A FRAMEWORK FOR IMPACTS OF BIO-ARCHITECTURE ON SOCIAL SUSTAINABILITY: EXISTING SITUATION AND POSSIBILITIES

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Thesis for the Master's Program in Architecture

Graduate School
Izmir University of Economics
Izmir
2023

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A Master's Thesis
Submitted to
the Graduate School of Izmir University of Economics
the Department of Architecture

Izmir
2023

ETHICAL DECLARATION

I hereby declare that I am the sole author of this thesis and that I have conducted my work in accordance with academic rules and ethical behavior at every stage from the planning of the thesis to its defence. I confirm that I have cited all ideas, information and findings that are not specific to my study, as required by the code of ethical behaviour, and that all statements not cited are my own.

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ABSTRACT

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Master's Program in Architecture

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August, 2023

This thesis investigates the existing effects of bio-architecture on social sustainability and discusses the possible uses of bio-architecture to create positive impacts on social sustainability. To be able to shift the way we impact the Earth, radical changes should be implemented in the way people design and make. The bio-integrations to architecture offer significant potential for sustainability. As the third pillar of sustainability, social sustainability needs careful attention while enabling shifts in the practice. This research aims to create a bridge between the bio-integrations to architecture and social sustainability by assessing the existing and possible effects. Social sustainability is investigated in existing case studies of bio-integrated architecture through its parameters: social interaction, participation, and social equity. In addition to discussing the existing situation, the possible uses of bio-architecture as a facilitator for improving social sustainability are discussed.

Keywords: Bio-architecture, social sustainability, sustainability of communities, bio-integration to architecture

ÖZET

BİYO-MİMARLIĞIN SOSYAL SÜRDÜRÜLEBİLİRLİK ÜZERİNDEKİ ETKİLERİ ÜZERİNE BİR ÇERÇEVE: MEVCUT DURUM VE OLASILIKLAR

Özel, Berfin

Mimarlık Yüksek Lisans Programı

Tez Danışmanı: Dr. Öğr. Üyesi Lale Başarır

Ağustos, 2023

Bu tez, biyo-mimarlığın sosyal sürdürülebilirlik üzerindeki mevcut etkilerini araştırmakta ve olumlu etkiler için olası kullanım potansiyellerini tartışmaktadır. İnsanların Dünya'yı etkileme biçimini değiştirebilmek için, tasarım ve üretim biçimlerinde köklü değişiklikler uygulanmalıdır. Biyo-entegrasyonlar mimariye sürdürülebilirlik bağlamında önemli bir potansiyel sunmaktadır. Mimarlığın tasarlama ve yapma biçimlerini değiştirirken, sosyal sürdürülebilirlik özenle göz önünde bulundurulmalıdır. Bu araştırma, biyo-mimarlığın sosyal sürdürülebilirliğe mevcut ve muhtemel etkilerini araştırarak ikisi arasında bir köprü oluşturmayı amaçlar. Sosyal sürdürülebilirlik; sosyal etkileşim, katılım ve sosyal eşitlik parametreleri yardımıyla, mevcut biyo-mimari vaka incelemeleri ile araştırılır ve biyo-mimarlığın sosyal sürdürülebilirliği iyileştirmek için bir kolaylaştırıcı olarak olası kullanımları tartışılmaktadır.

Anahtar Kelimeler: Biyo-mimarlık, sosyal sürdürülebilirlik, toplulukların sürdürülebilirliği, mimarlıkta biyo entegrastyon.

ACKNOWLEDGEMENTS

Thanks to my family who supported me in every stage of my education with love and endless enthusiasm, thanks to people in my circle whose refreshing existence helped me extend the possibilities, and thanks to my advisor Lale Başarır for her patience.

TABLE OF CONTENTS

ABSTRACT iv
ÖZET vi
ACKNOWLEDGEMENTS viii
TABLE OF CONTENTS ix
LIST OF TABLES xi
LIST OF FIGURES xii
LIST OF ABBREVIATIONS xiv
CHAPTER 1: INTRODUCTION 1
1.1. Problem Statement & Theoretical Background 1
1.2. Aim and Objective 2
1.4. Research Questions 3
1.5. Significance of the Research 3
1.6. Methodology 4
1.7. Overview of Structure 7
CHAPTER 2: A FRAMEWORK FOR BIOLOGY AND ARCHITECTURE 9
2.1. A Brief History of the Integration of Biology and Architecture 9
2.2. Importance of Biology in Design 11
2.3. Various Integrations of Biology and Architecture 12
2.3.1. Biomimicry, Biomorphism, Natural Algorithms & Evolutionary Design 13
2.3.2. Bio-utilization, Biophilia, Biomaterial 16
2.3.3. Synthetic Biology, Living Architecture/Construction, Bio-Manufacturing 18
2.4. Various Categorizations for Bio-integrated Architectures 20
CHAPTER 3: SOCIAL SUSTAINABILITY 25
3.1. Sustainability & Sustainable Development 25
3.2. One, Three and Multi Pillar Strategies to Define Sustainability 26
3.3. Social Sustainability 29
3.3.1. Several Frameworks for Social Sustainability 31
3.3.2. Parameters and Measures of Social Sustainability 34
3.4. Un Sustainable Development Goals 37
3.5. Sustainable Development Goal #11 Sustainable Cities & Communities 39
3.6. Social Interaction 41

3.7. Participation 43
3.8. Social Equity 44
CHAPTER 4: EFFECTS OF BIO-INTERACTIONS TO ARCHITECTURE ON SOCIAL SUSTAINABILITY 47
4.1. Case Studies 47
4.1.1. Eastgate Centre.. 47
4.1.2. German Pavilion, Expo '67 51
4.1.3. Beijing National Stadium.. 53
4.1.4. Bosco Verticale 55
4.1.5. The Kampung Admiralty 58
4.1.6. BIQ house and SolarLeaf.. 59
4.1.7. Hy-Fi Tower.. 61
4.2. Case Study Evaluation 63
4.2.1. Findings & Results.. 64
4.3. Possibilities 65
4.3.1. Biomimicry and Social Interaction, Participation, Social Equity 66
4.3.2. Biophilia and Social Interaction, Participation, Social Equity........................ 66
4.3.3. Biomaterial and Social Interaction, Participation, Social Equity.................... 67
4.3.4. Synthetic Biology and Social Interaction, Participation, Social Equity........... 67
4.3.5. The Bio-integrations for Social Interaction, Participation and Social Equity Indicators.. 68
CHAPTER 5: CONCLUSION & DISCUSSION 70
5.1. Discussion & Future Possibilities 70
5.2. Limitations of the Study.. 71
5.3. Conclusion 73
REFERENCES.. 75

LIST OF TABLES

Table 1. Bio Integrations in Architecture 24
Table 2. Case Study Evaluation Matrix 63

LIST OF FIGURES

Figure 1. Methodology Map of The Research 4
Figure 2a & 2b. Rib Vaults & Flying Buttresses 10
Figure 3a & 3b. Expiatory Temple & Passion Facade of Sagrada Familia 11
Figure 4. Levels and Dimensions of Biomimicry as Zari's Framework 13
Figure 5. Lotus Temple 14
Figure 6. Evolutionary Design Scheme of Bentley 15
Figure 7. Diagram of Bio-integration to Architecture on Timeline 22
Figure 8. Sustainability Concentric Model 27
Figure 9. Three Pillar Sustainability 28
Figure 10. Diagram of Griessler & Littig's approach, multi-pillar sustainabilities ... 29
Figure 11. Vallance, Perkins and Dixon's Threefold Scheme for Sustainable Development 32
Figure 12. 4 concepts of social sustainability by Eizenberg and Jabareen 34
Figure 13. Non-physical and predominantly physical factors of social sustainability in literature 36
Figure 14. United Nations 17 Sustainable Development Goals 37
Figure 15. UN SDG INDEX 2022 SDG #11 Dashboard Parameters 39
Figure 16. UN SDG #11 Targets and Indicators 40
Figure 17. Eastgate Centre 47
Figure 18a & 18b. Eastgate Centre Thermal Strategy Diagrams 47
Figure 19a, 19b & 19c. Orthographic Drawings of Eastgate Centre 48
Figure 20. Data Logger of Cooling Performance of Eastgate Centre 49
Figure 21a & 21b. Spider Web as Biomimicric Inspiration & Form Finding Study Model of German Pavillion 51
Figure 22. German Pavillion Expo'67 51
Figure 23. Beijing National Stadium 53
Figure 24. Bosco Verticale 55
Figure 25. Ploor Plan of Bosco Verticale 56
Figure 26a & 26b. Maintenance of Bosco Verticale 57
Figure 27a & 27b. Kampung Admiralty 58
Figure 28a & 28b. BIQ House and SolarLeaf 59

Figure 29a & 29b Hy-Fi Tower 61

LIST OF ABBREVIATIONS

UN: United Nations

SDG: Sustainable Development Goals

MDG: Millennium Development Goals

WCED: World Commission on Environment and Development

UNCED: The United Nations Commission on Environment and Development

NGO: Non-governmental Organization

ILO: International Labour Organization

CHAPTER 1: INTRODUCTION

1.1. Problem Statement & Theoretical Background

Anthropocene, the epoch of the profound impacts of human beings on Earth, has reached a point where the consequences cannot be unseen, the outcomes are not unavoidable, and taking action is necessary. As Armstrong stated, at the reached point, whether the Anthropocene is a good or a bad one, the consequence will be extinction and catastrophe (Armstrong, 2016). To be able to enhance and sustain one's chance of surviving, a transition from the Anthropocene to the Ecocene is desperately required (Armstrong, 2016). Being able to adapt to a shift like this, human beings need fundamentally revised systemic changes to the way we understand life and development, therefore the way we design and produce. To not go back where we started, to the Anthropocene, reestablishing and reforming the connection between nature and human is an essential part of this transition.

One perspective of this transformation and reconnection with nature and biology can be marked as bio-integrations to design and architecture. For such a shift to be achieved, a holistic new approach to architecture that incorporates biology and technology in the field at a maximum level should be adopted. As a part of the paradigm shift, new roles and responsibilities for architects and designers are actively being emerged. With the new developments in technology, changing ways of making, building, producing and designing are being discussed and emphasized more than ever.

In the search for a new era that holds the possible future projections of human lives, one of the essential notions is social sustainability. While reforming the relationship between nature and humans, it is necessary to reconsider the sustainability of the relationships between humans. These new changes, which reshape the discipline, offer exciting new questions and possibilities, particularly concerning the relationship of this new approach to social sustainability. This connection, which can be discussed in various contexts as another realm to be achieved for a new and better era, presents a gap in the literature that invites further exploration and investigation.

The relationship between bio-architecture and social sustainability is intricately linked, as bio-architectural interventions offer transformative opportunities to enhance social and community well-being and ecological harmony within the built environment. By integrating living systems and biological elements or knowledge into architectural design, bio-architecture offers healthier and more inclusive spaces that prioritize not only individual human needs but the needs of nature and communities. It is essential to understand how bio-architecture influences social sustainability, as it provides insights for designing resilient, equitable, and regenerative cities of the future. The information on the relationship between bio-architecture and social sustainability offers new ways of designing and making of the built environment which nurtures a sustainable coexistence between people and nature.

Biological integration into architecture has great potential for adapting the discipline for a better era. However existing bio-integrated designing and making practices right now are commonly studied with the environmental potential of them, the social possibilities are not involved to the literature widely which presents a gap. Moreover, the common approach for the biological integrations to architecture represents singular, one-scale actions. This approach as the result of singular or small-scale efforts needs to be widened to multi-scale, plural and comprehensive approaches.

1.2. Aim and Objective

This research aims to offer a framework to investigate and understand the existing effects of bio integrations to architecture on social sustainability and discuss the possibilities of enhancing social sustainability with the help of bio-architecture. The goal is to contribute to the discussion of future possibilities of bio-architecture in social aspects and open a discussion about this transdisciplinary area.

The research objectives of this thesis are to determine the framework of bio-architecture with the existing models of biology-integrated architectural practices and the possible future approaches. This study aims to explore the effects of bio-architecture on *social interaction, social equity, and participation* using qualitative methods and asses the relationship between social sustainability parameters and biological integration to architecture within its various modes.

The bio-integrated architecture notion is studied as a broad term to discuss the holistic, inter-scale, multi-dimensional approaches possible, after the detailed investigation of its various scopes.

Social sustainability is discussed with its common frameworks and parameters and the selected 3 parameters; social interaction, social equity and participation are investigated with their indicators on case studies and possibilities are discussed regarding them.

1.4. Research Questions

The research questions of this thesis circulate the relationship between bio-architecture and social sustainability:

- What are the existing effects of bio-integrated architecture on social sustainability?
- What kind of correlations there are between biological applications in architecture and their effect on social sustainability parameters?
- How can bio-architecture be used to create positive impacts on social sustainability?

1.5. Significance of the Research

The research maps out the relationship between two concepts that are mainly studied in particularly different disciplines and literature offers an advantage of peeking behind trans-disciplinary doors. Natural and social sciences brought together in the architectural discussions offer a broad perspective on the discipline. Filling this gap by contributing to a discourse that mainly focuses on the future possible lives of societies, in the built environment, brings a certain expansion to bio-architecture's framework and emphasizes its role and significance.

The biological integrations of architecture are mostly related to and studied with the environmental effects and environmental sustainability. To be able to find new ways of living, and be able to adapt to necessary transformations, like the ones from Anthropocene to Ecocene (Armstrong, 2016), the required changes and possibilities need to be studied extensively. The social aspects of these integrations and the possibilities that they might serve are understudied which might offer fruitful potential to the academia and the practice.

The research advances the dialogue about changing responsibilities of architects and designers for a new era. It offers a holistic perspective to the people who produce and can contribute to human lives to various extents.

1.6. Methodology

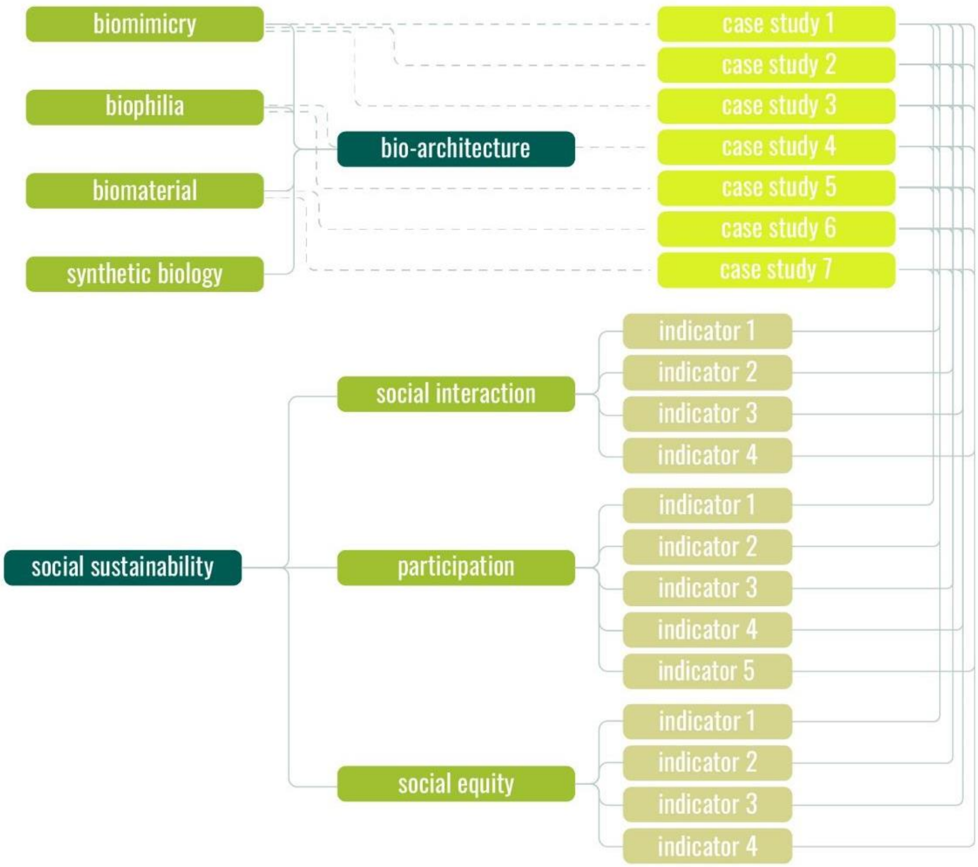

Figure 1. Methodology Map of The Research

Qualitative research methods are adopted for analysing the existing effects and discussing the possible impacts of bio-integrated architecture on social sustainability.

