KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
COLLEGE OF ART AND BUILT ENVIRONMENT
DEPARTMENT OF ARCHITECTURE

EXPLORING THE POTENTIAL OF BIOMIMICRY FOR S.T.E.A.M. LIVING-LEARNING COMMUNITIES IN GHANA: THE CASE OF KYEBI

(Living-Learning Community S.T.E.A.M Hub, Kyebi)

By

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(BSc. Architecture**)**

A Design Thesis submitted to the Department of Architecture, Kwame Nkrumah University of Science and Technology in partial fulfilment of the requirements for the award of a Master of Architecture degree.

MASTER OF ARCHITECTURE

AUGUST, 2024

DECLARATION

I hereby declare that this Design Thesis submission is my own work toward a Master of Architecture and that, to the best of my knowledge, contains no material previously published by another person or material which has been accepted for the award of any other degree of the university, except where due acknowledgment has been made in the text.

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ABSTRACT

The emergence of S.T.E.A.M. as a concept responds, in part, to the increasing emphasis on STEM disciplines, coupled with a declining focus on arts and culture in education. Living Learning Communities (LLCs), where faculty, staff, and students cohabit and learn collaboratively, have historical roots in early institutions and are widely recognized as a high-impact educational practice, positively influencing academic performance, especially in arts and STEM education. Biomimicry, derived from "bios" meaning life and "mimesis" meaning to imitate, involves studying nature's design solutions and applying them to address human challenges. This concept has captivated architects and engineers globally, offering inspiration for innovations and promoting a more sustainable built environment. Considering its strategic location, history, and recent exploitation of abundant mineral deposits, Kyebi's evolution into a city aligns with existing efforts for a smart, resilient, and sustainable community while enhancing S.T.E.A.M. education and promoting environmental sustainability through Biomimicry Architecture. The research adopts a mixed-methods approach, incorporating qualitative and quantitative data collection methods such as surveys, interviews, and observations with stakeholders including educators, students, and community members, to assess their perspectives on S.T.E.A.M. living-learning communities. Quantitative data were analyzed using descriptive statistics, while qualitative methods utilized thematic analysis to identify patterns and themes. Findings were presented through tables, charts, and narratives to address challenges, opportunities, and provide recommendations, contributing to the development of sustainable and innovative approaches to education and design in Ghana. Findings reveal a high level of interest among participants, including students, educators, and community members, in participating in STEAM programs and endorsing the incorporation of biomimicry architecture into the Hub's design. Stakeholder feedback informs the design process, highlighting preferences for specific programs and activities to be included in the Hub. Furthermore, the research proposes recommendations for future studies and emphasizes the importance of considering organic architecture principles in conjunction with biomimicry for holistic and sustainable design solutions. Overall, this thesis contributes to the advancement of sustainable architecture by demonstrating the potential of biomimicry to create innovative and environmentally friendly learning spaces.

Keywords: STEAM, STEM, Living-Learning Communities, Biomimicry, Biomimetic, Sustainability, Hub.

TURNITIN REPORT

Exploring the potential of biomimicry for S.T.E.A.M. Living Learning Communities in Ghana. The case of Kyebi (Final Draf...

FINAL DRAFT FOR ASSESSMENT

MARCH 2 2024 THESIS

Kwame Nkrumah University of Science and Technology

Document Details

Submission ID

trn:oid:::1:2899414098

Submission Date

Apr 25, 2024, 4:37 PM GMT

Download Date

Oct 18, 2024, 5:55 AM GMT

File Name

Exploring_the_potential_of_biomimicry_for_S.T.E.A.M._Living_Learning_Communities_in_Ghana._T....pdf

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ACKNOWLEDGEMENTS

First and foremost, I would like to thank and praise God, the Almighty, for providing me with countless blessings, knowledge, and opportunity to work on this thesis. I would like to express my profound gratitude to my family and friends for their unwavering support throughout my tertiary education.

I take this opportunity to express my gratitude to the people who have been instrumental in the successful completion of this thesis especially, Dr Ing. Alexander B. Marful, who served as my supervisor throughout this research for his tireless assistance, critiques, and suggestions.

My final gratitude goes to everyone who contributed to this research in any way, especially to my respondents and also Emmanuel Adzah, Henry Kofi Danso and Isaac Egyir Kwofie who lent their helping handing during the research.
God's blessings to you all.

DEDICATION

I dedicate this thesis to my mother, Beatrice Mortoo, whose unwavering support and encouragement have been a guiding light throughout my academic and personal journey. I am deeply grateful for her love and presence in my life. Additionally, I extend my dedication to my entire family for their support in all things great and small.

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LIST OF ABBREVIATIONS

AI – Artificial Intelligence

ESD – Ecologically Sustainable Design

J.H.S - Junior High School

KNUST – Kwame Nkrumah University of Science and Technology

LLC – Living-Learning Communities

RII - Relative Important Index

S.H.S - Senior High School

S.T.E.A.M. - Science, Technology, Engineering, Arts, and Mathematics

STEM – Science, Technology, Engineering, and Mathematics

CHAPTER ONE
1.0 GENERAL INTRODUCTION

1.1 CHAPTER OVERVIEW

This research aims to investigate the utilization of biomimicry in designing a Living Learning Community S.T.E.A.M Hub situated in Kyebi, Ghana. The chapter commences with an introduction that delves into the background context of the study, encompassing S.T.E.A.M education, Living Learning Communities, and Biomimicry. Subsequently, it delineates the research problem, rationalizes the site selection, articulates the research question, outlines the aims and objectives, underscores the significance of the research, provides an overview of the research structure, and acknowledges its limitations.

