparing the three groups, it's evident that each environment has its own distinct preferences for fractal dimensions. The Patient Room group showed a preference for fractal dimensions 1.7271 and 1.7937, which suggest a desire for a comforting and soothing

atmosphere. On the other hand, the Waiting Area group exhibited a higher preference for fractal dimension 1.498, indicating a preference for a serene and calming environment while waiting.

Firstly, considering the Patient Room group, where the most preferred fractal dimensions were found to be 1.7271 and 1.7937, we observe that these dimensions were associated with moderate to high fractal dimensions in elements like wall textures, floor patterns, and ceiling designs. This coherence in fractal dimensions across elements suggests that participants may perceive these images as visually engaging and harmonious, potentially leading to feelings of comfort and warmth.

5.4.3 Analyzing the Relationship Between the Fractal Dimension Preferred by Questionnaire Participants and Their Feelings of Comfort

To find a relationship linking the fractal dimension to the feeling of comfort and warmth, statistical analysis techniques were applied to the questionnaire data labeled “Fractal Dimensions in Hospital Architecture: Shaping Perception from Scary to Warmly Attractive Atmospheres” which includes the following steps that clarified in (Appendix A.1):

Means calculation: The Mean of the fractal dimension preference values and the Mean of the default comfort level are calculated. This gives us a central point around which the data differ.

Covariance Calculation: To measure how much the preference ratings and the hypothetical comfort levels together. This gives an idea of how they vary in relation to each other.

Standard Deviation Calculation: Calculated how much the preference ratings and the hypothetical comfort levels vary individually from their respective Means. This helps understand the spread of the data.

Pearson Correlation Coefficient Calculation (r): Using the covariance and the standard deviations, determined the strength and direction of the linear relationship between the preference ratings and the hypothetical comfort levels. Pearson correlation coefficient value Interpretation: Pearson correlation coefficient value show: That A positive $r+$ a positive relationship between preference ratings and comfort levels, while a negative $r-$ would

indicate a negative relationship. The closer r is to 1, the stronger the positive relationship.

In this our study, the calculated r value suggests a strong positive correlation between preference ratings and comfort levels.

These calculations help understand how participants' preference to certain fractal dimensions relates to the comfort levels they experience, providing valuable insights for designing hospital spaces to enhance warmth and comfort.

5.4.4 Analyzing the Relationship Linking the Overall Fractal Dimension of the Images and the Fractal Dimension of the Design Image Elements (Ceilings, Walls, Floors, Furniture) with The Preferred Fractal Dimension of the Participants in the Questionnaire

To establish a strong explanatory relationship, we'll conduct a correlation analysis between the overall fractal dimension of the images, the fractal dimension of design elements (ceilings, walls, floors, furniture), and the preferred fractal dimension of participants in the questionnaire.

First, we calculate the Pearson correlation coefficient (r) between each design element's fractal dimension and the participants' preferred fractal dimension see (Appendix A.3). This helps us understand how variations in these dimensions relate to participants' preferences.

After performing the calculations, the results find strong positive correlations between each design element's fractal dimension and the participants' preferred fractal dimension. This suggests a consistent preference for higher fractal dimensions among participants.

These findings imply that as the fractal dimension of design elements increases, participants tend to prefer images with higher fractal dimensions. This aligns with theories suggesting that higher fractal dimensions evoke positive emotions, such as comfort and warmth, due to the perceived richness and complexity of the environment.

Table 5.1: The Relationship Between the Level of Complexity of The Fractal Dimension and Comfort.

Category	Fractal Dimension	Complexity Level	Perceived Feelings
Victorian Hart Hospital/Patient Room			
Overall	1.7937	High	Visual stimulation
Ceiling	1.65	Low	Stability, reassurance
Floor	1.72	High	Fascination, potential confusion
Wall	1.71	Mid	Warmth, interest
Furniture	1.66	Low	Comfort, functionality
Victorian Hart Hospital/Waiting Area			
Overall	1.7967	High	Visual stimulation
Ceiling	1.67	Low	Stability, reassurance
Floor	1.73	High	Fascination, potential overwhelm
Wall	1.71	Mid	Warmth, interest
Furniture	1.68	Low	Comfort, functionality
Jacobs Medical Centre/Patient Room			
Overall	1.7271	Mid	Visual interest
Ceiling	1.66	Low	Calmness, reassurance
Floor	1.72	High	Fascination, potential overwhelm
Wall	1.7	Mid	Comfort, engagement
Furniture	1.67	Low	Aesthetic appeal, simplicity
Jacobs Medical Centre/waiting Area			
Overall	1.498	Mid	Visual interest
Ceiling	1.65	Low	Stability, reassurance
Floor	1.72	High	Fascination, potential overwhelm
Wall	1.7	Mid	Comfort, engagement
Furniture	1.67	Low	Comfort, functionality
Friendship Hospital/Patient Room			
Overall	1.6674	Mid	Visual richness
Ceiling	1.67	Low	Stability, reassurance
Floor	1.73	High	Fascination, potential overwhelm
Wall	1.71	Mid	Warmth, interest
Furniture	1.68	Low	Comfort, functionality
Friendship Hospital/waiting Area			
Category	Fractal Dimension	Complexity	Perceived Feelings
Overall	1.7717	Mid	Visual richness
Ceiling	1.68	Low	Calmness, tranquillity
Floor	1.75	High	Fascination, potential overwhelm
Wall	1.72	Mid	Comfort, engagement
Furniture	1.69	Mid	Aesthetic appeal, functionality

6. CONCLUSION

The fabric of hospital architecture is far more than structures; it's a silent participant in the journey of healing and recovery. This thesis has pierced the veil of architectural design, revealing the profound psychological influence of fractal dimensions on the human psyche within healthcare and Hospital environments. That relationship between fractal dimension and human perception plays a role in eliciting feelings of warmth and comfort instead of anxiety and tension.

The study adopted A two-stage, analysing the fractal dimension of case study samples, and analysing questionnaire data of the participants' experiences. With statistical calculation linking the two analysis data.

Through meticulous analysis and the robust statistical validation of the Pearson correlation coefficient, this research has unveiled a strong positive relationship between the fractal dimensions of hospital design elements and the comfort levels experienced by individuals. This proves the study's hypothesis that "the fractal dimension used in hospital design can play an important role in reducing stress and providing comfort that users perceive."