As the first leg of the research, the possible biological applications in architecture are categorised and studied according to different measures; type of integration used, the role of the biological integration, the role of the human designer, and the process. With this framework, it became possible to address the differences between various approaches which integrate biology into architecture at one level and holistic, inter-scale possibilities.

In the second leg, the social sustainability literature is studied and the different parameters and indicators of social sustainability in the literature are investigated. From this review, the most discussed parameters of social sustainability; *social interaction, participation and social equity* are selected (Figure 1) because of the relevance and the feasibility of studying them in the built environment for the investigation of the existing effects and possibilities of bio-integrated architecture on social sustainability. These parameters are discussed with their indicators especially related to the built environment. A set of indicators are selected according to their applicability to bio-integrations on architecture.

The lack of a complete matrix in this transdisciplinary field led to the offered selection of indicators for evaluating the impact of bio-architecture on social sustainability. Based on the relevant literature and existing works, a curation of indicators has been propagated to systematically evaluate the multifaceted dimensions of social sustainability influenced by bio-integrated architectural interventions. These selected indicators, encompassing social interaction, social participation, and social equity aspects, have been tailored to reflect the different aspects of bio-architectural practices and their potential usages in fostering sustainable communities. While there are several studies on the measurement of social sustainability, the framework offered for this research provides an assessment matrix and a roadmap to integrate social sustainability and bio-architecture concepts.

The seven case studies are investigated and discussed on these indicators via secondary data collected from media (photos and drawings, interviews, documents and online newspaper articles). A matrix (Table 2) including the ratings according to the indicators of social sustainability for bio-integration is prepared.

Then the possibilities of using bio integration for architecture holistically iteratively and on various scales are discussed with the indicators of social interaction participation and social equity. Also, the possible relationships between biomimicry, biophilia, biomaterials, synthetic biology and social interactions, participation, and social equity are discussed.

While creating the matrix for the case studies investigation, when encountering a lack of recorded or expressed information regarding a specific social sustainability indicator for the specific case study, it is presumed that the indicator is not provided or addressed. This assumption is made based on the absence of relevant data or documentation found within media sources and other available materials. This methodological approach allowed the research to be put in a systemic analysis while recognizing the potential limitations in capturing the full extent of the indicator's influence within the selected case studies.

The selection of case studies for this research was carefully chosen to achieve a comprehensive understanding of the effects of bio-integrations on social sustainability in architecture. The case studies were selected from a diverse range of bio-integration types: *biomimicry*, *biophilia* and *biomaterial* to be able to make inferences related to the bio-integration types. The selection is affected by the representability of its bio-integration type and data availability. Synthetic biology applications are not included as case studies since the existing examples are limited and do not allow observation of the mentioned indicators on an architectural scale.

The scale and the program of the case studies vary since the bio-integrations on various scales and programs which offer the proper amount of data are limited. Even though biological integrations are not a new or uncommon realm, according to the several requirements of the applications there are tendencies of using these strategies for specific scales or functions. However, they are all intentionally selected inside the architecture scale to be able to properly examine the effects of architectural applications instead of urban or material scales. The biomimicry case studies are; Eastgate Centre, Beijing Stadium and German Pavilion Expo’67. The biophilia case studies are Bosco Verticale and Kampung Admiralty. The biomaterial case studies include the BIQ House and Hy- Fi Tower.

The study acknowledges several limitations that should be considered. Firstly, the research mainly focuses on the architectural level, which may restrict a comprehensive examination of social sustainability across multiple layers. Additionally, secondary data from media includes information from the design period of the case study to present which limits the assessment of longer-term effects of bio-architectural interventions.

The qualitative approach allows for a comprehensive analysis but may require additional methodologies to translate findings into actionable outcomes. Moreover, relying on existing data from media sources may result in some information being omitted, affecting the comprehensive assessment of the actual impact of bio-integrations.

The selected case studies are not from a fixed program, scale and purpose. The diversity of selected case studies from various contexts may impact the generalizability of the findings. Lastly, the complexity and subjectivity of social sustainability parameters pose challenges in data collection, possibly influencing the robustness of the outcomes. Recognizing these limitations ensures a balanced understanding of the research findings.

1.7. Overview of Structure

In the second chapter, the biology in architecture and design is discussed in detail with the existing applications. The history of the use and inspiration of nature in architecture is unfolded. Several approaches to the use of biology in architecture are analysed and categorized into various sets.

The third chapter is a framework of the concept of "social sustainability" to map the concept in terms of definitions, approaches, parameters and measurement tools. The social sustainability concept as a first neglected third pillar of sustainability and sustainable development is examined. As a supporting notion, the United Nations Sustainable Development Goals and the #11th goal, sustainable communities are discussed with its mission and parameters. The selected 3 indicators of social sustainability; *social interaction, participation and social equity* for this research, are discussed in detail with their selected indicators for this research.

In the fourth chapter, the discussion is continued with the existing applications of biological integrations to architecture and the existing effects of them on social sustainability are investigated. The case studies are examined with the selected set of indicators of social interaction, participation and social equity and a matrix formed according to the collected data which offers a rating for the case studies. Then, the possible future bio-integration approaches and their potential as a facilitator for social sustainability are discussed. The holistic, iterative, interscale approach to bio-integrated architecture and its difference from the existing modes are emphasized within the framework of social sustainability.

Finally, the existing situation and the possibilities of impacts of bio-architecture on social sustainability are summarized. The key findings and the limitations of the research with the future potentials are discussed and concluded in the last chapter.

CHAPTER 2: A FRAMEWORK FOR BIOLOGY AND ARCHITECTURE

The integration between biology and architecture is not a new realm. Throughout history, human beings established evolving relationships with nature. which are observable in art and design histories. Even though the trace can be seen in history, this transdisciplinary universe started to grow very fast and very efficiently today. The bio-learning (Estevez, 2009) is not new for designers and with the emerging technologies and conditions, designers found new ways of establishing relationships with nature in the designing process while biotechnology became a significant constant in designers' lives. The information that is produced by this transdisciplinary field of biology and architecture becomes more valuable while the applications of this knowledge increase and impact. The different modes of the relationship between design/designer and nature (designing from/with/by nature) create a tremendous amount of new relationships between architecture and societies. The potential of biological integrations to architecture offers positive impacts on various realms including environmental, economic and social sustainability while it offers a potential for better ways of making and designing (Spiller and Armstrong, 2011).

Biology is used in various ways in architecture, leading to a big bunch of terms and study areas. Assessing a broad term like bio-architecture needs a clearly drawn framework. This chapter focuses on drawing a framework for the existing integration areas of biology and architecture.

2.1. A Brief History of the Integration of Biology and Architecture

In architecture, biology has been either an inspiration, guide or material for a long time. Even during periods marked by ideologies that excluded the past inclusions of natural elements in architecture and design, such as modernism, alternative approaches emerged that embraced other integrations of nature into the design, as exemplified by Latin America's modernism which involves regionalism and vernacularism and offers an in-between modernism with traditional approaches. (Diniz Moreira, 2006).

The built environment has been influenced by nature, from the use of natural materials to the inclusion of natural forms and patterns in various ways throughout human history.

The prehistoric settlements which have an uninterrupted relationship with nature were using stone, wood, and clay to build sheltering (Moffett, Fazio and Wodehouse, 2004). This can be addressed as the most primitive version of bio-material use in architecture. Natural forms and motifs can be traced in architecture to ancient times, with examples of animal statues, flora, and fauna drawings as a form of communication and expression, reliefs and motifs for ornamentation or symbolism purposes (Moffett, Fazio and Wodehouse, 2004). From ancient times until modernism, there has been a long history of ornamenting using shapes inspired by nature, as a form of bio-morphism.

Figure 2a & 2b. Rib Vaults & Flying Buttresses (Source: https://en.wikipedia.org/, 2023, https://www.thoughtco.com, 2019)

Key components of Gothic architecture, pointed arches, rib vaults, and flying buttresses (Figure 2a & 2b), may be recognized as reflections of natural inspirations, such as tree branches, turtle bones and bird wings (Ramzy, 2015). Art Nouveau style introduced free-flowing compositions based loosely on plant and animal forms for its period’s movements Late Baroque and Rococo (Moffett, Fazio and Wodehouse, 2004).

Figure 3a & 3b. Expiatory Temple & Passion Facade of Sagrada Familia (Source: www.archdaily.com, 2013, livelifebcn.com/, 2021)

As a late Gothic example, the unfinished church Sagrada Familia in Barcelona (Figure 3b), Catalonia, Spain designed by Antoni Gaudi shows a great inspiration from nature due to its organic forms mimicking the trees and shells.

Modernism can be discussed as one of the sharpest turning points in the change of these inspirations and uses of nature. Most of the integrations of nature and architecture till that point were ornamental or formal based and dismissed with new sets of understandings such as “ornament being crime” (Loos, 1913).

However, with modernism and improvements in technology, new integrations with nature started to occur. The “Form follows function” principle of modernism can be interpreted as having functional aims like daylight, ventilation, thermal comfort etc. Additionally, alternative approaches to modernism incorporated traditional methods including natural materials to the design (Diniz Moreira, 2006).

In conclusion, biological inspirations and integrations have always accompanied architecture in different forms. With the 21st-century improvements in biotechnology, the integrations becoming, and should become more complex to be able to solve 21st-century problems of architecture.

2.2. Importance of Biology in Design

To be able to develop new ways of thinking, new systems, and new know-how, the most logical course of action is to use the existing flawlessly working system as a source, inspiration, and educator and add on it. Biological integrations into architecture and design offer significant environmental improvements and a great potential to jump into Ecocene (Armstrong, 2016).

The opportunities and solutions that biological integrations into architecture present may be defined within a broad range, including economic advantages, democratized access to the design and building processes and ecological benefits with sustainability-focused interventions.

Including today's knowledge and needs, responsible and conscious use of biological knowledge gained a crucial role in design on every scale. With this increasing need and knowledge, the integrations of biology and architecture have diversified into various relationships.

2.3. Various Integrations of Biology and Architecture

Pawlyn, in his book, explains various terms indicating several integration types of biology to design. He frames all the interaction between biology and architecture with an umbrella term: biodesign (Pawlyn, 2011). Biodesign refers to a more generic way of understanding the transdisciplinary field connecting nature and architecture and saves all studies from the limits of their own. Also, it refers to the philosophy of not confining the design with only the present natural possibilities, but going beyond what is already there (Pawlyn, 2011).

Some terms that are being used interchangeably for the integrations have vague or understudied definitions. *Bio-inspired* or *nature-inspired architecture* has a hazy place in literature ranging from biomimicry implementations to loose formal connections. *Bio-informed architecture*, on the other hand, can be defined as "an architecture that is aware of the systems, logics, morphologies and resources offered by nature and that can respond to design problems fully and mindfully with these offerings without compromising any other biological matter". Another definition offered for bio-informed architecture is "designing by learning from nature's best ideas which cover the process of learning and transferring knowledge from the biological principles of the morphology, structures and/or functions." (Arslan Selçuk and Mutlu Avinç, 2021, 2022) which offers a closer categorization to biomimicry. The *biolearning* term by Estevez can be also associated with bio-informed architecture which is used for the process of learning from nature (Estevez, 2009).

2.3.1. Biomimicry, Biomorphism, Natural Algorithms & Evolutionary Design

Biomimicry is one of the most controversial terms because of different definitions brought to the discourse by various theoreticians. Otto Scmitt coined the phrase "biomimetics" in the 1950s, while Jack Steele introduced the term "bionics" in the 1960s (Pawlyn, 2011). In 1962, the term "biomimicry" initially appeared as a broad term covering the notions of cybernetics and bionics (Bensaude-Vincent et al., 2002). In 1997, Benyus' book "Biomimicry: Innovation Inspired by Nature" promoted the term in the design fields (Benyus, 1997).

According to Benyus, biomimicry is “using nature's genius for designing in a conscious way” (Benyus, 1997). While she opens a broad window with her definition since she includes the formal mimicking of nature in the design process and outcomes, Pawlyn narrows the biomimicry term to; using nature’s logic to solve functional problems (Pawlyn, 2011).

Biomimicry is used as a strategy for several design problems, Pawlyn categorized these problems that biomimicry can answer as structural, material, waste management, water management, thermal environment, light and energy (Pawlyn, 2011).

Figure 4. Levels and Dimensions of Biomimicry as Zari’s Framework (Source: Zari, 2007; inspired by El Ahmar, 2011)

Zari offers a detailed framework for existing biomimetic design applications which consist of three levels, the organism, behaviour and ecosystem (Figure 4) (Zari, 2007).

The first level, organism mimicking, involves mimicking the whole or a part of an individual organism, such as a plant or an animal. The second level, mimicking behaviour, may involve adopting a specific feature of an organism's behaviour in a broader environment. The third level involves mimicking the whole ecosystem and the general principles that enable them to successfully operate (Zari, 2007). Besides these three levels, Zari also offers five possible dimensions of biomimicry: form, material, construction, process, and function (Zari, 2007).

The mimicking act according to Pawlyn surely should be function-based and not necessarily reflected in aesthetics (Pawlyn, 2011). Pawlyn’s narrowed definition points to the differentiation of biomimicry from *biomorphism.*

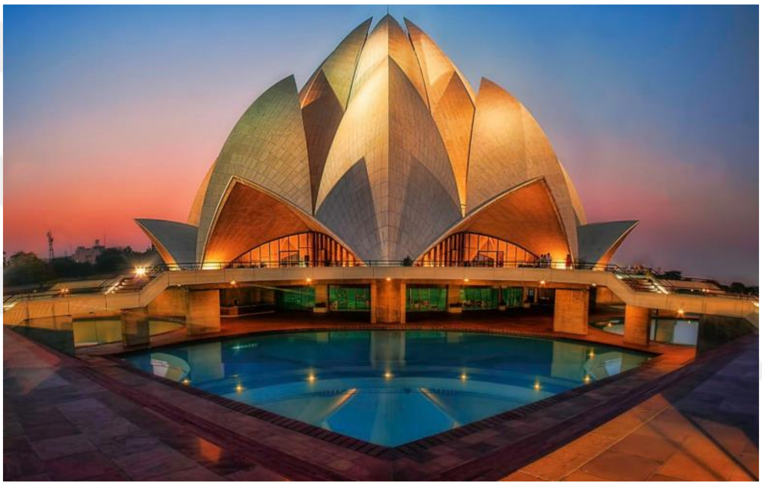

Figure 5. Lotus Temple (Source: www.re-thinkingthefuture.com, 2021)

Bio-morphism concentrates on pure aesthetic applications, the morphological reflection of biology to design, and mimics the shapes and forms of nature in design outcomes (Pawlyn, 2011). Only form-based applications from nature are the indicators of this group. The bio-morphic integration into the architecture or design is not based on problem-solving but more based on aesthetical judgement and symbolic narratives. A known example is Lotus Temple shaped like a lotus flower for a symbolic metaphor (Figure 5). For this study, the definition of biomimicry has been held as Pawlyn’s definition of function-based solutions from nature to design.