1.2 BACKGROUND OF STUDY

In the current era of rapid technological advancements and globalization, STEAM education has emerged as a response to the growing emphasis on STEM fields, aiming to integrate creative disciplines such as art into traditional STEM education (Daugherty, 2014; Herro et al., 2017; Perignat et al., 2019). This shift addresses concerns about the diminishing focus on arts education in favor of STEM subjects in recent decades (Stewart et al., 2021). The transition from STEM to S.T.E.A.M education underscores the importance of incorporating design and aesthetics alongside scientific and technical knowledge (Bilgiler et al., 2019). Informal educators have embraced STEAM as a means of engaging students with diverse learning styles, highlighting the role of creativity in scientific inquiry and problem-solving (Mejias et al., 2021).

According to Caldwell (2021), the concept of Living Learning Communities (LLCs), where students and faculty reside and study together, traces its roots back to early colleges, pioneered by John Dewey and Alexander Meiklejohn (Buell et al., 2017; Choset, 2021; Love, 2012). This "collegiate model" provided students with a holistic university experience, akin to contemporary LLCs, where students share living spaces and academic pursuits (Blimling, 2015). The resurgence of LLCs in the late 1990s led to their widespread adoption in modern higher education, offering various configurations, from themed residential halls to integrated curricula with co-curricular activities (Dunn & Dean, 2013). LLCs have proven to enhance student retention, academic performance, and overall well-being, serving as high-impact educational

environments (Otto et al., 2015; Naylor-Tincknell, 2016). While traditionally associated with general education, LLCs are expanding into diverse curricular areas (Matthews et al., 2012).

Biomimicry, derived from the Greek word's "bios" meaning life and "mimesis" meaning to imitate, entails studying nature's design solutions and applying them to address human challenges, particularly in architecture (Rao, 2014; Spaho, 2011). Benyoucef & Razin (2018) define biomimicry as a novel engineering approach inspired by nature, applied across various domains such as design, transportation, and architecture. Architecture, as an interdisciplinary field, draws influence from natural, technical, and social sciences, with biology serving as a prevalent source of inspiration. Despite historical architects like Le Corbusier recognizing biology's relevance, they often overlooked nature's deeper lessons, focusing more on superficial representations (Pathak, 2019). However, architects have long sought inspiration from nature's efficient structures, recognizing its potential for multifunctional designs. El-Zeiny (2012) highlights the global interest among architects and engineers in biomimicry, viewing it as a catalyst for innovation and sustainability in the built environment.

Peri-urban areas, bridging urban and rural zones, have garnered attention for initiatives aimed at enhancing resilience and sustainability (Marful et al., 2019). Factors such as decentralization, developmental projects, industrialization, and democratization have spurred urbanization in Ghana, particularly in towns like Kyebi, the capital of Akyem Abuakwa State. Kyebi's strategic location, historical significance, and recent exploitation of mineral resources have fueled its transformation into a burgeoning city. Efforts to foster Kyebi's development include the formulation of an integrated master plan to ensure its future as a smart, resilient, and sustainable urban center (Marful et al., 2019). However, the prospect of gold and bauxite commercialization presents both opportunities and challenges, necessitating a comprehensive long-term growth strategy for the community (Marful et al., 2019).

1.3 PROBLEM STATEMENT

In Ghana, according to Nyaaba et al. (2024), the promotion of Science, Technology, Engineering, Arts, and Mathematics (S.T.E.A.M.) education faces hurdles due to a lack of infrastructure. Despite the proven benefits of Living-Learning Communities (LLCs) in enhancing student outcomes globally, as evidenced by Naylor-Tincknell (2016), their implementation in Ghana remains limited. This limitation, compounded

by multifaceted challenges in S.T.E.A.M. fields, accentuates the urgent need for innovative approaches. Baumeister et al (2020) advocate for a paradigm shift towards nature-integrated architecture, highlighting the potential of biomimicry. However, the application of biomimicry principles within Ghanaian S.T.E.A.M. remains largely unexplored, hindering both sustainability efforts and educational opportunities. Addressing this gap requires comprehensive research to unlock the transformative potential of biomimicry in Ghanaian LLCs and advance S.T.E.A.M. education initiatives across the country and potentially in Kyebi where the study was based.