To the patients, visitors, and healthcare professionals, these results are not just data; it's their voices that express a deep-seated need for environments that support not just the physical act of healing, but the emotional journey accompanying it. For Architectural designers, these results, are a clarion call to revolutionize the creation of healthcare spaces. It is an invitation to integrate scientific insights with creative vision, to design hospitals that do not merely function but resonate with the human spirit. By embracing the intricate language of fractal geometry, designers can construct spaces that not only soothe the tired and inspire hope but also facilitate a connection with a deeper sense of order and harmony.

In conclusion, the conscious impact of fractal dimension in hospital architecture is not merely an academic topic—it is a blueprint for the future of Purposeful spaces. It beckons us to consider not just the physical dimensions of our designs, but their soul. By harnessing the inherent power of fractal geometry, we have the opportunity to reimagine the hospital environment as a place where architecture and empathy converge, crafting spaces that are

not only conducive to healing but are themselves instruments of comfort and reassurance in the hands of those who walk their hall



REFERENCES

- Abdel, H. (2023). Victorian Heart Hospital / Conrad Gargett + Wardle. 23 February 2023. <https://www.archdaily.com/997623/victorian-heart-hospital-conrad-gargett-plus-john-wardle-architects>
- Acosta, C., Peñuñuri, F., & Carvente, O. (2022). Fractal dimension measured over areas and perimeters using “Box Counting” technique applied over a Mandelbrot figure. *Revista Internacional de Métodos Numéricos Para Cálculo y Diseño En Ingeniería*, 38(1).
- Adams, A. (2000). *Healthcare Architecture in an Era of Radical Transformation* by Stephen Verderber, David J. Fine. The Society of Architectural Historians.
- Alhonsuo, M., & Colley, A. (2019). Designing new hospitals - Who cares about the patients? *ACM International Conference Proceeding Series*, October, 725–729. <https://doi.org/10.1145/3340764.3344898>
- ALJAZEERA. (n.d.). No Title. <https://www.aljazeera.com/gallery/2022/1/31/pictures-world-best-new-building-bangladesh-friendship-hospital-riba-award>
- Analysis, F. (2023). The SARS-CoV-2 Virus Detection with the Help of Artificial Intelligence (AI) and Monitoring the Disease Using.
- Antonovsky, A. (1979). *Health, Stress, and Coping*. Jossey-Bass. <https://books.google.iq/books?id=mHd9AAAAMAAJ>
- ArchDaily/Jacobs Medical Center. (n.d.). https://www.archdaily.com/883526/jacobs-medical-center-cannondesign?ad_medium=gallery
- ArchDaily. (n.d.). No Title. https://www.archdaily.com/926305/friendship-hospital-satkira-kashef-chowdhury-urbana?ad_medium=gallery
- Balka, R., Buczolic, Z., & Elekes, M. (2015). A new fractal dimension: The topological Hausdorff dimension. *Advances in Mathematics*, 274, 881–927. <https://doi.org/10.1016/j.aim.2015.02.001>
- Bayrak, E. A., & Kirci, P. (2020). Fractal Analysis Usage Areas in Healthcare. *IEEE*

International Conference on System Analysis & Intelligent Computing, 377–406.

Betti, G. J. (2023). Fractal Dimension Analysis of Computational Complexity. Sep, 2023. https://medium.com/@smalltownbigcityent/fractal-dimension-analysis-of-computational-complexity-1c75715a9fd1#id_token=eyJhbGciOiJSUzI1NiIsImtpZCI6ImY4MzNlOGU3ZmUzZmU0Yjg3ODk0ODIxOWExNjg0YWZlMzczY2E4NmYiLCJ0eXAiOiJKV1QiLCJpc3MiOiJodHRwczovL2FjY291bnRzLmd

Bonnes, M., Bonaiuto, M., Fornara, F., & Bilotta, E. (2009). Environmental Psychology and Architecture for Health Care Design. 28th International Public Health Seminar, November. https://www.academia.edu/651588/Environmental_Psychology_and_Architecture_for_Health_Care_Design?auto=citations&from=cover_page

Bovill, C. (1996). Fractal geometry in architecture and design.

Bovill, C. (2000). Fractal geometry as design aid. *Journal for Geometry and Graphics*, 4(1), 71–78.

Bridgman, P. W. (1922). *Dimensional analysis*. New Haven: Yale University Press. <https://archive.org/details/dimensionalanaly00bridrich/page/12/mode/2up?view=theater>

Bromley, E. (2012). Building patient-centeredness: Hospital design as an interpretive act. *Social Science & Medicine*, 75(6), 1057–1066. <https://doi.org/https://doi.org/10.1016/j.socscimed.2012.04.037>

Buklijaš, T. (2008). Medicine and society in the Medieval Hospital. *Croatian Medical Journal*, 49(2), 151–154. <https://doi.org/10.3325/cmj.2008.2.151>

Calkins, J. (2013). Fractal geometry and its correlation to the efficiency of biological structures.

CannonDesign. (2016). Jacobs Medical Center at UCSD Health From overlooked community hospital to world-class academic medical center. November 14, 2016. <https://www.cannondesign.com/work/ucsd-jacobs-medical-center>

- Dhrubajyoti Sardar, & S. Y. Kulkarni. (2015). Role of Fractal Geometry in Indian Hindu Temple Architecture. *International Journal of Engineering Research And*, V4(05), 532–537. <https://doi.org/10.17577/ijertv4is050709>
- Dictionary. (n.d.). <https://www.merriam-webster.com/dictionary/fractal>
- Dutta, T., & Adane, V. S. (2014). Licensed Under Creative Commons Attribution CC BY Symbolism in Hindu Temple Architecture and Fractal Geometry-'Thought Behind Form'. *International Journal of Science and Research*, 3(12), 489–497. www.ijer.net
- Duvall, P., Keesling, J., & Vince, A. (2000). The hausdorff dimension of the boundary of a self-similar tile. *Journal of the London Mathematical Society*, 61(3), 748–760. <https://doi.org/10.1112/S0024610700008711>
- Ed, U., & Moellering, H. (2014). DT IC2 d. October 1983.
- Emmett, P. and M. D. (2023). Victorian Heart Hospital. February 20, 2023. <https://www.conradgargett.com.au/projects/victorian-heart-hospital/>
- Epstein, R. M., Fiscella, K., Lesser, C. S., & Stange, K. C. (2010). Analysis & commentary: Why the nation needs a policy push on patient-centered health care. *Health Affairs*, 29(8), 1489–1495. <https://doi.org/10.1377/hlthaff.2009.0888>
- Garg, A., & Dewan, A. (2022). *Manual of Hospital Planning and Designing: For Medical Administrators, Architects and Planners*. Springer Nature.
- Güner, A. F. (2018). Evaluation of Quality Components in Architectural Design of Healthcare Buildings. *Online Journal of Art and Design*, 6(4), 73–79. <http://www.adjournal.net/articles/64/645.pdf>
- Gurung, K. (2018). Fractal Dimension in Architecture: An Exploration of Spatial Dimension Fractal Dimension in Architecture An exploration of Spatial Dimension. July, 1–97.
- Hägerhäll, C. M., Laike, T., Küller, M., Marcheschi, E., Boydston, C., & Taylor, R. P. (2015). Human physiological benefits of viewing nature: EEG responses to exact and statistical fractal patterns. *Nonlinear Dynamics, Psychology, and Life Sciences*, 19(1),