Natural algorithms as an additional realm can be investigated with the biomimicry notion. With the increasing technology, mimicking the behaviour of biological matter like growth patterns, swarm movements, and mimicking evolution (evolutionary tools for form, structure, and environmental optimizations) has become possible and significantly useful. Natural algorithms can be used to harvest the logic or system from biology, or they can simply be used to create forms, land use patterns, morphological extremes etc. Therefore, even though this research is investigated within biomimicry, the use of the tools may diversify the categorization.

Concerning natural algorithms, evolutionary architecture is essentially explored in the context of genetic evolutionary algorithms in the literature. Evolutionary design is originated from evolutionary biology, computer science, and design (Bentley, 1999). Frazer examines architecture as a form of artificial life using the concepts of morphogenesis, genetic coding, replication, and selection. (Frazer, 1995) *Evolutionary architecture* is defined by Frazer as follows:

> *"An Evolutionary Architecture investigates fundamental form-generating processes in architecture, paralleling a wider scientific search for a theory of morphogenesis in the natural world. It proposes the model of nature as the generating force for architectural form. ...The aim of an evolutionary architecture is to achieve in the built environment the symbiotic behaviour and metabolic balance that are characteristic of the natural environment."* (Frazer, 1995, p.9)

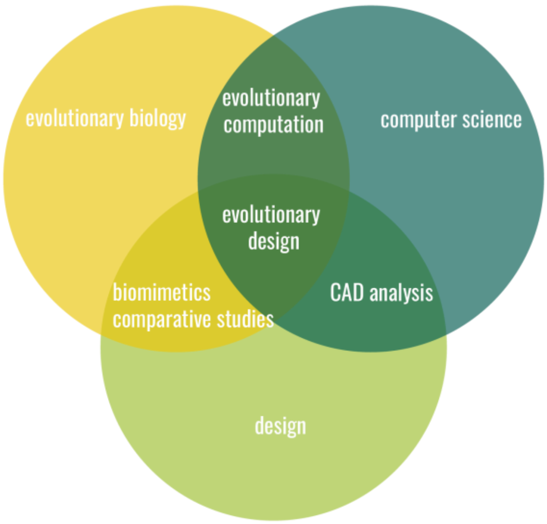

Figure 6. Evolutionary Design Scheme of Bentley (Source: Bentley, 1999)

Bentley examines the evolutionary design with genetic algorithms. The main notions discussed in the genetic or evolutionary algorithms are *fitness*, *selection*, *genotype-*

phenotype mapping, variation, execution and population (Bentley, 1999; Cogdell, 2018)

2.3.2. Bio-utilization, Biophilia, Biomaterial

Bio-utilization refers to the direct usage of natural elements in the design (Pawlyn, 2011). Bio-utilization by this definition, has a broad spectrum of examples for the engagement of natural elements to design processes and may vary from bio-material studies for construction optimization to biophilic applications like plantations for thermal cooling. The use of algae on facades for clean energy purposes or the use of timber for home construction may be addressed as bio-utilization.

Even though the *biophilia* term was first used by Erich Fromm in 1964 with the definition "love of life", the popularizing event was the proposal of Edward Wilson in 1984 (Zhong, Schröder and Bekkering, 2022). Biophilia, introduced by Wilson's 1980s writings, emphasizes the innate and hereditary instinctive connections and emotional responses human beings tend to create, with nature and forms of life (Wilson, 1984; Ramzy, 2015; Zhong, Schröder and Bekkering, 2022). It suggests that to achieve, wellness and good design in spaces, human beings should be engaged with nature and natural elements as much as possible, thus human beings should be surrounded by these life forms and design should not disconnect this bond, on the contrary, it should strengthen it (Wilson, 1984). Not only flora and fauna but also the daylight, clean air and water are referred to as the natural elements nearby.

Kellert defines biophilia as follows;

> *"Biophilia refers to humans' inherent affinity for the natural world, which is revealed in nine basic environmental values."* (Kellert, 2005, p.3)

According to him, the 9 typologies of values are; *Aesthetic* (physical appeal of and attraction to nature) [1], *Dominionistic* (mastery and control of nature) [2], *Humanistic* (emotional attachment to nature) [3], *Moralistic* (moral and spiritual relation to nature) [4], *Naturalistic* (direct contact with and experience of nature) [5], *Negativistic* (fear of and aversion to nature) [6], *Scientific* (study and empirical observation of nature) [7], *Symbolic* (nature as a source of metaphorical and communicative thought) [8], *Utilitarian* (nature as a source of physical and material benefit) [9] (Kellert, 2005, p.34)

*Biomaterial*s are another bio-utilization type that offers the use of biological matter as content to produce functional design components in architecture varying from bricks to paints, ceramic tiles to fabric. Because of their common sustainable features, biomaterials become one of the most studied areas in the design world in the last couple of years. The definitions of biomaterials vary greatly since they are employed in a variety of disciplines, including medicine and engineering. A very wide framework that can be adopted for biomaterials is; "materials that have biological origins, whether they be a part of a living organism or a substance produced by that living being" (Turhan et al., 2022).

Biomaterials possibly can be categorized according to the livelihood of the biological substance in the material processes. For example, timber as one of the most primitive biomaterial use examples in architecture does not show any livelihood in the processing and usage processes of the material. Numerous bio-composites from organic waste also show similar situations.

The use of alive matter without any manipulation on the biological level can also be discussed under the biomaterial term if the "material" itself is going to be held as a broad term "a type of physical thing having qualities that allow it to be used to make other things" (Cambridge Dictionary, 2023a). An example of this kind of biomaterial use can be collecting a microscale living organism while providing the proper living conditions sustainably and getting benefits from its biological features such as CO_2 absorption can be also discussed inside the term biomaterial.

The purposes of biomaterial use are mainly the significant possibilities it offers for environmental sustainability, the potential of decreased construction costs with local production networks and systems and the possible circularity that can be achieved in the design process which offers a positive impact to all pillars of sustainability.

Bio-fabrication and *bio-construction* terms refer to fabrication processes of the bio-integrated design that mostly involve the adaptation of a material process into fabrication (Zolotovsky, 2012).

Estevez introduces the *bio-digital architecture* term (Estevez 2009). He projects a bio-digital future where the forms are organic, structural systems are living, materials systems are integrated with the natural DNA and digital software, and production processes include natural growth and/or robotized productions of different parts (Estevez, 2009). The bio-digital architecture defined in the UIC Barcelona Bio-Digital Architecture Master's program with a scheme of reflections:

> *"Nature + Computation = BioDigital*
> *BioDigital = Biology + Digital*
> *BioDigital = Natural Intelligence + Artificial Intelligence*
> *BioDigital = Biological Techniques + Digital Techniques*
> *BioDigital = Genetics + Algorithms/Parametrics*
> *BioDigital = Bio-Learning + Machine-Learning*
> *BioDigital = Organic forms + Digital tools*
> *BioDigital = Bio-Manufacturing + Digital-Manufacturing"*
> (Source: http://www.biodigitalarchitecture.com)

2.3.3. Synthetic Biology, Living Architecture/Construction, Bio-Manufacturing

One of the definitions offered for *synthetic biology* by Dade-Robertson is:

> *"To design and engineer biologically based parts, novel devices and systems as well as redesign existing, natural biological systems" (Dade-Robertson, 2021)*

And another definition from the book by Endy is as follows:

> *"Synthetic biology, in its modern form, is often associated with the genetic manipulation of organisms and attempts to systematise biological knowledge and to standardise descriptions of gene-level biological processes such that they can be engineered to create new systems (relatively) easily and reliably." (Endy, 2005)*

As can be seen from the definitions offered, synthetic biology investigates the design and engineering of living matter. Synthetic biology in architecture concentrates on the further possibilities of biological integrations with the adoption of protocols involving the manipulation of biological matter by humans and highlights the properties of living matter like growth, repair, sensitivity and replication (Armstrong and Spiller, 2010). Synthetic biological applications include notions such as protocells, which can be defined as non-biological materials that indicate lively effects, and natural computing (Armstrong, 2015).

The questions cultivated from the notion include “Can we grow buildings?” “Can buildings self-assemble themselves, or heal themselves in the cases of wear out or be damaged?” (Armstrong and Spiller, 2010; Dade-Robertson, 2021). Since synthetic biology by definition crosses the boundary of using what exists in nature, either knowledge or the utilization of the natural beings as it is, the concept revokes the realm of going beyond natural and artificial (Dade-Robertson, 2021). There are several approaches and notions employing synthetic biology protocols and/or theories in architecture and design.

Biomanufacturing is defined by Estevez and Navarro as; a type of production process that involves biotechnologies and utilizes biological systems to manufacture biomaterials and biomolecules (Estevez and Navarro, 2017). By this definition, it is possible to place bio-manufacturing as a specific making protocol in synthetic biology.

Estevez develops an outline around the genetics and bio-genetic architecture with a design and thinking strategy to highlight the future potentials; “working with DNA as though it were natural software and working with software as though it were digital DNA” (Estevez, 2009)

Living construction term can be discussed with the notion “livelihood” in nature/biology. Living construction/architecture mainly is the ideology of buildings/design products that are self-made and/or self-healing. (Dade-Robertson, 2021). Dade-Robertson offers the term as a future transdisciplinary possibility of synthetic biology and architecture (Dade-Robertson, 2021)

The manifesto of Armstrong and Spiller for protocell architecture offers a robust perspective for synthetic biology applications and possibilities:

> *“We do not wish to imitate nature, we do not wish to reproduce nature, we want to produce architecture in the way a plant produces its fruit. We do not want to depict, we want to produce directly, not indirectly, since there is no trace of abstraction. We call it protocell architecture.*
> *…Protocell architecture is equipped with design ‘handles’ that enable the architect to persuade rather than dominate the outcome of the system through physical communication. As such, these systems are unknowable, surprising and anarchic.”* (Spiller and Armstrong, 2011)

The synthetic biology approaches come with numerous ethical concerns and questions while offering a very broad perspective on the full integration of biology science into architecture. The manipulation on the biological level refers to several concerns including the security of existing biological matters and ecosystems, generational problems since it includes genetic manipulations that are inherited by the next generations, consent discussions both for the used biological matter and for the other living matter that can be impacted from this operation including the surrounding ecosystem of the design and the human-being users.

2.4. Various Categorizations for Bio-integrated Architectures

The categorizations and diversifications can be made from several angles for this framework. The related disciplines, formal/functional approaches, and overlapping concepts in the bio-integrated architecture applications can be used to categorize them.

The *adopted biological entity* as framed above is one of the most defining categorizations. The biomimicry integrations adopt the strategies, logic and systems, on the organism/behaviour/ecosystem levels (Zari, 2007), while biomorphic examples adopt mainly formal features.

The bio-utilization integrations adopt the biological matter itself, for biophilia, it can be translated as using the natural elements in design without any transformation of them. Biomaterials work on the use of biological matters as well however, the design problems and/or materializations are studied with the processing of natural elements to have certain responses.

Another measure is the *role of the designer* which changes drastically between the integration types. The biomimicry, biophilia and some applications of biomaterials themselves don’t change the existing roles and operations of designers a lot and maintain a top-down decision-maker role, which can be defined shortly as *director.* Synthetic biology and some other biomaterial approaches require careful and continuous consideration of the biological matter, and with the changing role of biological matter, the designer may be positioned as the *mediator* between wetware and design (Turhan et al., 2022). In other words, the role of the human designer changes according to the role and ability of transformation and guidance of the bio-integration.

Furthermore, emergent applications and theories propagate the question of "Who is the designer?" since the utilization of living matter alters the top-down approach to design and guides the design process. As Spiller and Armstrong offer in their manifesto, for the synthetic biology approaches, the designer "persuades rather than dominates" and the outcome is doesn't have to envisioned before, on the contrary, the outcome can be unknowable and surprising (Spiller and Armstrong, 2011).

The role of biological entities can be investigated in two possible statuses: passive and active. Passive roles indicate the indirect influence of biological entities on the design. Even though biological integration offers an original design and fabrication process, the biological entity does not have a saying in the design and fabrication processes. Biomimicry and biophilia notions can be classified as passive bio-integrations in that sense. For instance, using an animal's bone form as a lightweight structural strategy shows the passive role of biological entities. Even though using the strategy affects the design, the animal or the form of that biological structure is not able to manipulate the design process itself.

The active roles indicate direct manipulation of biological entities to actively guide design-fabrication-maintenance processes. The classification of biomaterials can vary depending on the properties, biological entities and fabrication processes involved, and whether they display passive qualities or if they are actively engaged in the design-fabrication-maintenance processes. In this context, synthetic biology applications are classified in active roles, since they affect and guide the design-fabrication-maintenance chains dramatically.

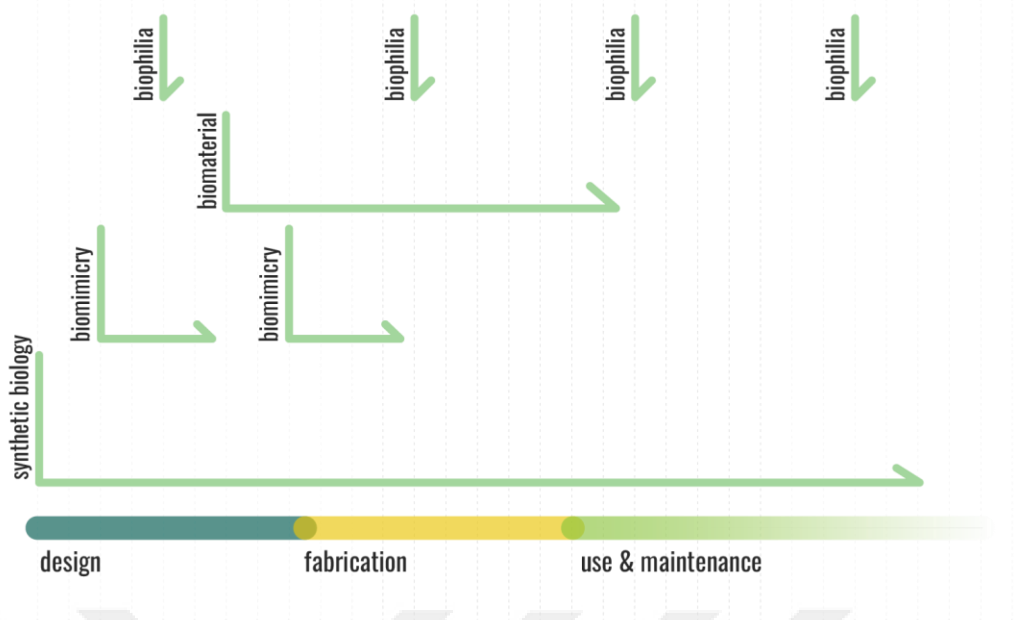

Figure 7. Diagram of Bio-integration to Architecture on Timeline

Another categorization that can be applied to the measure set for bio-integrations to architecture can be process-related (Figure 7). The various integration types are located at various points throughout the architectural timeline, in terms of their application timeframes. Biomimicry as a design problem-solving strategy is mostly adopted in the early stages of design which offers a time period of application inside the design period. Additionally, it can also be employed in the fabrication phase to adopt a biological strategy for production like a swarm intelligence technology for construction robots on the site. The biophilic applications including the daylight, and ventilation parameters require attention in the early stages of the design process. However, it is possible to integrate biophilic interventions into the architecture or space in the late stages of design and in the fabrication and usage processes as well. Biomaterials can be employed as simpler material solutions for an existing scheme of design like using mycelium bricks for a wall, or can be integrated as a primary problem-solving strategy to the design process. Synthetic biology, since it offers guidance on the design and fabrication processes, needs to be integrated into the process early and maintain its active role throughout the use and maintenance process.

To conclude, while the transdisciplinary universe of biology/nature and architecture is growing every day, many new ways of communication and integration emerge and are thrown into the discourse. To create the framework of this research, even though it is possible to widen this terminological study, the framework is restricted to the ones explained above. Furthermore, the provided and adopted frameworks and definitions have the potential to be expanded and offer more ambiguous borders that may accurately reflect the existing numerous approaches and applications.

Biological integrations into architecture offer tremendous potential for environmental, social, and economic sustainabilities. Some of the specific bio-integrations to architecture are studied with their psychological effects like biophilic design, however, the social scale of the biological integrations remained a gap in the literature.

Table 1. Bio Integrations in Architecture

Biological Integration Types to Architecture	**Type of Integration that is used**	**Role of Biological matter**	**Role of (human) Designer**	**Process (design / fabrication / use & maintenance)**
biomimicry	logic/system	Passive	Director	design/fabrication
bio-inspired architecture	logic/system, form	Active / Passive	Director	design
bio-informed architecture	logic/system	Active / Passive	Director	design
bio-morphism	form	Passive	Director	design
natural algorithms in architecture	logic/system	Active	Director / Mediator	design/fabrication
evolutionary architecture	logic/system		Director	design
bio-utilization	element	Passive	Director	
biophilia	element	Passive	Director	design/fabrication/use & main.
bio-material	element	Passive	Director	design / fabrication
living architecture (construction)	element, logic/system	Active	Mediator	design-fabrication-use & main.
bio-digital architecture	element, logic/system	Active	Director / Mediator	design
bio-genetic architecture	element, logic/system	Active	Mediator	design-fabrication-use & main.
bio-manufacturing	element, logic/system	Active	Mediator	design-fabrication-use & main.
bio-fabrication	element	Active / Passive	Mediator	design/fabrication
bio-architecture	logic/system, element	Active & Passive	Director / Mediator	design-fabrication-use & main.

CHAPTER 3: SOCIAL SUSTAINABILITY

3.1. Sustainability & Sustainable Development

Cambridge Dictionary defines sustainability as: *"the quality of being able to continue over a period of time."* (Cambridge Dictionary, 2023b). Due to the cruciality of the notion and the necessity for action in both academic and non-academic practices, sustainability is being studied extensively and in multi-disciplinary fields. The sustainability term is introduced in dictionaries mainly in the 20th century however equivalent terms that existed in various languages have long histories (Du Pisani, 2006).

Sustainable development, as we know it today, was propagated with the observability of the destruction of nature by human beings through technological developments, industrialization, and movements and ideologies accompanying them and started to be addressed in the 19th century, even though it can be traced through history to further dates with an extensive unfolding of the terms *progress* and *development* issues (Du Pisani, 2006). While in the 18th century, the concerns about the effects of the increased population started to be discussed, in the 19th century the environmental effects of non-renewable sources became topics of argument and inconsiderate destruction of the limited natural resources started to be addressed (Du Pisani, 2006). The development and sustainability issues gained critical importance in the 20th century.

The 1960s were the years that awareness of the downsides of technological improvements increased with a generally optimistic perspective on to issue however in the 1970s the progress and improvement ideals were losing their popularity due to their revealed relationship to the destruction of resources and their threats. (Du Pisani, 2006)

There are several significant dates and events in the history of sustainability and sustainable development. The declaration of the United Nations Conference is one of the primary ones held in 1972 and emphasized the necessity of global action. The first uses and significant mentions of the sustainability term and sustainable development notion are pointed to several dates and events. The International Union for the

Conservation of Nature released the World Conservation Strategy in 1980 which is one of the pioneer studies for sustainable development (Mckenzie, 2004), and The Brundtland Report is published by The United Nations Commission on Environment and Development (UNCED) in 1987 which represents a significant milestone for the sustainability discourse. Many more environmental actions took place with the increased awareness of the need for action including non-governmental organizations, and environmental summits (Mckenzie, 2004; Du Pisani, 2006).

The Brundtland report (Our Common Future, 1987) by World Commission on Environment and Development (WCED) declared the emergency of the action and became a paradigm-shifting event in the sustainability discourse. Brundtland Report defines sustainable development as follows:

> *"Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (World Commission on Environment and Development, 1987, p.16)

The initial focus of the definition of sustainability and sustainable development was on the consequences of human acts on the environment and the need for immediate action, but it has since expanded to encompass a wider spectrum of issues.

3.2. One, Three and Multi Pillar Strategies to Define Sustainability

Various strategies have been applied since the sustainability discourse emerged and a comprehensive definition is needed for sustainability. The most known strategies to define sustainability are called one-pillar, three-pillar and multi-pillar strategies.

The one-pillar strategy concentrates on the environmental aspects of sustainability. As the primary focus of sustainability studies, environmental sustainability remained the most studied notion by scholars, politicians and policy-makers.

One pillar strategy emerged as the first action point to the results of industrialization and human impact, therefore the initial focus was naturally the environmental impacts. However, the immediate necessity for a more composite and comprehensive terminology is needed and emerged rather than only relating it to the ecological discourse (Ahman, 2013). As a response to this need; the three-pillar strategy includes the environmental [1], economic [2] and social [3] pillars of sustainability which promotes a wider and more inclusive perspective to the discourse.

Figure 8. Sustainability Concentric Model (Source: Mckenzie, 2004)

Three aspects of sustainability merged with two different models, one is the concentric spheres model which places the economic aspect as the inner circle, the social aspect as its outer circle and the environmental aspect contains both of them (Figure 8); the other and the more common approach is the three equal intersecting spheres (Figure 9) (Mckenzie, 2004).

Environmental sustainability refers to preserving the existence and operation ability of ecology, including preventing damage from using non-renewable energy sources, preserving the air and water, and limiting the destruction of biodiversity.

Economic sustainability refers to maintaining the functionality of economic systems, considering the economic situation of the next generations (Hansmann, Mieg and Frischknecht, 2012) and focusing on resource management, production and consumption lines, and the distribution of welfare.

As the third pillar, social sustainability mainly refers to the continuity of the social structures, systems, and institutions in a social group. More detailed definitions of social sustainability are going to be discussed later in this chapter.

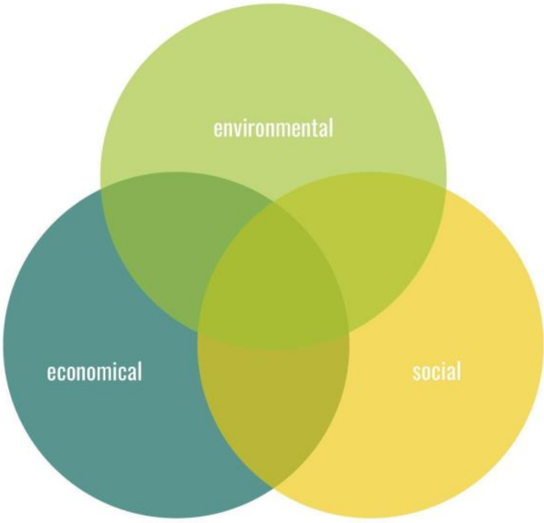

Figure 9. Three Pillar Sustainability

Different pillars defined within the sustainability discourse have interrelated relationships with independent discourses and equal values (Ahman, 2013). Griessler & Littig emphasise the significance of real integration of the three pillars; ecological, social and economic, in theory and in practice and argue that it is the only way for true sustainability to be achieved (Griessler and Littig, 2005).

Despite its more comprehensive approach in contrast to the one-pillar strategy, it still is criticized or found deficient, and some additions are offered to three pillar approach. Griessler and Littig's proposal for the enrichment of the three pillars includes cultural-aesthetic, religious-spiritual, and political-institutional sustainabilities to the main three pillars (Figure 10) (Griessler and Littig, 2005). In addition to their proposal of a multi-pillar approach, they emphasize the vagueness of the relationship between the 3 pillars. (Griessler and Littig, 2005)

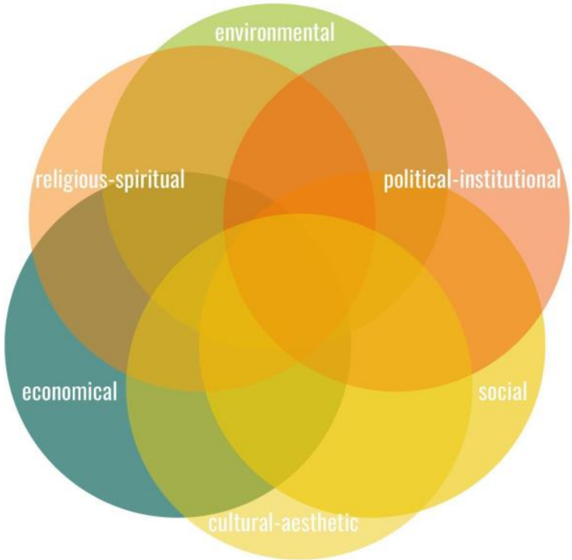

Figure 10. Diagram of Griessler & Littig's approach, multi-pillar sustainabilities (Source: Griessler and Littig, 2005)

3.3. Social Sustainability

The emergence of the term social sustainability can be addressed in the Brundtland Report (Ahman, 2013)**.** Since the social aspect of sustainability was added to the sustainability discourse later, it was the least-studied pillar in sustainability literature for a long period of time (Eizenberg and Jabareen, 2017). And even though the social sustainability concept is recognized broadly in the literature later, its definition stayed and studied as a vague term. (Dempsey et al., 2011)

Both the definition of social sustainability and the measures, indicators and parameters of the notion stayed vague which is both the reason and the consequence of the literature gap. The difficulty of defining the notion is related to several reasons; the ambiguity of the indicators, parameters or measurements is one of them. Some of the realms that are mostly related to social sustainability have also vague definitions which make creating the framework for social sustainability harder (Ahman, 2013).

Theoreticians who study social sustainability usually refer to the challenge of the ambiguity of social sustainability in terms of its measurement difficulties (Ahman, 2013; Eizenberg and Jabareen, 2017). The set of parameters and indicators of social sustainability change according to theoreticians, individual cases, context and approaches. Moreover, social sustainability needs a definition that contains its dynamic nature rather than a static definition, since it has a changing and evolving nature. (Dempsey et al., 2011)

The changing perceptions of the terms *territory* and *community* are also significant limitations in defining the sustainability of a community, concerning the definition of the *community* being amorphous since the boundaries change according to the parameter that is being analyzed (Mischen et al., 2019). Furthermore, the "community" phenomena call for a territorial dimension as stated by Dempsey et al. (Dempsey et al., 2011). In addition to this constraint, the unmissable relationship between urbanity and thus the community and the specific geography makes it difficult to define solid parameters that can be applied to every case (Mischen et al., 2019). Also, the uniqueness of a place requires some site-specific solutions and measurement sets (Ahman, 2013).

Scale is another important factor when discussing social sustainability (Dempsey et al., 2011). To be able to measure or discuss social sustainability in a specific place and community, the scale plays an important role since it changes the framework of social sustainability. Whether the discussion is placed on a neighborhood or on a country requires different indicators accordingly. The assessment systems that only focus on global or national scales are not successful to respond to the assessment needs of regional and local scales (Mischen et al., 2019).

Griessler and Littig also relate the difficulties of defining social sustainability to the unclear division of analytical, normative, and political aspects of it so that it can be studied explicitly (Griessler and Littig, 2005).

Vallance, Perkins and Dixon point out the necessity of sustainable development definitions to be comprehensive enough to be followed and applied to not only developed countries but also less-developed / developing ones (Vallance, Perkins and Dixon, 2011)

3.3.1. Several Frameworks for Social Sustainability

Griessler & Littig's definition of social sustainability is as follows:

> *"Social sustainability is a quality of societies. It signifies the nature-society relationships, mediated by work, as well as relationships within society."* (Griessler and Littig, 2005, p.12)

Griessler & Littig, define sustainability with the concept of "need" in parallel to the Brundtland definition (Griessler and Littig, 2005). While defining sustainability with the realm of need, Griessler & Littig mention certain functional systems and institutions and point out the three significant actors in them; economy, politics and culture which they claim are mandatory for the improvement of the relationships between society and nature (Griessler and Littig, 2005). Based on a "need" oriented approach to defining sustainability, they mention the primary -material- needs for a decent life: the necessity to have food, housing, clothing, sexuality, health care, a healthy environment, access to safe drinking water and sanitary facilities, freedom from bodily harm, and protection in case of illness, old age, and social hardship and broaden the scope with "actions and opportunities" which includes needs such as education, recreation/leisure, social relationships, self-fulfillment (Griessler and Littig, 2005).

They point out both analytical and normative nature of social sustainability in terms of the need for clear and detailed indicators and also well-defined ideas on social values that are related to social sustainability. (Griessler and Littig, 2005)

The relationship between society and nature, which is one of the key elements in Griessler& Littig's framework of social sustainability, is only changeable with the effects of "work" (Griessler and Littig, 2005). They claim, to achieve socially sustainable development, changing the existing concepts of work and social welfare is needed (Griessler and Littig, 2005). Furthermore, secure incomes and psycho-social effects of work, gender-related issues of working are significant factors to take into account (Griessler and Littig, 2005). Griessler and Littig's framework has a significant place on the discourse due to its comprehensive approach to the pillar strategies for defining social sustainability and the emphasis on the work concept.

The contradiction of discussing sustainability with development-related issues is also highlighted in the literature since this leads the conversation in a more capitalist direction and distances the discussion from low-income countries even though sustainability needs to be comprehensive enough to include low-income developing countries as well (Mischen et al., 2019)

Mischen et al. offer a widened definition of social sustainability of the Brundtland report definition as follows;

> "*A sustainable community is the aggregate of functionally and socially connected individuals and organizations that share collective resources in such a way that engages members in self-determination governance processes resulting in the equitable provisioning of the health, educational, and material well-being among its residents while not negatively affecting future generations or other communities' uses of these resources."* (Mischen et al., 2019, p.10)

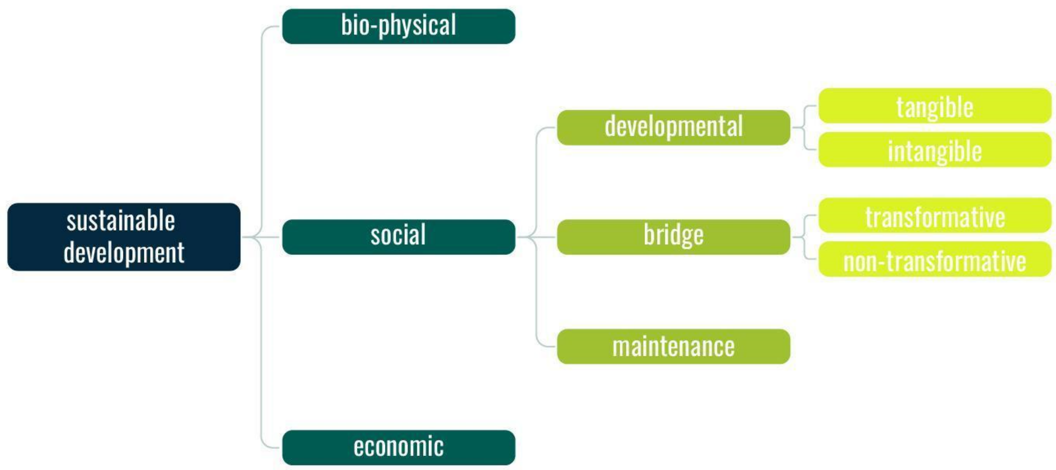

Figure 11. Vallance, Perkins and Dixon's Threefold Scheme for Sustainable Development (Source: Vallance, Perkins and Dixon, 2011, p.4)

Vallance, Perkins and Dixon approach the social sustainability notion with their own threefold scheme which consists of development sustainability, bridge sustainability, and maintenance sustainability (Figure 11) (Vallance, Perkins and Dixon, 2011).