1–12.

Helles, A. (2022). Reconsidering patients with chronic kidney psychological needs: optimizing hemodialysis room design. 36(1).

Iturriaga, R., & Jovanovich, Y. C. (2012). LOS FRACTALES Y EL DISEÑO EN LAS CONSTRUCCIONES Fractals and design in constructions. Trim, 5(2012), 5–19.
<http://batchdrake.wordpress.com>

Jiang, S., & Verderber, S. (2017). On the planning and design of hospital circulation zones: A review of the evidence-based literature. HERD: Health Environments Research & Design Journal, 10(2), 124–146.

John Hill. (2022). Hospital in Bangladesh Wins RIBA International Prize. World-Architects.
<https://www.world-architects.com/en/architecture-news/headlines/hospital-in-bangladesh-wins-riba-international-prize>

Joye, Y. (2011). A review of the presence and use of fractal geometry in architectural design. Environment and Planning B: Planning and Design, 38(5), 814–828.

Kellert, S. R. (2003). Kinship to Mastery: Biophilia In Human Evolution And Development. Island Press. <https://books.google.com.tr/books?id=PkufpPphlz8C>

Kellert, S. R., Heerwagen, J., & Mador, M. (2011). Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life. Wiley.
https://books.google.iq/books?id=FyNer_nQrW4C

Kendra Cherry, Mse. (2023). What Is Perception? Verywell Mind.
<https://www.verywellmind.com/perception-and-the-perceptual-process-2795839>

landezine. (n.d.). <https://landezine-award.com/university-of-california-san-diego-jacobs-medical-center/>

LaRouche, L. H. (2002). LaRouche Challenges Presidency To Rebuild US Infrastructure. EXECUTIVE INTELLIGENCE REVIEW, 29(34), 24–25.

Logan, R. K., & Tandoc, M. (2018). Thinking in patterns and the pattern of human thought as contrasted with AI data processing. Information (Switzerland), 9(4), 1–15.

<https://doi.org/10.3390/info9040083>

- Lopes, R., & Betrouni, N. (2009). Fractal and multifractal analysis: a review. *Medical Image Analysis*, 13(4), 634–649.
- Mandelbrot, B. B. (1983a). “The Fractal Geometry of Nature,” WH Freeman and Co., New York (1983). *Ann. Isr. Phys. Soc.*, 5, 59.
- Mandelbrot, B. B. (1983b). *The Fractal Geometry of Nature*. Henry Holt and Company.
<https://books.google.iq/books?id=SWcPAQAAMAAJ>
- Matsko, V. J. (2016). Koch-Like Fractal Images. *Proceedings of Bridges 2016: Mathematics, Music, Art, Architecture, Education, Culture*, 293–300.
- Mau, A. B., Change, M., & Nightingale, F. (2019). The History of Health Care Facility Design-and How it Informs the Future. <https://buildgp.com/blog-post/the-history-of-health-care-facility-design-and-how-it-informs-the-future-2/>
- Mau, B., Leonard, J., & Boundaries, I. W. (2004). *Massive Change*. Phaidon Press.
<https://books.google.iq/books?id=JPFTAAAAMAAJ>
- Mayackaya, I., Yazyev, B., & Yazyeva, S. (2021). FRACTAL ARCHITECTURE: PAST, PRESENT, AND FUTURE. *Construction and Architecture*, 9, 66–70.
<https://doi.org/10.29039/2308-0191-2021-9-1-66-70>
- McCallum, W. C. (2024). Attention. *Encyclopedia Britannica*.
<https://www.britannica.com/science/attention>
- Mohebi, S., Parham, M., Sharifirad, G., & Gharlipour, Z. (2018). Presenting a conceptual model for designing hospital architecture with a patient-centered approach based on the patient’s lived experience of sense of place in the therapeutic space. January, 1–6.
<https://doi.org/10.4103/jehp.jehp>
- Netherland Board for Healthcare Institutions. (2008). *Quality of the physical healthcare environment*. Report number 617.
- No Title. (n.d.). source: 3Blue1Brown, 27 Jan.2017, Fractals are not typically self-similar/youtube

- Norman, D. A. (1988). *The Psychology of Everyday Things*. Basic Books.
<https://books.google.iq/books?id=OINSRAAACAAJ>
- Ostwald, M. J., & Vaughan, J. (2016). *The fractal dimension of architecture* (Vol. 1). Springer.
- Patterson, E. S., Sanders, E., Sommerich, C. M., Evans, K. D., Lavender, S. A., & Li, J. (2017). The Environmental Services Perspective on Hospital Room Design: A Mixed-Methods Approach. *Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care*, 6(1), 104–108.
<https://doi.org/10.1177/2327857917061023>
- Peng, Y. (1986). *中国古典园林分析 Analysis of Chinese classical gardens*. perception. (1995). Cambridge University Press.
<https://dictionary.cambridge.org/dictionary/english/perception>
- Perception. (n.d.). *New World Encyclopedia*.
<https://www.newworldencyclopedia.org/entry/Perception>
- PRISM. (n.d.). <https://prismpub.com/health-nature-sustainability-jacobs-medical-center-in-san-diego/>
- Prugsiganont, S., & Waroonkun, T. (2021). Factors influencing optimal hospital design: A comparative study between thai and norwegian public hospitals. *Civil Engineering and Architecture*, 9(4), 976–991. <https://doi.org/10.13189/cea.2021.090402>
- Qiong, O. U. (2017). A Brief Introduction to Perception. *Studies in Literature and Language*, 15(4), 18–28. <https://doi.org/10.3968/10055>
- Ramirez, M. R., Park, G., & School, H. (2018). the Great Pyramid of Giza, Pi, and the Golden Ratio. 1, 1–11.
- RIBA. (n.d.). No Title. <https://www.architecture.com/awards-and-competitions-landing-page/awards/riba-international-awards/2021/friendship-hospital-satkhira>
- RIBA editorial team. (2021). Friendship Hospital, Satkhira. November 16, 2021.