Development social sustainability refers to the basic needs of people divided as tangible (potable water and healthy food, medication, housing etc) and intangible or less tangible (education, employment, equity and justice) (Vallance, Perkins and Dixon, 2011).

Bridge social sustainability refers to establishing a better relationship between the bio-physical environment and people. Bridge sustainability includes transformative and non-transformative ways. Transformative approaches are defined as more radical changes in the integration of people and environment while the non-transformative approaches include narrower focused, conventional interventions, not life-changing solutions but simpler smaller implementations (Vallance, Perkins and Dixon, 2011).

Maintenance social sustainability refers to preserving and/or improving certain characteristics in the sociocultural realm which is related to people's quality of time, social networks etc. (Vallance, Perkins and Dixon, 2011).Vallance, Perkins and Dixon point out the complexity of social sustainability due to its conflicting elements while arguing the conflicts and alignments between development, bridge and maintenance of social sustainabilities, and emphasize the importance of complex thinking for true problem-solving instead of utopian tendencies (Vallance, Perkins and Dixon, 2011).

Within this framework, they emphasize the role of access to basic needs in socially sustainable development since only when people have proper access to their basic needs than it is possible for them to address environmental concerns (Vallance, Perkins and Dixon, 2011). Concerning the context, they point out that whether in developed countries or developing ones, only in a true social equation, it is realistic to expect a true perception of sustainability and its importance, and participation in the actions is possible (Vallance, Perkins and Dixon, 2011). Vallance, Perkins and Dixon contribute to the discourse with a comprehensive base for the definition and framework for social sustainability while discussing the varieties and emphasizing the main factors that affect social sustainability.

Figure 12. 4 concepts of social sustainability by Eizenberg and Jabareen (Source: Eizenberg and Jabareen, 2017)

Eizenberg and Jabareen draw a conceptual framework for social sustainability using 4 concepts; equity, safety, urban forms, and eco-presumption (Figure 12) (Eizenberg and Jabareen, 2017).

Some approaches to social sustainability limit its definition to an instrument to achieve environmental sustainability (Ahman, 2013; Eizenberg and Jabareen, 2017). Concerning the studies that emphasize the importance of equal attention to all pillars to achieve ultimate sustainability, degrading social sustainability as a tool for environmental ideals is a very limited and narrow approach.

3.3.2. Parameters and Measures of Social Sustainability

Since the beginning of the development of the discourse, academicians and practicians have studied social sustainability by illustrating their frameworks and defining their own parameters or indicators for such social sustainability. These parameters vary in terms of their focuses however a common base can be detected in different studies.

Defining the indicators of social sustainability is a challenging task for several reasons. Even though the definition of social sustainability has a certain foundation, the objectives, indicators and parameters of social sustainability contain a great variety according to the theoretician/researcher who studies them and according to context (Griessler and Littig, 2005). While the effort in defining and analysing social sustainability is increased, some scepticism on defining the term with one particular parameter set and definition is also argued widely by the theoreticians (Ahman, 2013).

According to Eizenberg and Jabareen, the associations with physical parameters alone are useful for measuring and gathering quantitative data however, it is also a very limited approach to social sustainability and requires other non-physical parameters to be included (Eizenberg and Jabareen, 2017) Griessler & Littig refers to the need to use not only the standards of natural sciences but also including to data of social interactions and relationships with nature as well. (Griessler and Littig, 2005)

Bramley et al., draw a framework for the parameter set to investigate the relationship between urban form and social sustainability in which they intersecting notions of social capital, social cohesion and social exclusion. (Bramley and Dempsey, 2006)

Additionally, they underline the dimensions that are more likely linked to social sustainability literature which are interaction in the community/social networks [1], community participation [2], pride/sense of place [3], community stability [4] and security (crime) [5]. (Bramley and Dempsey, 2006).

Murphy refers to the 4 pre-eminent concepts of the social pillar; Equity [1], awareness for sustainability [2], participation [3] and social cohesion [4] (Murphy, 2012).

Figure 13. Non-physical and predominantly physical factors of social sustainability in literature (Source: Dempsey et al., 2011)

The received literature for this set of parameters includes: Chan and Lee, 2008; Meegan and Mitchell, 2001; Turkington and Sangster, 2006; Jacobs, 1999; Bramley et al., 2009; Yiftachel and Hedgcock, 1993; Urban Task Force, 1999; Hopwood et al., 2005; Littig and Griessler, 2005; Burton, 2000a.

Dempsey et al. draw a table of factors that are related to social sustainability. The non-physical and physical factors include the studied concepts around the social aspects of sustainable development or social communities listed in various theoreticians' work (Figure 13) (Dempsey et al., 2011) Dempsey et al. discuss the parameters of a sustainable community in a neighbourhood scale in relation to collective aspects; social interaction/social networks in the community, participation in collective groups and networks in the community, community stability, pride/sense of place, safety and security." (Dempsey et al., 2011, p.6). Dempsey et al. provides a solid set of parameters of social sustainability and offers a common ground from the academicians to the literature which aligns with this research's framework for social sustainability parameters and indicators.

Ahman defines social sustainability with the terms: basic needs and equity, education, quality of life, social capital, social cohesion/integration/diversity and sense of place (Ahman, 2013).

Griessler & Littig suggests three sets of core indicators for social sustainability:

> *"basic needs and the quality of life (individual income, poverty, income distribution, unemployment, education and further training, housing conditions, health, security, satisfaction with work, health, housing, income and the environment); social justice within sustainability (distribution of economic goods, equal opportunities, regarding the quality of life and participation in society, gender equity and migrants); social coherence (integration into social networks, involvement in activities as volunteers as well as measures for solidary and tolerant attitudes.)"* (Griessler and Littig, 2005)

3.4. Un Sustainable Development Goals

Figure 14. United Nations 17 Sustainable Development Goals (Source: https://www.un.org/sustainabledevelopment/news/communications-material/)

United Nations declared Sustainable Development Goals (SDGs) in 2015, as an improved replacement for the eight Millennium Development Goals (MDGs) (Mischen et al., 2019). UN's SDGs are a set of 17 goals for countries to evaluate and take action with developing strategies (Figure 14). The aim of this set of goals is to create guidelines for the countries for their sustainable development agendas and encourage their action with international evaluation reports.

Countries are effectively working on and reporting to the UN’s SDG’s. The importance of the UN’s SDG’s is mostly related to its internationality and effective structure which promotes significant studies not only by decision-makers but also by academicians and practitioners. Such an integration promises more comprehensive actions for sustainability to be achieved.

Based on the most recent trend data, The dashboards assist determine priorities for additional efforts and illustrate whether countries are on track or off track to meet the objectives by 2030 (Sachs et al., 2022) Data come from both official statistics and non-traditional statistics including universities, independent research centres and NGOs (Sachs et al., 2022). Additionally, every year, a report for the world and specific region reports are published. The SDG Index evaluates each country's overall performance in relation to the 17 SDGs, assigning each SDG the same weight, giving a score from 0 to 100 which is the target value (Sachs et al., 2022).

The measurement process of SDGs is transparently and thoroughly explained to avoid any ambiguity or misconception so that people/policymakers can comprehend, interpret, and work effectively with the reports and data.

Furthermore, to create discourse and increase awareness about the notion, various online accessible sources are created. Among these sources, the researchers and practitioners are invited and encouraged to contribute to the discourse and actions for achieving the SDGs.

3.5. Sustainable Development Goal #11 Sustainable Cities & Communities

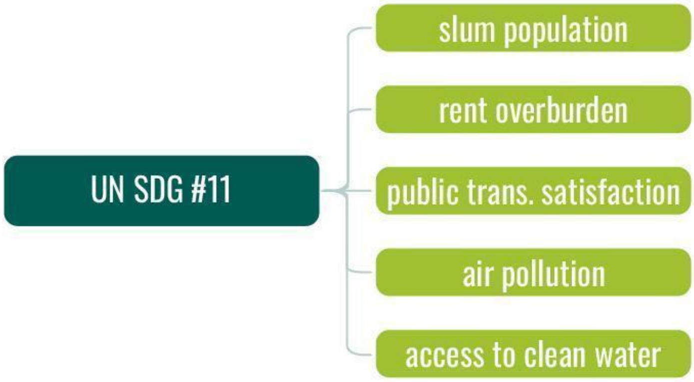

Figure 15. UN SDG INDEX 2022 SDG #11 Dashboard Parameters (Source: https://dashboards.sdgindex.org/map/goals/sdg11/ratings)

The 11th goal for sustainable development refers to sustainable communities and cities and is declared by United Nations as; "*Make cities and human settlements inclusive, safe, resilient and sustainable*" (United Nations, 2022). The main themes addressed in the 11th SDG are waste management, air pollution, local disaster risks, population, slum dwellings, and public transportation (Figure 15).

The relationship between the 11th sustainable development goal of the UN; Sustainable Cities & Communities and social sustainability discourse contributes to the dialogue to expand and to be updated with continual data flow. Additionally, the specified targets and indicators (Figure 16) of the SDG can offer a clear framework for the discourse of not only to social sustainability considering its ambiguous definition and parameters but also to environmental and economic sustainabilities.

Target	Indicator
Target / 11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.	Indicator / 11.1.1 // Proportion of urban population living in slums, informal settlements or inadequate housing
Target / 11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons.	Indicator / 11.2.1 // Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities
Target / 11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries	Indicator / 11.3.1 // Ratio of land consumption rate to population growth rate Indicator / 11.3.2 // Proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically
Target / 11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage	Indicator / 11.4.1 // Total per capita expenditure on the preservation, protection and conservation of all cultural and natural heritage, by source of funding (public, private), type of heritage (cultural, natural) and level of government (national, regional, and local/municipal)
Target / 11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations	Indicator / 11.5.1 // Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population Indicator / 11.5.2 // Direct economic loss attributed to disasters in relation to global domestic product (GDP) Indicator / 11.5.3 // (a) Damage to critical infrastructure and (b) number of disruptions to basic services, attributed to disasters
Target / 11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	Indicator / 11.6.1 // Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities Indicator / 11.6.2 // Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)
Target / 11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities	Indicator / 11.7.1 // Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities Indicator / 11.7.2 // Proportion of persons victim of physical or sexual harassment, by sex, age, disability status and place of occurrence, in the previous 12 months
Target / 11.a Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning	Indicator / 11.a.1 // Number of countries that have national urban policies or regional development plans that (a) respond to population dynamics; (b) ensure balanced territorial development; and (c) increase local fiscal space
Target / 11.b By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels	Indicator / 11.c11.b.1 // Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030 Indicator / 11.b.2 // Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies
Target / 11.c Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials.	

Figure 16. UN SDG #11 Targets and Indicators (Source: https://sdgs.un.org/goals/goal11)

In conclusion, social sustainability, the third pillar of sustainability, has a complex discourse in terms of its various frameworks, definitions, set of parameters, indicators and measurements. Even though the discourse is complex, the significance of the social aspects of sustainability has been proven by the frameworks, indexes and international initiatives. For this research, the most studied parameters by several academicians are selected for examining the effects of bio-architecture on social sustainability which are *social interaction*, *social equity* and *participation*.

These parameters can be easily associated with each other and can be defined with intersecting and/or concentric models which is not unexpected for the sociological notions. The focus of each parameter for this research will be defined thoroughly in the next part.

3.6. Social Interaction

Social interaction has a lot of definitions as one of the popular terms in sociology and social science discourses. It can be broadly defined as "the bonds or relationship between two or more individuals in a community" (Rasidi, Jamirsah and Said, 2012, p.3). One of the definitions of social interaction is "the way in which personalities, groups, and social systems, act toward and mutually influence one another." (Bardis, 1979, p.3). In another approach, social interaction is defined as "the process of reciprocal influence exercised by individuals over one another during social encounters" (Little, 2016, p.913).

Social interaction is mostly associated with social networks and social cohesion. Since it refers to the engagement of people to the community it has correlations with participation as well. It is the key element that makes a group of people habituating in a specific area, a community (Dempsey et al., 2011). People's mental and psychological health in communities is significantly impacted by social interaction (Chen et al., 2023). Since it has a huge impact on the well-being of individuals and communities, it plays an active role in social sustainability.

Even though social interaction is one of the necessary notions for social sustainability it is not always a positive attribute, meaning it also includes negative social interactions like avoidance, preferred lack of interaction and disturbance. (Dempsey, 2008).

Social interaction is studied with many research designs and data types. There are studies examining social interaction with the amount of time people spend in a place, introducing indexes that group social interactions into several levels and create a matrix accordingly or offer mathematical equations compositely combining several quantitative data types that can be collected (Chen et al., 2023).

Social interaction can be investigated on 4 different dimensions; type/mode, amount, quality, and duration. All of these dimensions are affected by many notions and by each other and numerous parameters can be introduced.

Even though there are indirect interactions as well according to some definitions of social interaction, the basic direct social interaction types can be examined in 2 forms, face-to-face and virtual (Little, 2016). The parameters for the type of social interaction are mainly environmental factors. Virtual social interaction includes; messaging, video-chatting, social media interactions etc. and it is not directly related to the environment and space (Little, 2016). Face-to-face social interaction requires an environmental context. To be able to relate social interaction to the built environment, face-to-face interaction is selected as the base for social interaction type and public spaces are defined as the base context to investigate the effects and possibilities for this research.

The amount of social interaction can be related to the environmental and spatial conditions, physical accessibility, density, cultural and demographic features, values and norms of the communities and individuals and their socialization patterns, safety and many more parameters. (Bardis, 1979; Forrest and Kearns, 2001; Dempsey, 2008; Chen et al., 2023) The amount of social interaction is investigated with the density. Density refers to the number of people per square meter of public space. For private programs, public spaces (if there are any) and circulation areas are considered. For the buildings with public programs, the total areas are considered.

The quality of social interaction can be affected by the individuals' interaction capacity and communication skills, social values and norms of the communities and individuals and their socialization patterns, and comfort (Bardis, 1979; Forrest and Kearns, 2001; Dempsey, 2008; Chen et al., 2023), To assess the relationship between bio-integrations to architecture and social interaction quality, the design and distribution of public spaces with bio-integration is investigated. The design and distribution of public spaces with bio-integration refer to the biological integrations to the design of public spaces, whether it includes a bio-utilization element that serves the design of public spaces or a system/inspiration to design and distribution of them.

The duration of the social interaction can be affected by comfort, environmental conditions like fresh and clean air and thermal comfort, social context of the interaction, social norms and values, security feeling, etc. (Bardis, 1979; Forrest and Kearns, 2001; Dempsey, 2008; Chen et al., 2023) The duration of the social interaction in public spaces is assessed with thermal comfort and fresh and clean air. Thermal comfort and fresh and clean air provided by bio-integration are investigated.

The factors affecting social interaction dimensions can vary more than pointed out above since it includes human behaviour and because of the uniqueness of each encounter. Furthermore, as it can be traced, the parameters of all dimensions overlay each other. Therefore, an indicator grouped in the quality dimension has also an impact on the amount, duration and/or type. The categorization of these indicators is based on perceived relevance and potential impact.

3.7. Participation

Participation can be described as people taking part in social and community activities, and local events occur and are well attended (Forrest and Kearns, 2001). It both includes collectively mobilizing for a cause or attending local sports teams (Dempsey, 2008). As one of the most discussed terms in social sustainability, participation is an essential part of the sense of community and social cohesion (Dempsey, 2008; Dempsey et al., 2011).

Participation is a significant parameter for social sustainability since it promotes inclusivity, equity and social cohesion. It connects the systems, decision-making processes, production, maintenance and usage processes to the users and people affected by these processes and systems.

Participation can be discussed in various frameworks with numerous parameters, indicators, or measures. For this study, participation in bio-integrated architecture is evaluated in 4 dimensions; participation in to design process, participation in the fabrication process, participation in the maintenance of bio-integration, and participation during the use of bio-integrated architecture. With this time-related framework, it is possible to examine the effects of participation in bio-integrations to architecture.

For assessing the effects of participation to design processes, the parameters are; Collaborative design meetings and focus groups [1] and surveys & questionnaires [2]. Collaborative design meetings and focus groups refer to more active participation in the design processes while the surveys & questionnaires encounter shorter but still effective participation modes.

For evaluating the effects of participation in fabrication processes, the parameter is the involvement of local labour and production actors in bio-integrations fabrication. This parameter refers to the engagement of community members and their businesses or labour in the fabrication of bio-integrations. When the bio-integration includes the direct utilization of biological elements (bio-utilization) the indicator encompasses the local sourcing of the producers and labour of fabricating/growing the element and the utilization of local processing networks (if applicable). In the case of biomimicry, relates to the creation of designs influenced by nature employing local labour.

For assessing the effects of participation in maintenance and use processes, the parameters are; voluntary/ sequential systems for maintenance [1] and community activities including the bio-integration [2] Voluntary/ sequential systems for maintenance can be exemplified as a user group that sequentially take charge of the plant's maintenance of a biophilic building. Community activities incorporating bio-integration can include community gardening events and courses or harvest events for bio-utilization.

3.8. Social Equity

Social equity, mostly discussed with the social justice notion, refers to the fair distribution of resources (Dempsey et al., 2011) Equity is included in the social sustainability framework since the inequality and lack of justice are directly proportional to people's alienation from their living space (Eizenberg and Jabareen, 2017). Social equity is an important parameter of social sustainability since it offers fairness and balance between different groups.

Equity and justice terms need a context to be built upon which can be defined as people from different ethnicities, races, religions, sexual orientations, values, norms, disabilities and well-being, ages and generations. The inclusiveness and accessibility notions as a part of social justice and equity discourses, have a significant space in built environment and architecture discourses.

To be able to assess the possible and existing effects of bio-integrations to architecture on social equity, the equity between income groups and disabilities and wellbeing are used.

The social equity for different income groups is related to the parameters of bio-integration; affordability of the use of bio-integration [1], maintenance affordability & resilience of the bio-integrated design [2] and local material/product / biological matter [3] usage are examined. Affordability of the use of bio-integration is discussed with entrance/ticket fees of the building or rent of the spaces and its relation to the minimum wage of that country. If the case study includes spaces that can be used by everyone for free and benefit from bio-integration, affordability is considered achieved. Maintenance affordability & resilience of the bio-integrated design refers to the possible alienation of specific income groups from the case building (if applicable). The high maintenance and refurbishment fees possibly disconnect some income groups from the bio-integration. For public buildings, since the maintenance is not paid by the users, the indicators are not applicable. The local material/product/biological matter indicator is to investigate the possible local bio-solutions to support the local economy and improve the equal distribution of resources and potentials in the community. It can refer to the utilization of local bio-elements or local materials for the fabrication of the bio-integrated design.

Local material/product/biological matter that has a close relationship with the local labour indicator to assess participation in fabrication processes. Even though the use of local labour also has a social equity effect and vice versa, local resource use is discussed under the social equity umbrella since it covers the economic equity potentials.

The social equity for disabilities and well-being, the bio-integration or bio-element effects as a possible mental facilitator are discussed. The bio-elements being possible mental facilitators refer to the potential of biological integrations in terms of some of their mental positive effects. The mental facilitation can be related to the bio-integration as either design of the space with bio-integration with proper signage or circulation strategies, or as utilization of biological elements for its positive effects.

CHAPTER 4: EFFECTS OF BIO-INTERACTIONS TO ARCHITECTURE ON SOCIAL SUSTAINABILITY

4.1. Case Studies

4.1.1. Eastgate Centre

Figure 17. Eastgate Centre (source: https://archestudy.com/)

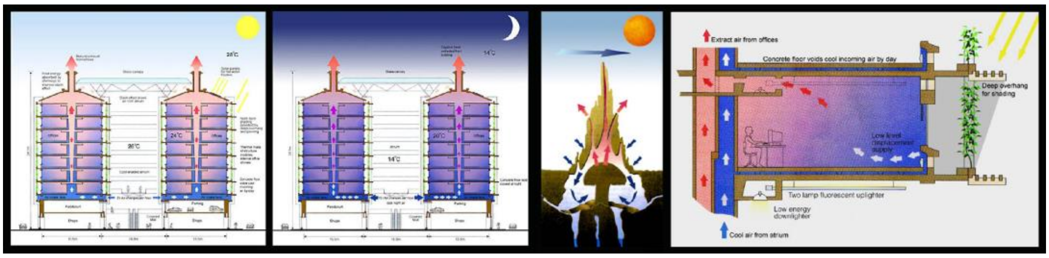

Figure 18a & 18b. Eastgate Centre Thermal Strategy Diagrams (Source: www.mickpearce.com/Eastgate.html)

The Eastgate Centre is built in Harare, Zimbabwe, in 1996 and designed by Mick Pearce. It consists of commercial and office spaces and it is known for its biomimicry design that mimics termite mounds ventilation system. With the mimicked system the passive cooling technique enables the building to regulate the temperature and provide thermal comfort and airflow thus fresh air without an extensive amount of energy consumption (Figure 18a & 18b).

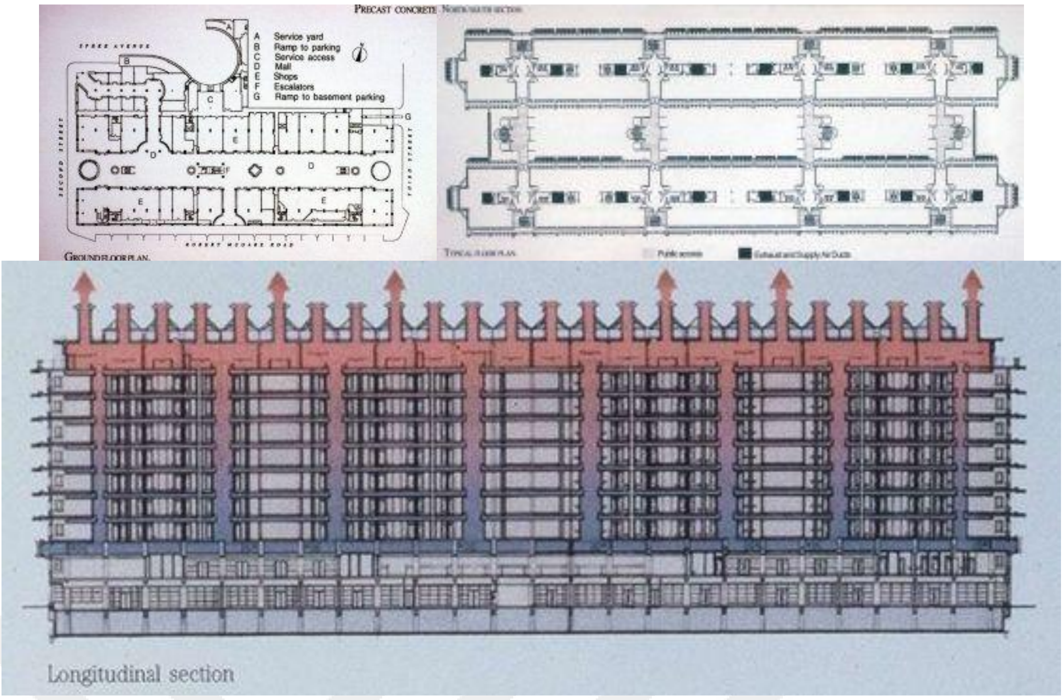

Figure 19a, 19b & 19c. Orthographic Drawings of Eastgate Centre (Source: https://www.engineeringforchange.org/solutions/product/eastgate-centre-harare-zimbabwe/)

The design and distribution of public spaces of Eastgate Centre is not provided with any bio-integration as can be traced by the orthographic drawings (Figure 19a, 19b & 19c). The distribution is rather based on traditional layout principles. Furthermore, there is no bio-data introduced other than the biomimicry application of termite mounds ventilation system to the building.

The user density of the building is not manipulated with bio-integration. The biomimicry design strategy might have an indirect effect on the user density especially in public spaces however it doesn’t have any recorded direct effect or purpose related to it assigned to the bio-integration.

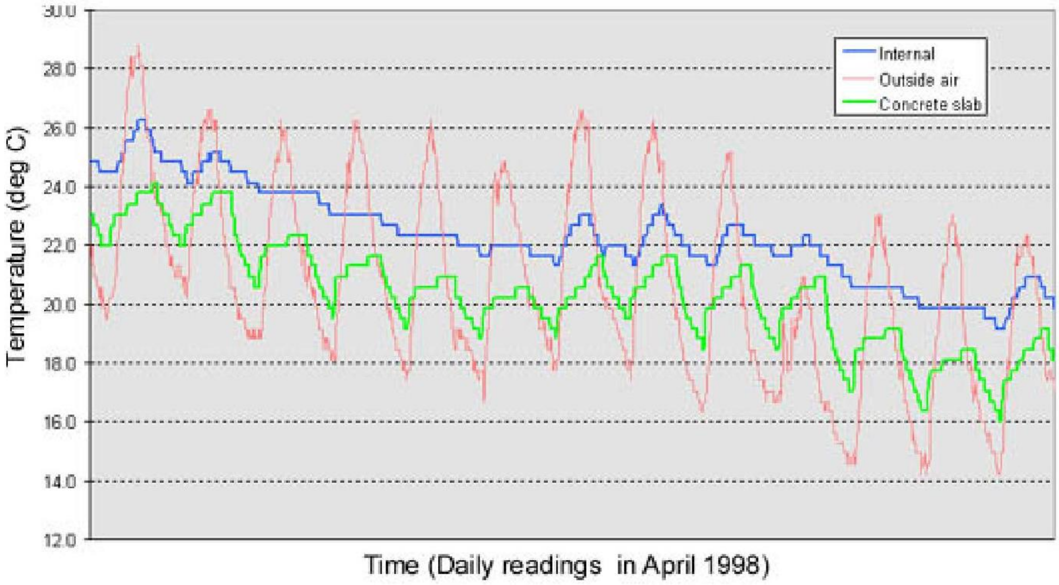

Figure 20. Data Logger of Cooling Performance of Eastgate Centre (Source: https://www.mickpearce.com/Eastgate.html)

Thermal comfort and airflow are provided with biomimicry design principles. The termite mounds are mimicked to be able to passively ventilate the building and provide thermal comfort and airflow (thus the fresh air). The climatic measurements of the building with this bio-integration showed great performance.

According to the climatic performance data (Figure 20), the Eastgate Centre shows equal to or slightly better performance than that originally predicted by Ove Arup the Engineers; consumes less than 50% of the energy used in conventionally air-conditioned buildings and achieves pleasant comfort conditions for all but 2 weeks in 52 weeks of the year (Pearce, 2016).

There are no pieces of evidence for participation in the design processes of bio-integration found in the media and other sources. Therefore, collaborative meetings and focus groups, and survey and questionnaire studies are considered as not integrated into the bio-integration process.

The fabrication process of the Eastgate Centre is considered to include participation since according to the information given on the website of Mick Pearce, the local human resources used for the needed labour for construction:

> *"The new order moves away from the international glamour of the pristine glass tower archetype towards a regionalized style that responds to the biosphere, to the ancient traditional stone architecture of Great Zimbabwe and to local human resources."* (Pearce, 2016).

Voluntary or sequential systems for maintenance are not indicated, and the community activities which specifically related to the termite mound's biomimicry application, are not documented or reported in the available sources. Although the public spaces within the Eastgate Centre have the potential for hosting community events, there is a lack of connection between these spaces and the bio-integration inspired by the termite mound.

The affordability of use of Eastgate centre can be investigated on 2 levels. The office's rent information is not provided by any of the authorities. However public spaces on the lower floors are free to use and the bio-integration which functions as a thermal comfort strategy can be experienced free of charge in these public spaces. Thus, the affordability is documented as achieved.

The resilience of the design can be discussed with the building's age since it is built in 1996 and not any information about a big deformation or malfunctioning is reported in the media. It still continues to its function actively; therefore, the resilience of the building is considered achieved. Since most of the people of Harare use the building as a free-of-use public space, the maintenance affordability of the building indicator is recorded as not applicable (NA).

The bio-integration is not affecting the material, but the design of the building. The material used for the building is precast concrete, glass, and steel. The materials are very common ones in the architectural discipline however the source producers of these materials are not specified. Therefore, the local material is considered not achieved.

The mimicked ventilation system as bio-integration does not provide a direct link to mental disabilities, mental health and well-being. Even though there is an indirect possible effect, since thermal comfort improves mental health (Inavonna, Hardiman and Purnomo, 2018), bio-integration is not explicitly recognized as a mental facilitator for this case study.

4.1.2. German Pavilion, Expo '67

Figure 21a & 21b. Spider Web as Biomimicric Inspiration & Form Finding Study Model of German Pavilion (Source: https://en.wikipedia.org/wiki/Spider_web,
source: https://www.archdaily.com)

Figure 22. German Pavilion Expo'67 (Source: https://www.archdaily.com,)

The West German Pavilion, also known as the "Bundesgartenschau," is built in Stuttgart, Germany, in 1955 and designed by Frei Otto (Figure 22). It was a temporary exhibition pavilion. The tensile canopy structure is another biomimicry example focused on structure technology.

A single bio-integration is adapted to the structure. Frei Otto used spider webs as a structural strategy for lightweight tensile structures made with cable nets (Figure 21a & 21b). The knitting technique of the spiders is used as the steel mesh framework which holds the tensile structure. This way the most optimised, lightweight version with the least material created the complex. Huge spaces are created with very little material.

The bio-integration isn’t used to design and distribute public spaces and the density is not the aim or the result of the structural design achieved with biomimicry. The thermal comfort and fresh air are not the result of the structural design even though since the pavilion has openings throughout the space the fresh air might be achieved.

There is no evidence of participatory design including collaborative design meetings, focus groups or surveys. The pieces of the structure were fabricated in Germany however the assembly and disassembly details of the structure is not certain. Since most of the fabrication process is not managed locally, also because of the lack of documentation about the local/non-local labour employment, the local labour is considered not achieved.

Since the case study is a temporary structure, the maintenance-related indicators (maintenance participation and maintenance affordability) are not applicable. The aim of the structure offers or provides space for possible community activities however the spider-web-influenced structure of the design is not linked directly to the community events.

The brochure of Expo 67 in Montreal states that the entrance to pavilions and private exhibits is free (Canadian Corporation for the 1967 World Exhibition, 1963). Thus, the affordability of the use was achieved throughout the fair. The tent and all components of the structure were fabricated in Germany therefore the local material indicator was not succeeded. The biomimicry integrated structure has no direct link with mental health or mental disabilities, thus not being considered as mental facilitators.