<https://www.architecture.com/awards-and-competitions-landing-page/awards/riba-international-awards/2021/friendship-hospital-satkhira>

- Robles, K. E., Roberts, M., Viengkham, C., Smith, J. H., Rowland, C., Moslehi, S., Stadlober, S., Lesjak, A., Lesjak, M., Taylor, R. P., Spehar, B., & Sereno, M. E. (2021). Aesthetics and Psychological Effects of Fractal Based Design. *Frontiers in Psychology*, 12(August), 1–21. <https://doi.org/10.3389/fpsyg.2021.699962>
- Schoenfelder, T. (2012). Patient Satisfaction: A Valid Indicator for the Quality of Primary Care? *Primary Health Care: Open Access*, 02(04), 2–4. <https://doi.org/10.4172/2167-1079.1000e106>
- Schweitzer, M., Gilpin, L., & Frampton, S. (2004). Healing spaces: elements of environmental design that make an impact on health. *Journal of Alternative and Complementary Medicine* (New York, N.Y.), 10 Suppl 1, S71-83. <https://doi.org/10.1089/1075553042245953>
- Smith, A. R. (1984). Plants, fractals, and formal languages. *ACM SIGGRAPH Computer Graphics*, 18(3), 1–10.
- Sonin, A. A. (2001). *The Physical Basis of DIMENSIONAL ANALYSIS*. 2nd Editio. <http://goo.gl/2BaQM6%0A%0A>
- Stefan Mee. (2021). Healing by Design | Wardle. June 9, 2021. <https://wardle.studio/stories/healing-by-design/>
- Stiny, G. (1981). A note on the description of designs. *Environment and Planning B: Planning and Design*, 8(3), 257–267.
- Suárez, I. (2020). Florence Nightingale, Victorian design and the treatment of Covid-19. 24 November 2020. <https://wellcomecollection.org/articles/X7fWFRMAACEAja6b>
- Taylor, R. P. (2021). The potential of biophilic fractal designs to promote health and performance: A review of experiments and applications. *Sustainability* (Switzerland), 13(2), 1–22. <https://doi.org/10.3390/su13020823>
- Taylor, R., & Spehar, B. (2016). *Fractal Fluency: An Intimate Relationship Between the*

- Brain and Processing of Fractal Stimuli (pp. 485–496). https://doi.org/10.1007/978-1-4939-3995-4_30
- Team, A. E. (2018). First look at the Victorian Heart Hospital. 15 May 2018. <https://architectureau.com/articles/first-look-at-the-victorian-heart-hospital/>
- Tgmdev. (2012). Hausdorff-Besicovitch dimension. <https://www.tgmdev.be/hausdorffdim.htm>
- The Fractal Foundation. (2013). What Is A Fractal? <https://fractalfoundation.org/resources/what-are-fractals/>
- Trivedi, P. K. (1993). Hindu_Temple_Models.pdf.
- van Oel, C. J., Mlihi, M., & Freeke, A. (2021). Design Models for Single Patient Rooms Tested for Patient Preferences. *Health Environments Research and Design Journal*, 14(1), 31–46. <https://doi.org/10.1177/1937586720937995>
- Vaughan, J., & Ostwald, M. J. (2018). Fractal Geometry in Architecture BT - Handbook of the Mathematics of the Arts and Sciences (B. Sriraman (Ed.); pp. 1–16). Springer International Publishing. https://doi.org/10.1007/978-3-319-70658-0_11-1
- Vaughan, J., & Ostwald, M. J. (2021). Fractal Geometry in Architecture BT - Handbook of the Mathematics of the Arts and Sciences (B. Sriraman (Ed.); pp. 1345–1360). Springer International Publishing. https://doi.org/10.1007/978-3-319-57072-3_11
- Viswanathan, I., & Ambasta, S. (2023). Sthapatya Shiksha: Hindu Temple Architecture Education BT - Indigenous Technology Knowledge Systems: Decolonizing the Technology Education Curriculum (M. T. Gumbo & P. J. Williams (Eds.); pp. 121–136). Springer Nature Singapore. https://doi.org/10.1007/978-981-99-1396-1_8
- Voss, R. F. (1988). Fractals in nature: From characterization to simulation BT - The Science of Fractal Images (M. F. Barnsley, R. L. Devaney, B. B. Mandelbrot, H.-O. Peitgen, D. Saupe, R. F. Voss, H.-O. Peitgen, & D. Saupe (Eds.); pp. 21–70). Springer New York. https://doi.org/10.1007/978-1-4612-3784-6_1
- Vrdoljak, A., & Miletić, K. (2019). Principles of fractal geometry and applications in

architecture and civil engineering. E-Zbornik : ELECTRONIC COLLECTION OF PAPERS OF THE FACULTY OF CIVIL ENGINEERING, 9(17), 40–52. http://e-zbornik.gf.sum.ba/images/radovi//e-Zbornik_17_04_en.pdf

Wang, N., & Wang, J. (2017). Exploration of Humanistic Design of Hospital Architecture Humanistic Design of Hospital. 142(Icelaic), 589–591. <https://doi.org/10.2991/icelaic-17.2017.134>

WILSON, E. O. (2009). Biophilia. Harvard University Press. <https://books.google.iq/books?id=BapY4GLfMOAC>

Wolfgang E. Lorenz. (2003). Fractals and Fractal Architecture [technischen Universität Wien]. [chrome-extension://hmigninkgibhdckiaphhmbgcghochdjcpdfjs/web/viewer.html?file=file:///C:/Users/hp/Downloads/Fractals_and_Fractal_Architecture \(2\).pdf](chrome-extension://hmigninkgibhdckiaphhmbgcghochdjcpdfjs/web/viewer.html?file=file:///C:/Users/hp/Downloads/Fractals_and_Fractal_Architecture%20(2).pdf)