4.1.3. Beijing National Stadium

Figure 23. Beijing National Stadium (Source: https://www.designingbuildings.co.uk/wiki/Beijing_National_Stadium)

The Beijing National Stadium (Figure 23), Bird's Nest with its other name, was built in Beijing, China, for the 2008 Olympic Games. It is designed by Herzog & de Meuron. The building includes restaurants, bars, hotels, retail shops, and recreational spaces besides its 80.000 people capacity stadium.

The Beijing National Stadium is investigated as a biomimicry case study with respect to the wider definitions of biomimicry especially by Benyus and Zari (Benyus 1997, Zari, 2007). The building uses a singular bio-integration which is based on the inspiration coming from the interwoven structure of bird nests. The bio-integration includes structural/formal inspiration on the behaviour level (Zari, 2007) however the biological inspiration is not used exactly to solve a design problem or used as a function. Rather it serves Chinese traditional symbolism with its vessel shape and nest-like form serves to the balance theme that is aimed. The form of the steel frame is intentionally made to look like a bird's nest instead of using the strategy for structural problem-solving. In that sense, it is a good example between biomorphism and biomimicry.

The bio-integration of Beijing National Stadium includes a structural and formal strategy of the shell of the building, not directly related to the design and distribution of the public spaces. In addition, the stadium has an 80.000 people capacity and it is not designed or optimized with bio-integration which is related to the form and structure of the building.

Natural ventilation is enabled with the decision of not enclosing the facade (Herzog & de Meuron, no date), however, the environmental factors for social interaction, fresh air and thermal comfort, are not provided with the bio-integration of bird's nest. Air pollution, one of the most significant topics of the Olympics in Beijing are controlled with drastic measures both in 2008 and in 2022. However, the air quality around the building is still mostly documented as “Unhealthy For Sensitive Groups” and has not intervened with the bio-integration of the building (IQ Air, 2023).

There is no evidence of a participatory design process including collaborative meetings, focus groups, and surveys reported. The news report that there were thousands of migrant workers hired for the construction (Leaver, 2008; Zhang and Zhao, 2009) however the local workers were also effectively employed for the construction of the building(‘Beijing Olympic Stadium’, 2008). The buildings do not have documented evidence of participation in the maintenance processes of the bio-integration through voluntary or sequential systems and there is no evidence that there are community events that are related directly to the bio-integration of the building.

The tickets to go inside Beijing National Stadium vary starting from CNY 40 to CNY 160 (5.94 $ - 23,79 $), free for children under 1.2m, according to a travel guide last updated in 2023 (He, 2019). (The used exchange rate is the average in 2022 is 1 CNY = 0.1487 USD) (Exchange Rates UK, 2023) According to the International Labour Organization Statistics, The minimum wage in 2022 in China is 390 $. The ticket / minimum wage ratio is 1,52 - 6,1 % which is a relatively affordable ratio.

The bio-integration of the building does not include the utilisation of special materials or matters. The mainly used materials for the building are concrete, steel and high-tech transparent membrane, ETFE. However, the steel used for the realisation of the bio-inspired structure, Q460 is innovated and produced by China's own steel makers (‘Beijing Olympic Stadium’, 2008) and produced in Shanghai as puzzle pieces, therefore the local material used is considered achieved. Any mental facilitation of bio-integration as a form of structure is not detected.

4.1.4. Bosco Verticale

Figure 24. Bosco Verticale (Source: archdaily.com, 2015)

Bosco Verticale or Vertical Forest was designed by Stefano Boeri Architetti and built in Milan, Italy, in 2014 (Figure 24). It consists of 2 high-rise buildings which were equipped with a total of 800 trees (480 first and second-stage trees, 300 smaller ones, 15,000 perennials and/or ground-covering plants and 5,000 shrubs (Stefano Boeri Architetti, 2017). As one of the most popular biophilic design examples, Bosco Verticale provides the amount of vegetation equivalent to 30,000 square metres of woodland and undergrowth (Stefano Boeri Architetti, 2017) and enhances biodiversity while inhabiting birds and insects with a rough estimate of 1,600 specimens of birds and butterflies (Archdaily, 2015).

Figure 25. Ploor Plan of Bosco Verticale (source: https://www.archdaily.com/)

The integration of an extensive amount of greenery is used as a facade shield, thus the design and distribution of public spaces and the density optimization are not shaped and provided by the bio-integration as can be traced on the floor plans (Figure 25).

The biophilic integrations provide thermal comfort inside the space since it regulates the daylight while creating a satisfying microclimate and regulating the humidity, producing O_2 and absorbing CO_2. Thus, it serves the thermal comfort and fresh air indicators and improves the air quality of the city (Arup, 2017)

There is no evidence of participatory design such as collaborative design meetings, focus groups and surveys. To produce the botanical content that is used for the building, a garden centre close to the site, in Como is used. Therefore, local labour and business are recorded as achieved.

The maintenance of the building is provided as a service by gardeners, and not integrated as a participation possibility. The community activities including the greenery integrated into the building are not encountered in the available sources.

There are short-term and long-term rentals in the building besides available units for purchase. According to Forbes news from 2020, the most expensive house in the building, the penthouse was on sale for around $17.5 million. Furthermore, Bosco Verticale faced criticism for its initial sale prices, which averaged around 10,000 Euros per square meter in 2016 (International Association of Horticultural Producers, 2019). Italy has no minimum wage declared by the law, however, it is possible to evaluate the prices of Bosco Verticale with the average wage according to the statistics of ILO which is declared as $ 3640.3 for 2021 (International Labour Organization, 2021) which shows the hard possibilities of purchase. Therefore, the affordability of the bio-integration is considered not achieved.

Figure 26a & 26b. Maintenance of Bosco Verticale (Source: https://www.archdaily.com/)

Thanks to its thorough engineering and botanical and horticultural studies, the biophilic content of the building offers a satisfying amount of natural content in every season. Therefore, so far, the resilience achieved since the building is relatively new, even though it is not exactly possible to analyse the ageing effects yet. The maintenance and greening operations are managed at the condominium level (Stefano Boeri Architetti, 2017) and according to a magazine article from 2020, the monthly maintenance cost per tenant for three gardeners (Figure 26a & 26b) to trim the 20,000 bushes and 800 trees on the facades of the Bosco Verticale skyscrapers in Milan is €1500 ($1800) (Amman, 2020; Willenbrock, 2020) which is a very high level related to the average wage of Italy, $ 3640.3 (International Labour Organization, 2021)

The botanic content used for the buildings is cultivated in a nursery and garden centre close to Milan (Stefano Boeri Architetti, 2017) which indicates the local biological matter used for the building with local labour. According to the studies, being in relation to nature has positive mental health effects (Kellert, 2005; Bratman et al., 2019; Huntsman and Bulaj, 2022). The Bosco Verticale, since provides continuous relation with natural elements and humans achieves to be a potential mental facilitator.

4.1.5. The Kampung Admiralty


Figure 27a & 27b. Kampung Admiralty (Source: https://www.archdaily.com)

The Kampung Admiralty is a mixed-use public complex including several standalone buildings, designed by WOHA for senior citizens and completed in 2017 (Figure 27a & 27b). The concept of the complex is called the “club sandwich strategy for the vertical village”. The complex includes housing for the elderly, medical facilities and social spaces like shops, and eateries. One of the aims of the complex is to bring necessary amenities together for “supporting inter-generational bonding and promote active ageing in place” (Block, 2018).

The bio-integration is not directly used to design and distribute public spaces with bio-integration and is also not used related to population density. While the universal standards were used for the environmental quality of the complex, the biophilic content supported the natural ventilation and sun filtering functions, also contributing to the cleaning of air with its extensive plant content. Therefore the fresh air and thermal comfort are considered achieved for The Kampung Admiralty.

Participatory research by an independent institution Experientia for Singapore Ministry of Health Action Plan For Successful Ageing is conducted (O’Loughlin, 2018) including co-creation workshops and ethnographic videos including people's ideas and needs on certain realms are recorded and presented which are also used as data for design processes. Collaborative design meetings and surveys are achieved.

The locality of the labour and businesses used are not expressed in the available sources.

There are community gardens including a variety of edibles and tropical ornamentals (Green Roofs, 2017) for users to spend time and interact with the plants (WOHA, 2020) which can contribute to the maintenance of a portion of the gardens and also creates space for the community events like Singapore Gardener's Cup (National Parks, 2022) and organizations like openings (one PA, 2023) in the community park.

Although it includes private housing on the upper floors, the ground floor is designed as a "community living room" which integrates non-habitants to use the complex and ground-level biophilic applications free of charge. Therefore, affordability is considered achieved.

There is no evidence of the maintenance affordability and no references to the resilience of the bio-integration mostly related to the new age of the structure found.

The terraces are covered with local plants (Block, 2018) Because of the mental positive effects of biophilia (Kellert, 2005; Bratman et al., 2019; Huntsman and Bulaj, 2022) the bio-integration of the complex is considered a mental facilitator.

4.1.6. BIQ house and SolarLeaf

Figure 28a & 28b. BIQ House and SolarLeaf (Source: https://www.archdaily.com/)

As a pilot project for International Building Exhibition, the BIQ house (Figure 28a) is built in Hamburg in 2013 by Splitterwerk Architects and Arup. It is a 4-storey residential structure which is the first algae-powered bio-reactive building.

The bio-reactive façade (Figure 28b) generates renewable energy from algal biomass and solar thermal heat which is a system that can be both used in new buildings and adapted to the existing ones. The biomass and heat generated by the façade can be used for the needs of the building and can be stored for later use (Wurm, 2013). The algae absorb CO_2 to create biomass.

The design and distribution of the public spaces and the population density don’t have any relation to the bio-reactive facade. Since to be able to create biomass, algae consume CO_2, decreasing CO_2 emission by 2.5 tons per year (Talaei, Mahdavinejad and Azari, 2020) and thus bio-interaction serves the fresh and clean air and climate change (Wurm, 2013). While the algae facade elements produce energy, they also filter daylight, produce thermal heat with the biomass of the algae and contribute to the thermal comfort of the building. (Wurm, 2013; ongreening, 2015)

There are no pieces of evidence of participation to design including collaborative design meetings and surveys, participation in fabrication including local labour and participation in maintenance with the use of voluntary or sequential systems and community events including the bio-integration detected in the available sources.

The cost of the algae facades of the BIQ house is stated as $ 2200-2300 for m_2 (Wilkinson et al., 2017). There is no published number related to the rents or purchase costs of the building, thus affordability is considered not achieved.

There is no exact information about the maintenance costs, however, it is stated that the system is automated in such a way that decreases the maintenance efforts and costs (IBA Hamburg, Roedel and Petersen, 2013)

It is known that the algae are cultivated in the lab environment for this project however the source location is not specified, and therefore the local material/biological element is not considered achieved. Since the algae facade refers to a co-living with natural elements, which is known for its good mental effects (Kellert, 2005; Bratman et al., 2019; Huntsman and Bulaj, 2022).

4.1.7. Hy-Fi Tower

Figure 29a & 29b Hy-Fi Tower (Source: https://www.arup.com/news-and-events/hyfi-reinvents-the-brick, https://www.archdaily.com)

The Hy-Fi Tower is a temporary installation and event space built in the courtyard of MOMA, New York City, USA, in 2014 by The Living. The 13-meter structure is constructed with 10,000 compostable mycelium bricks that are manufactured (Figure 29a & 29b). The bricks are produced with mycelium and agricultural waste. After 3 months, the structure is disassembled, and the mycelium bricks were composted and returned to the local community gardens.

The design and distribution of spaces and the density optimization of the structure are not related to its bio-integration. The biomaterial bricks don’t have a direct influence on thermal comfort and fresh air.

Participation in the design process with collaborative design meetings, groups and surveys is not reported on the available sources. Participation in the fabrication process with local labour and businesses is not included. Since the structure is temporary the maintenance participation is not applicable for investigation. The structure hosted various public cultural events for its time however since the events were not directly related to the bio-integration of the structure, they are not considered.

The public installation was placed in the courtyard of MoMA which has tickets between $ 14 - $25 (MoMA, 2023), offering a relatively cheap experience for the visit. Since the structure was temporary the maintenance costs and resilience of the bio-integration are not applicable to the analysis. The local biological matters were used to create the bricks (World Architecture Community, 2014). Even though not directly linked like a biophilia example, the biomaterials also offer a co-living experience with natural elements which has potential positive mental effects (Kellert, 2005; Bratman et al., 2019; Huntsman and Bulaj, 2022)

4.2. Case Study Evaluation

Table 2. Case Study Evaluation Matrix

		social interaction					social participation						social equity					
		Quality	Amount/ possi-bility	Duration		Total Score	Design		Construction	Maintenance & Use		Total Score	Income Groups			Disabilities & Wellbeing	Total Score	Total Score
	Case Study Building / Social Sustainability Criteria	Design & Distribution of Public Spaces	Optimized Population Density in Public areas	Fresh & Clean Air	Thermal comfort		Collab. Design Meetings & Focus Groups	Surveys and Questionnaires	Local Labour & Businesses for	Voluntary/ sequential systems for maint.	Community Activities		Affordability of Use	Maintenance Afford. & Resilliance of design	Local material / product / biological	Bio-elements as Mental Facilitators		
biomimicry	Eastgate Center	0	0	1	1	2	0	0	1	0	0	1	1	NA	0	0	1	**4**
biomimicry	The West German Pavillion	0	1	0	0	1	0	0	0	NA	0	0	1	NA	0	0	1	**2**
biomimicry	Beijing National Stadium	0	0	0	0	0	0	0	1	0	0	1	1	NA	1	0	2	**3**
						3						**2**					**4**	
biophilia	Bosco Verticale	0	0	1	1	2	0	0	1	0	0	1	0	0	1	1	2	**5**
biophilia	The Kampung Admiralty	0	0	1	1	2	1	1	0	1	1	4	1	0	1	1	3	**9**
						4						**5**					**5**	
biomaterial	BIQ house and SolarLeaf	0	1	1	0	2	0	0	0	0	0	0	0	1	0	1	2	**4**
biomaterial	Hy-Fi Tower	0	0	0	0	0	0	0	0	NA	0	0	1	NA	1	1	3	**3**
						2						**0**					**5**	

4.2.1. Findings & Results

The rating matrix (Table 2) is evaluated with a scheme; the scores from 0 - ¼ achievements are considered “low”, ¼ to ½ is “medium”, ½ to ¾ is “good” and ¾ to 1 is considered “great”.

The biomimicry case studies have relatively low performance for social interaction indicators, with a score of 3 / 12. The performance of biomimicry in social participation is measured as low with a score of 2 / 14. German Pavilion since it is a temporary structure is not evaluated with its maintenance participation. The social equity performance of biomimicry case studies is 4 / 9, classified as medium. In total biomimicry shows medium performance in terms of social sustainability with a score of 9 / 35 (Table 2).

The biophilia case studies show good performance with a score of 4 / 8 on the matrix (Table 2). The social participation of the biophilia examples is good as well with 5 / 10 and the social equity score of them is 5 / 8 which is classified as great. In total biophilia shows good performance with a score of 14 / 26 according to the matrix (Table 2).

The biomaterial case studies have a low score of 2 / 8 for social interaction and 0 / 9 for social participation. The social equity performance of the biomaterial case studies is classified as good. In total biomaterial case studies show low performance with a score of 7 / 24.

In total, the utilization of biological matter (biomaterial or biophilia) shows similar scores to biomimicry case studies, in terms of total social sustainability score with 21 / 50 (bio-utilization types) and 9 / 35 for biomimicry case studies on the matrix (Table 2). This situation shows both the approaches' potential and the need for further research on their unique possible contributions.