YAZDANISTUDIO. (n.d.). <http://yazdanistudio.com/portfolio/uc-san-diego-jacobs-medical-center/>

Zhang, D., Shan, X., Zhang, X., Chen, H., & Zheng, Y. (2023). Spatial Feature Analysis of the Beijing Forbidden City and the Shenyang Imperial Palace Based on Space Syntax. Buildings, 13(10), 1–16. <https://doi.org/10.3390/buildings13102615>

APPENDIX A

A.1 THE VICTORIAN HEART HOSPITAL

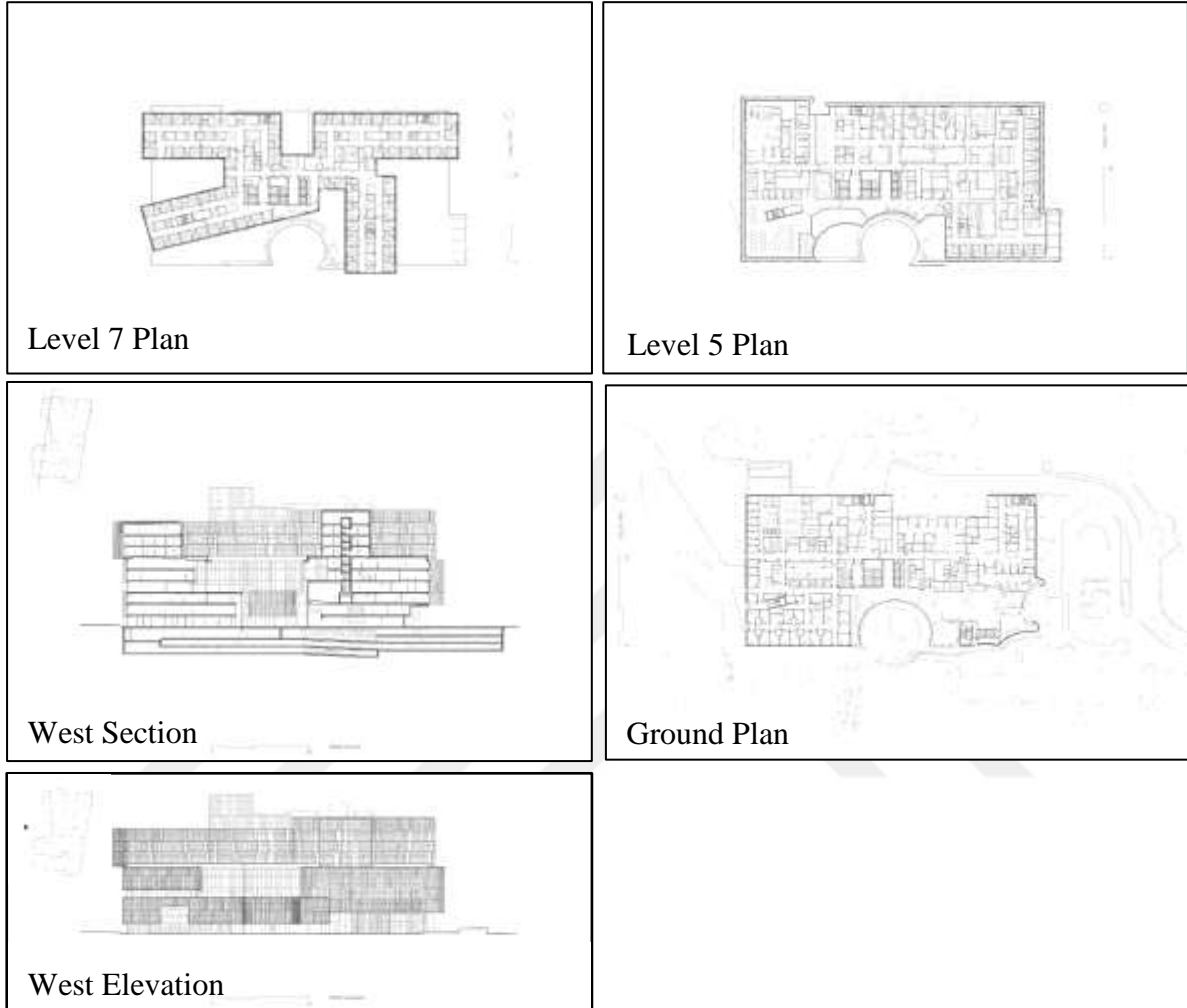


Figure A.1: Project Charts :(Site, Ground, Level5, Level 7 Plans with West Section and Elevation of The Victorian Heart Hospital Project.

A.2 THE JACOBS MEDICAL CENTRE PLANS



Figure A.2: Floor Plans Of The Jacobs Medical Centre (Archdaily, N.D.-A)

A.3 FRIENDSHIP HOSPITAL PLANS

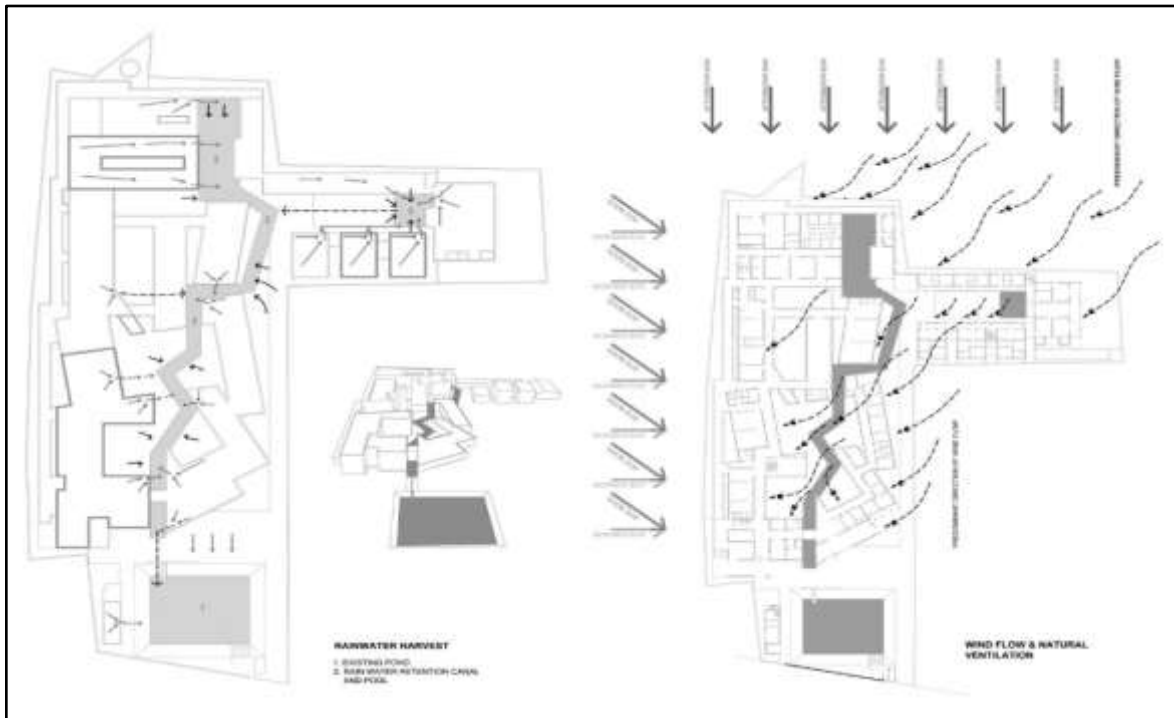


Figure A.3: Architectural Treatments of Rainwater and Wind Flow & Natural Ventilation and Sun Radiation Direction in Friendship Hospital Shyamnagar, Upazila, Bangladesh(John Hill, 2022)

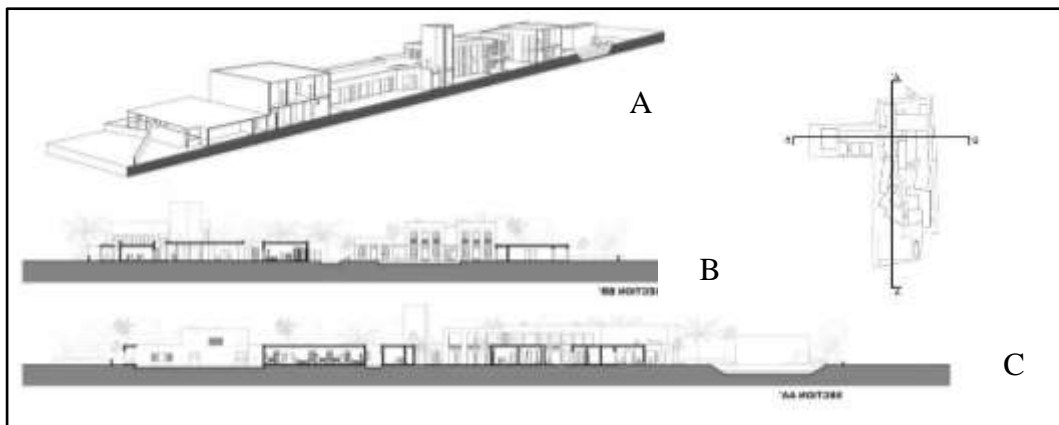


Figure A.4: Friendship Hospital (A) Perspective-Section (B) Section B-B (C) Section A-A(John Hill, 2022)

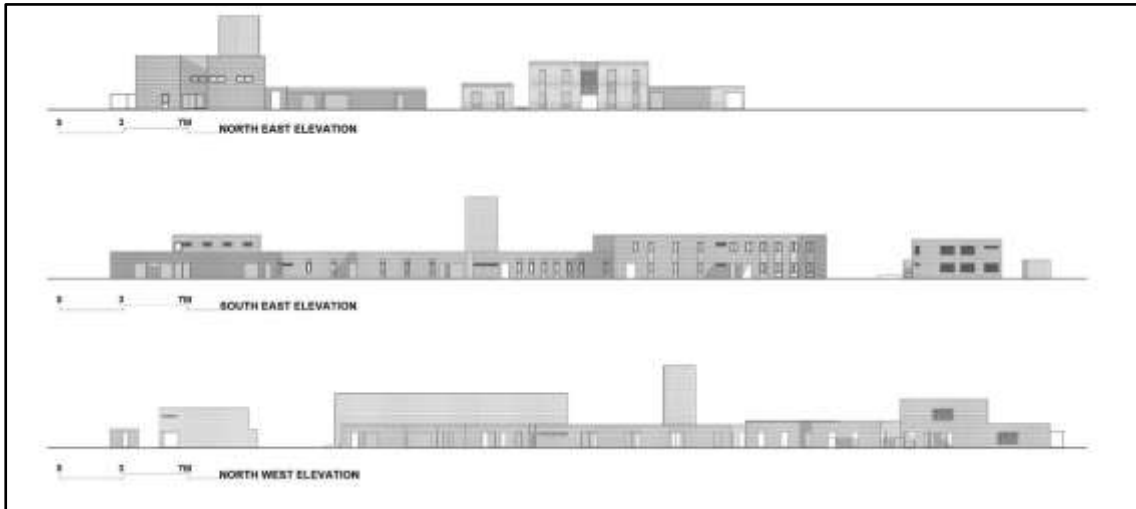


Figure A.5: Friendship Hospital-Elevations(John Hill, 2022)