The social equity is more affected by the bio-integrations with a 14/24 score while the social interaction 9/28 and social participation 7/33 scores for the existing bio-integration examples are low. This claims the need for further exploration of bio-integrated design strategies that foster these concepts.

The scores don't indicate the overall performance of the building in terms of the indicators. Since the selected indicators are investigated through their bio-integration of them, they show whether that building's bio-integration showed any action on that matter.

Some of the buildings are not measured with some of the indicators. The temporary buildings cannot be measured with maintenance-related indicators. Also, public buildings are not evaluated with their maintenance affordability since the users of these public spaces are not charged regularly.

The intention and the purpose of the bio-integration in the overall design also affects the performance of the integration. As can be seen from the analysis, in some of the buildings, the bio-integration of them is intended to focus on some social sustainability notions which leads them to have great performance (ex: The Kampung Admiralty). If the purpose of bio-integration is related to a social aspect, it might offer more potential than a bio-integration with the purpose of environmental optimization. The intention enhances the impact of bio-integrations.

It is visible that some bio-integration types tend to be used in some parameters of social sustainability more easily and effectively. For example, biophilia shows better results on social participation compared to the other types of bio-integrations. The feasibility and accessibility of the bio-integrations affect their performance as well since it restricts or frees possible application to certain scales and programs. In this context, the bio-integrations which require more sources including financial ones, tend to have less performance like biomimicry.

Overall, the matrix shows existing examples of the impacts of bio-integrations on social sustainability and their tendencies of them which underscores the potential of adopting the concept with good strategies while showing the strengths and weaknesses.

4.3. Possibilities

The existing applications of bio-integrations are singular, one integration is employed for one architectural piece on one specific scale. To enhance the potential of bio-integrations the multiple, iterative adaptions on various scales are needed. This holistic approach refers to systemic integrations, including the biological knowledge/data/matter/intelligence to every step from design to maintenance and use, on every scale from the facade of the building to the layout of the public space inside, and it should be used multiple times for several design, fabrication and maintenance solutions from various types of integrations.

4.3.1. Biomimicry and Social Interaction, Participation, Social Equity

Biomimicry, the design discipline of solving problems using the logic behind natural elements, is mainly related to structural, material, managerial, energy-related and thermal design solutions. The research areas of biomimicry are more defined as related to environmental sustainability and structural and economic optimizations (Pawlyn, 2011). Thus, the social interaction and participation concepts are likely to be applied to the design process rather than the latter processes. With the inclusion of bottom-up approaches including the community members and stakeholders, the link between the desired design solution and the user's preferences and wishes can be enhanced. Also, the design process can be designed as a cultivator of social interaction between designers, designers and users, users, users and non-users which offers a social cohesion system for each biomimicry application to architecture in a specific place.

The existing biomimicry examples in architecture tend to be big-scale public projects because of their engineering and economic demands. Therefore, the accessibility to such projects is limited to their usability of them in accordance with their function. The small-scale biomimicry projects have the potential to serve to social equity due to increased accessibility with affordable and feasible applications. Furthermore, the increase in variety of the biomimicry application library can affect the accessibility and feasibility of them due to the optimization and know-hows introduced.

4.3.2. Biophilia and Social Interaction, Participation, Social Equity

Biophilic design have positive effects on humans on a psychological level (Kellert, 2005). Thus, this positive effect on the individual scale can be used as the catalyser in public spaces and moved to the bigger scales. The mental well-being of the individuals positively affects the social interaction and participation. Also, studies show, people living in buildings that are surrounded by natural elements have stronger social ties, better social interactions, a greater sense of safety and a better feeling of community than the ones surrounded by nothing but concrete and asphalt. (Kellert, 2005)

Furthermore, the biophilic integrations have the potential to reveal possible interaction and participation areas like the maintenance of the floral integrations and the hobby-purposed uses and activities around the integrations.

Biophilia, because of its accessible nature, can be conducted by everyone which makes the bio-integration accessible for different income groups, different religions/ethnicities/gender identifications, and for different disabilities or well-being conditions.

4.3.3. Biomaterial and Social Interaction, Participation, Social Equity

In biomaterial applications, the interaction between humans and biology, even when not obvious like biophilic design examples, is still more intricate and profound than initially perceived. The biomaterials that surround people offer tectonic and cognitive levels of interaction, shaping their physical environment and affecting their perceptual experiences. Also, as a part of the biophilia theory, it is possible to include biomaterials as the natural elements to be around that have potentially positive effects on human lives (Kellert, 2005; Bratman et al., 2019; Huntsman and Bulaj, 2022).

The manufacturing process of biomaterials can easily become a participation notion. Even though changes according to every biomaterial's manufacturing process, it is not impossible to downsize the process to a personal and/or community scale which can be used as a social cohesion entity. With the help of social policies on several levels, the fabrication processes in a specific scale, a neighbourhood, or a city, can be included to the social ties of a community.

Biomaterials have great potential to decrease the financial burdens of architecture with the local and sustainable approaches. Thus, the biomaterial use for architecture can serve to close the gap between income groups.

4.3.4. Synthetic Biology and Social Interaction, Participation, Social Equity

Synthetic biology as a futuristic member of bio-integrated research offers evolving ways of making architecture. Synthetic biology has the potential of democratizing the area, disconnected from the ethical concerns attached to it. Thus, a future scenario includes the equity of sheltering with the help of notions like growing your own house (Dade-Robertson, 2021). With the potential democratization effects (Estevez and

Navarro, 2017), the participation of communities to design, fabrication and maintenance processes might evolve into more active ones.

4.3.5. The Bio-integrations for Social Interaction, Participation and Social Equity Indicators

The bio-integration can help revolutionize the design and distribution of spaces. The natural algorithm use for layout might offer new solutions for the optimization of design, distribution of the spaces and the density of the space. The growth patterns or behavioural imitations of living- beings can provide varieties of designs that potentially offer innovative solutions to design problems. The evolutionary design systems can be integrated to the space layout design (Jo and Gero, 1998). Furthermore, with including biological utilization as the design parameter, it is possible to improve the design and quality of spaces.

As it can be observed from some of the existing examples, bio-integrations, biomimicry, biophilia, biomaterials and living architecture offer environmental advantages including thermal comfort, fresh air and more, which affects the social concepts. The extensive and repeated use of these strategies might have considerable effects on social sustainability.

The participation to the design and application of bio-integrations offers considerable possibilities for social sustainability of bio-integrations. Including the community to the process links the outcome of the bio-integrated architecture and/or design to the real users' needs (Bramley and Dempsey, 2006; Dempsey, 2008) and offer a more comprehensive approach to bio-integration rather than top-down applications that might not be embraced or not usable for the community.

The use of local labour and businesses offer possibilities of circular systems that enables community members to contribute to the fabrication of their own buildings/urban spaces which increases the sense of belonging and serves to social sustainability of the systems (Bramley and Dempsey, 2006).

Employing voluntary/sequential systems for bio-integrations like watering/trimming volunteers for biophilic integrations users may serve to social sustainability of the communities.

Community activities are one of the most discussed realm in relation to the social participation and sense of belonging discourses (Bramley and Dempsey, 2006; Dempsey, 2008) The possible examples that can be integrated are gardening events for biophilic applications, the agricultural initiatives and events that community members can grow their on food, material fabrication systems enabling community members to grow and process bio-materials at home or at public areas which then can be used for their own buildings or neighbourhood. An example to such activities is Singapore Gardeners Cup (National Parks, 2022). These community activities have great potential to improve social participation, sense of belonging and social sustainability.

The affordability of use/experience of bio-integration can be supported by the low-cost studies of biophilia and biomaterials. The concept of "growing your own food in the garden" can be reintegrated as "using the waste from your garden as material for architecture and/or growing your own material and expands beyond traditional boundaries to the concept of "growing your house" (Dade-Robertson, 2021) which incorporates a series of possibilities into closing the gap between the income groups if supported with true policies and ethical basis.

The maintenance affordability and the resilience of the bio-integration has a significant effect on the accessibility of them between income groups. With the high level of engineering and related scientific studies, the bio-integration can be automized, like the bio-reactive facades of BIQ house, the life cycle and seasonal changes can be optimized like the Bosco Verticale (IBA Hamburg, Roedel and Petersen, 2013; Stefano Boeri Architetti, 2017) and further decision makings according to the program and public/private uses of the architecture can be adapted.

The local material usage can affect the social equity in terms of income groups greatly. The decrease of the transportational costs and related expenses can have positive impact on the social equity between income groups due to the increased affordability. Also, use of local biological matter can reduce the costs of producing non-bio content for materials.

The near existence with the natural elements have positive mental effects (Kellert, 2005; Bratman et al., 2019; Huntsman and Bulaj, 2022). With very accessible integrations like plantation, ventilation, daylight; it is possible to serve the mental health which serves to the equity for disabilities and diiferent wellbeing conditions.

CHAPTER 5: CONCLUSION & DISCUSSION

5.1. Discussion & Future Possibilities

Bio-architecture offers significant potential in various dimensions including supporting a shift from the existing ways of making, existing systems and know-hows to new, more sustainable and innovative ones. To achieve the best version of this shift and use the bio-architecture for it, the bio-integrations should be redefined in architecture and their possibilities should be discussed and experimented on various levels.

Bio-architecture literature and applications offer a broad amount of approaches and terms enriching the discourse. While all subcategories have a tremendous amount of potential for sustainable architecture, these disciplines are not used systematically and holistically. Various parameters can be introduced to systematically investigate these bio-integrations to architecture including the role of biological entry and human, the type of integration and the processes they can be integrated into.

To be able to integrate bio-architecture to new era(s), it is necessary to examine the relationship of bio-integrations with social sustainability. Social sustainability needs careful attention in the practice of design since it encompasses the well-being and quality of life of individuals and communities within the built environment. The bio-integrations to architecture offer tremendous amounts of potential for social sustainability with the true use of them.

Based on qualitative analysis of the existing bio-integrated architecture case studies and discussion on the holistic future possibilities, it can be concluded that the one-scale and singular approaches of bio-integration to architecture are beneficial for several reasons but not fulfilling the needs of social sustainability directly.

From the analysis of existing case studies, it can be traced that some of the bio-integrations tend to serve certain social sustainability parameters than others. The feasibility, accessibility and intention of the designer and decision-makers affect the performances of bio-integrations on social sustainability drastically. These correlations can be used for optimization and true decision-making processes in the bio-integrations to architecture. With well implemented strategies, these strengths and weaknesses can be used to contribute to social sustainability.

The holistic, inter-scale and iterative approaches to bio-architecture offer a much broader perspective and a possibility to shift on the ways of people design and make. Bio-integration into architecture can be used as a powerful tool to improve social sustainability. Furthermore, bio-architecture can serve to the systemic changes, big-scale policy actions and community initiatives which can multiply the effects on social sustainability on different scales.

Future advancements in the transdisciplinary field between biology and architecture offer significant shifts in the perception of design and architecture. The self-sustaining systems, growing houses and architecture as a biological element on the site has much potential to impact social sustainability through architecture positively.

Further possibilities for this research might include utilizing quantitative and/or mixed research methods and practices to reinforce the discourse and emphasize the necessity of natural integrations to architecture with qualitative data.

Moreover, to improve discussion, the parameters of social sustainability can be varied, and research can be widened to multi-scales, for example, neighbourhood or city scales might be useful to work on to take actions for social sustainability with bio integrations to design. Additionally, the specific location and specific time addressed for the measurement of social sustainability can strengthen the studies.

Also, to advance conversation and possibilities of bio-architecture on social sustainability on a transformation from Anthropocene to Ecocene, diversifying the focuses and scopes may enhance the depth of understanding and serve to the existing gap in knowledge, urgent and focused attention from researchers, academics and policymakers.

5.2. Limitations of the Study

To be able to discuss the architectural effects, this research focuses specifically on the architectural level which is a limited scope compared to the multi-level approaches suggested for comprehensive studies of social sustainability (Mischen et al., 2019). While this choice permits a concentrated analysis, it might restrict the assessment of social sustainability across multiple layers and present challenges in converting findings into actionable measures.

Social sustainability as a long-term concept, requires long-term constant measures (Mischen et al., 2019). However, this research primarily focuses on the existing situation and collects secondary data obtained from media sources which include only the content from the buildings' design process up to the present. Therefore, the longer-term possible effects are not included in the investigation.

The qualitative approach is adopted to be able to discuss broad concepts and examine the intricacies and nuances of the subject matter. Even though this approach can provide valuable insights, it may require additional complementary methodologies to translate findings into actionable outcomes.

Furthermore, the discussion of the existing effects is investigated with the secondary data sources, meaning the existing data is reviewed. In addition, to be able to create a systematic analysis, if any data is not found for the investigated indicators, it is considered "not achieved (0)". However, since the data collected from these available sources are the only source to examine the indicators investigated in the research, some of the information might be omitted. For example, participation in the design process might not be documented in the public media even though implemented in their process. The restricted access to data can result in inhibiting a comprehensive assessment of the actual impact of bio-architectural interventions.

Related to the lack of bio-architectural examples in similar contexts, the case studies were selected from diverse environmental, cultural and social contexts which introduce various external factors that may influence the outcomes. These variables can potentially impact the generalizability and transferability of the research findings. Hopefully, with the growing number of bio-integrated architecture examples, it can be possible to examine the effects on social sustainability while using similar variants in terms of the program, user profile, scale, cultural context etc.

The selected parameters and the social sustainability, as outlined in Chapter 3, present difficulties in data collection because of the obscurity of the terms, the unstandardized nature of the concept, dynamic definitions, and the inherent subjectivity of qualitative measurements. These factors contribute to the difficulty in obtaining precise and objective data which can affect the robustness of the outcomes.

5.3. Conclusion

This research aimed to investigate the existing effects of bio-integrated architecture on social sustainability and explore the possibilities of enhancing social sustainability with bio-architecture. The existing examples of bio-integration to architecture are examined with qualitative analysis and possibilities are discussed.

To be able to examine the existing effects, first, the bio-architecture is defined thoroughly, and social sustainability and its parameters, indicators and measures are discussed from various perspectives. Then as case studies, the existing examples of biological integration into the architectural design from different sub-categories are selected and examined with the selected parameters of social sustainability, *social interaction, social equity and participation* via their indicators in qualitative sources. After analysing the existing situation, the holistic, inter-scale and iterative approaches of biological integrations and their possible value to social sustainability are discussed.

The existing bio-architecture examples show strengths and weaknesses according to their types, the feasibility, accessibility, and intention of bio-integration. The relationship between different bio-integration types, and relatable indicators for social sustainability show great potential to use bio-integrations for positive social sustainability impacts. There are significant amount of possible uses of bio-integrations for positive effects to social sustainability. The holistic, inter-scale and iterative implications show the greatest potential since they unfold the strengths of every possible bio-integration.

The findings of this research highlight the existing impacts of bio-integrated architecture and shows the potential of bio-integration to adapt the discipline of architecture for a better era. It also emphasizes the importance of adopting a holistic, inter-scale, and iterative approach to bio-architecture to achieve the best results for social sustainability. It contributes to the transdisciplinary gap by integrating natural and social sciences together in architectural discussions.

By offering a framework to assess the impact of bio-architecture to social sustainability, research contributes to the discussion of the assessment and the measurement of the mentioned notions and provides a baseline for the possible matrixes and indicators for future works.

The research also contributes to the discussion on changing responsibilities of architects and designers. By examining the existing situation and possibilities it offers new pathways for architects and designers and it provides fruitful potential both for academia and practice. It contributes to the discussion of future developments and advancements on the transdisciplinary area and serves to the need for extensive study for a shift from Anthropocene to Ecocene.

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