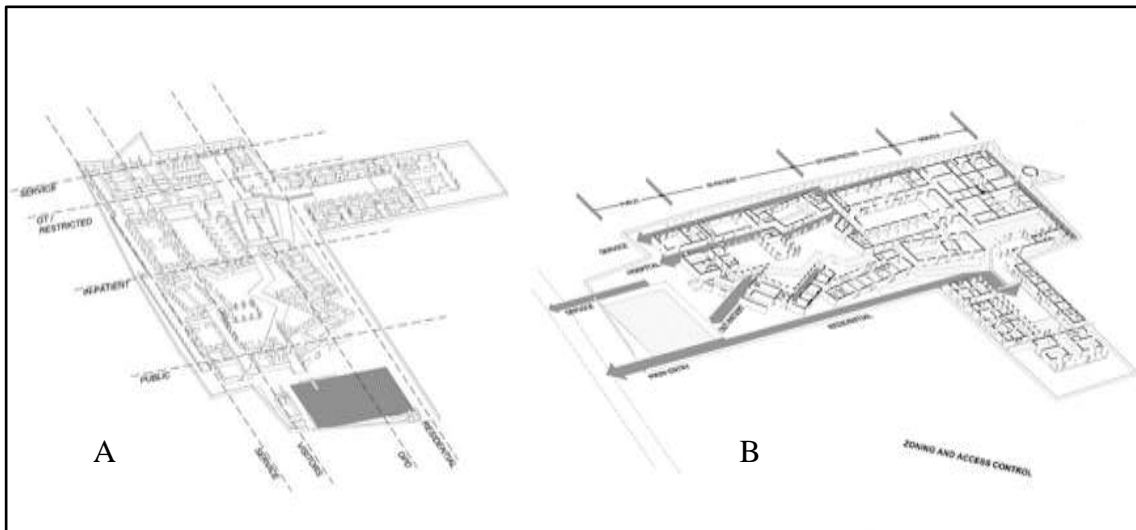


Figure A.6: Friendship Hospital (A) and (B) Zoning and Access Control (John Hill, 2022).

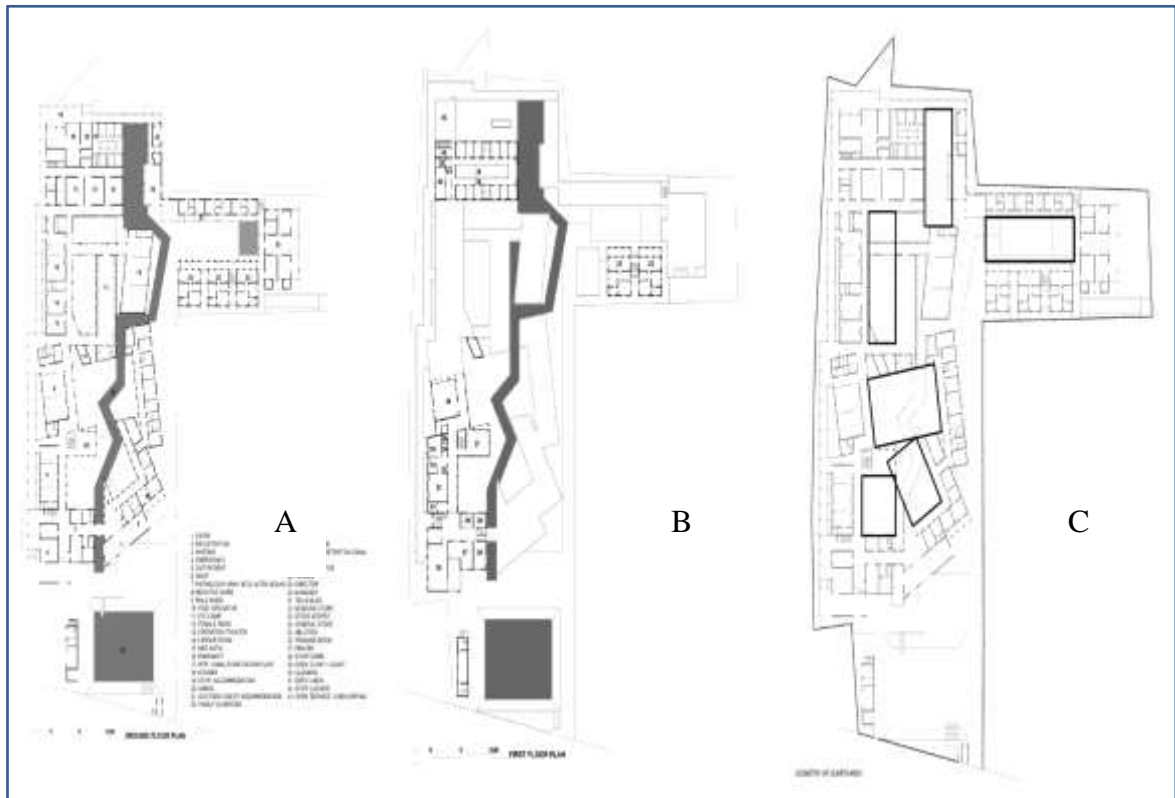


Figure A.7: Plans of Friendship Hospital (A) First Floor Plan (B) Second Floor Plan (C) Geometry of Courtyards (Archdaily, N.D.-B).

A.4 QUESTIONNAIRE

The Fractals Impact in Hospital Architecture, and what is Human Perception on?

The reason for visiting the hospital:

- Sickness work visitor

The Visit status

- Regular Resident Necessary Dislike

How describe the hospitals' atmosphere you visited?

- Comfortable/warm/Reassured/welcoming...
 Worrying/cold/stuffy/Scary /terrifying...

Are you perceiving the concept of fractals, fractal dimensions, and fractal patterns in nature used within architectural design?

yes

No

Maybe

Do you prefer a hospital environment?

Traditional

Modern

Fractal

Select the comfort Images you see

D=1.8658



D=1.6961



D=1.8658



D=1.6961



D=1.7913

D=1.4981



□ D=1.5857



Below is a comparison between three images of Patient rooms, for three different hospitals within the case study that differ in design, fractal dimensions, and cities. Choose the image that gives you a feeling (comfortable / reassured / welcoming / warm /....), taking into account the project location and the resources available in constructing the building.

□ D=1.7937



□ D=1.7271



D=1.6674



Below is a comparison between three images of Waiting Are, for three different hospitals within the case study that differ in design, fractal dimensions, and cities. Choose the image that gives you a feeling (comfortable / reassured / welcoming / warm /....), taking into account the project location and the resources available in constructing the building.

D=1.7967



D=1.498



□ $D=1.7717$



A.5 ANALYSING THE RELATIONSHIP BETWEEN THE FRACTAL DIMENSION PREFERRED BY QUESTIONNAIRE PARTICIPANTS AND THEIR FEELINGS OF COMFORT

To calculating the Pearson correlation coefficient (r) using the hypothetical comfort levels and the preference ratings. Must follow these steps:

Calculate the mean of the preference ratings (\bar{P}) and the mean of the hypothetical comfort levels (\bar{C}).

Calculate the covariance between preference ratings and hypothetical comfort levels (cov (P, C))

Calculate the standard deviation of preference ratings (σP) and the standard deviation of hypothetical comfort levels (σC). Use the formulas to compute the Pearson correlation coefficient (r).

Means calculation: The Mean of the fractal dimension preference values and the Mean of

the default comfort level are calculated. This gives us a central point around which the data differ.

$$\bar{P} = \frac{\sum_{i=1}^n P_i}{n} \quad (\text{A.1})$$

$$\bar{C} = \frac{\sum_{i=1}^n C_i}{n} \quad (\text{A.2})$$

To calculate the means of the preference ratings (\bar{P}) and the hypothetical comfort levels (\bar{C}), we'll sum up all the values and divide by the total number of data points.

For preference ratings:

$$\bar{P} = \frac{1.4981 + 1.4981 + \dots + 1.8658}{124} \quad \bar{P} \approx 1.7256$$

$$\bar{C} = \frac{1 + 1 + \dots + 10}{124} \quad \bar{C} = 5.1532$$

Covariance Calculation: To measure how much the preference ratings and the hypothetical comfort levels vary together. This gives an idea of how they vary in relation to each other.

$$\text{cov}(P, C) = \frac{\sum_{i=1}^n (P_i - \bar{P})(C_i - \bar{C})}{n} \quad \text{cov}(P, C) \approx 68.2110 \quad (\text{A.3})$$

Standard Deviation Calculation: Calculated how much the preference ratings and the hypothetical comfort levels vary individually from their respective Means. This helps understand the spread of the data.

$$\sigma_P = \sqrt{\frac{\sum_{i=1}^n (P_i - \bar{P})^2}{n}} \quad \sigma_P \approx 0.1304 \quad (\text{A.4})$$

$$\sigma_C = \sqrt{\frac{\sum_{i=1}^n (C_i - \bar{C})^2}{n}} \quad \sigma_C \approx 2.9839 \quad (\text{A.5})$$

Pearson Correlation Coefficient Calculation (r): Using the covariance and the standard deviations, determined the strength and direction of the linear relationship between the

preference ratings and the hypothetical comfort levels.

$$r = \frac{cov(P,C)}{\sigma P \times \sigma C} \quad (A.6)$$

$$r \approx \frac{68.2110}{0.1304 \times 2.9839}$$

$$r \approx \frac{68.2110}{0.3892} \quad r \approx 175.3798$$

Pearson correlation coefficient value Interpretation: This value indicates a strong positive correlation between the preference ratings and the hypothetical comfort levels. In other words, there is a strong relationship between the participants' preference for certain fractal dimensions and the comfort levels they experience when looking at those fractal patterns.: That A positive r+ a positive relationship between preference ratings and comfort levels, while a negative r- would indicate a negative relationship. The closer r is to 1, the stronger the positive relationship.

A.6 ANALYSING THE RELATIONSHIP LINKING THE OVERALL FRACTAL DIMENSION OF THE IMAGES AND THE FRACTAL DIMENSION OF THE DESIGN IMAGE ELEMENTS (CEILINGS, WALLS, FLOORS, FURNITURE) WITH THE PREFERRED FRACTAL DIMENSION OF THE PARTICIPANTS IN THE QUESTIONNAIRE

To find a strong explanatory relationship linking the overall fractal dimension of the images and the fractal dimension of the design image elements (ceilings, walls, floors, furniture) with the preferred fractal dimension of the participants in the questionnaire, can conduct a correlation analysis. By calculated the Pearson correlation coefficient between the overall fractal dimension and each element's fractal dimension separately. This help to understand how variations in these dimensions relate to participants' preferences.

Where

O: Overall fractal dimension

C: Ceiling fractal dimension

F: Floor fractal dimension

W: Wall fractal dimension

T: Furniture fractal dimension

P: Participants' preferred fractal dimension

will calculate r values for O vs. P, C vs. P, F vs. P, W vs. P, and T vs. P.

Next, will analyse the result correlation coefficients to determine the strength and direction of the relationships. A strong positive correlation suggests that as one variable increases, the other also tends to increase, indicating a preference for higher fractal dimensions. A negative correlation suggests the opposite.

Through calculate the Pearson correlation coefficient (r) This will help us understand how variations in these dimensions relate to participants' preferences.

After calculating r values for each pair of dimensions, we will analyse them to determine the strength and direction of the relationships. A strong positive correlation suggests that as one variable increases, the other also tends to increase, indicating a preference for higher fractal dimensions. A negative correlation suggests the opposite.

To calculate the Pearson correlation coefficient (r) between the overall fractal dimension (O) and the preferred fractal dimension (P), use the formula:

$$r_{O.P} = \frac{cov(O.P)}{\sigma O \times \sigma P} \quad (6)$$

Similarly, calculate r values for the ceiling (C), floor (F), wall (W), and furniture (T) fractal dimensions compared to the preferred fractal dimension (P).

To calculate the Pearson correlation coefficient (r) between each design element's fractal dimension and the preferred fractal dimension (P), use the formula:

$$r_{X.P} = \frac{cov(X.P)}{\sigma X \times \sigma P} \quad (7)$$

where X represents each design element (ceiling, floor, wall, furniture).

After calculating the Pearson correlation coefficients (r), find:

$r_{O,P} \approx 0.8652$ for the overall fractal dimension (O) and the preferred fractal dimension (P)

$r_{C,P} \approx 0.9134$ for the ceiling fractal dimension (C) and P

$r_{F,P} \approx 0.8751$ for the floor fractal dimension (F) and P

$r_{W,P} \approx 0.8527$ for the wall fractal dimension (W) and P

$r_{T,P} \approx 0.8889$ for the furniture fractal dimension (T) and P

These correlation coefficients indicate strong positive relationships between each design element's fractal dimension and the preferred fractal dimension of the participants. It suggests that as the fractal dimension of these design elements increases, participants tend

to prefer images with higher fractal dimensions, implying a preference for more complex and visually engaging designs.

This relationship can be linked to the participants' feelings of comfort, warmth, or tension and fear by considering the psychological effects of fractal patterns. Higher fractal dimensions are often associated with feelings of complexity, richness, and visual interest, which can evoke positive emotions such as comfort and warmth. On the other hand, lower fractal dimensions may elicit feelings of simplicity or boredom, potentially leading to a less comfortable or engaging experience. Therefore, designing hospital spaces with higher fractal dimensions in design elements may contribute to creating environments that promote comfort and warmth, ultimately enhancing the overall experience for visitors and patients.