1.4 SITE JUSTIFICATION

Given Kyebi's ongoing initiatives in STEAM education, currently limited to only primary and junior high schools due to infrastructure inadequacy, the town's strategic location, historical significance, and recent mineral mining activities present a compelling rationale for establishing a Living Learning Community STEAM Hub. This decision harmonizes with Kyebi's ongoing efforts to develop a comprehensive master plan aimed at fostering a smart, resilient, and sustainable community as elucidated by Marful et al. (2019). Additionally, the selection of Kyebi for the S.T.E.A.M Hub design aligns cohesively with existing proposals for an ICT hub, digital campus, and events center, providing a conducive environment for extending STEAM education initiatives across all educational levels. Moreover, Kyebi's diverse biodiversity, facing threats from urbanization and industrialization, highlights the importance of integrating biomimicry principles into the hub's design. By leveraging nature's innovation, the S.T.E.A.M Hub not only advances environmental sustainability but also facilitates educational progress and innovation within the community.

1.5 RESEARCH QUESTION

1. How is S.T.E.A.M. education currently progressing in Ghana.
2. What are the potentials of Living-Learning Communities for S.T.E.A.M. in Ghana.
3. What are the challenges and opportunities in implementing biomimicry in S.T.E.A.M. living-learning communities in Kyebi.
4. How can biomimicry be applied to design a sustainable Living-Learning Community S.T.E.A.M. Hub in Kyebi.

1.6 AIM OF STUDY

The research aims to explore the integration of biomimicry principles into S.T.E.A.M. Living-Learning Communities in Ghana, focusing on Kyebi with a goal of offering insights for innovative and environmentally friendly education practices in Ghana.

1.7 OBJECTIVES OF THE STUDY

The objectives of the research are to:

1. Identify how S.T.E.A.M. education is currently progressing in Ghana.
2. Investigate the potential of Living-Learning Communities for S.T.E.A.M.
3. Examine the challenges and opportunities in implementing biomimicry in S.T.E.A.M. living-learning communities in Kyebi.
4. Apply the concept biomimicry to design a sustainable Living-Learning Community S.T.E.A.M. Hub in Kyebi.

1.8 SIGNIFICANCE OF THE STUDY

Researching the potential of biomimicry for S.T.E.A.M. Living-Learning Communities in Ghana holds significant importance across multiple dimensions as it firstly provides valuable insights into the progression of S.T.E.A.M. education in Ghana, shedding light on current practices and areas for improvement. Secondly, the exploration of Living-Learning Communities for S.T.E.A.M. in Kyebi offers a platform to develop innovative educational models that foster collaboration, interdisciplinary learning, and community engagement. Thirdly, examining the challenges and opportunities in implementing biomimicry underscores the importance of adopting sustainable practices and promoting environmental conservation within educational settings. Lastly, applying biomimicry principles to design a sustainable S.T.E.A.M. Hub in Kyebi showcases the practical relevance of biomimetic concepts, potentially leading to the development of eco-friendly educational facilities and inspiring creative solutions to educational and environmental challenges in Ghana. And even though similar researches were done on the potential of biomimicry in design, its application in the design of a Living Learning Community S.T.E.A.M. Hub in the Ghanaian context is yet to be researched.

1.9 SCOPE OF THE STUDY

The theoretical scope of this research is to explore the potential of biomimicry in S.T.E.A.M. living Learning communities in Ghana. The study was based on the perception of students and educators related to S.T.E.A.M. education and also the community members of Kyebi on the potential of biomimicry in S.T.E.A.M. living-learning communities in Kyebi. Participants from the major universities in Ghana especially Kwame Nkrumah University of Science and Technology will be included in the study.

1.10 RESEARCH METHODOLOGY

This research grounded in transformative worldview with the intention to impact change adopted a mixed-methods approach, integrating qualitative and quantitative data collection methods to explore the integration of biomimicry for S.T.E.A.M. Living-Learning Communities within the Ghanaian context. Surveys, interviews, and observations were conducted with educators, students, and community members to elucidate stakeholder perspectives on these interdisciplinary approaches to education. Complementing these primary data sources, comprehensive literature reviews were conducted to contextualize the study within existing research on S.T.E.A.M. education, Living-Learning Communities, biomimicry, and sustainable design principles. Quantitative data analysis employed descriptive statistics to discern trends from survey responses, while qualitative data from interviews and observations utilized thematic analysis to uncover nuanced insights. Through the presentation of findings via tables, charts, and narratives, this methodology aims to provide a holistic exploration of biomimicry's potential in enhancing S.T.E.A.M. education within Living-Learning Communities, thereby contributing to the advancement of sustainable educational practices and environmental conservation efforts in Ghana.

1.11 ETHICAL CONSIDERATIONS

The research adhered to ethical principles and guidelines, including obtaining informed consent from participants, ensuring confidentiality and anonymity, and minimizing harm and risk to participants, in line with the ethical guidelines of KNUST.

1.12 LIMITATION OF THE STUDY

The crucial limitation of the study will be the inability of the affiliated institutions to provide the required relevant data to support the research. In addition, there will be a limitation due to inadequate funding and the relative scope of the study. The issue of low response rate is also a likely foreseen limitation of the research as respondents may be reluctant to provide names of colleagues and pressuring them to comply results in ethical concerns.

1.13 RESEARCH ORGANISATION AND FRAMEWORK

For the aim of this study to be achieved, the dissertation was presented in an order of six (6) chapters which are as follows:

Chapter 1 gives a brief outline of the study, highlighting the research background, problem statement, the aim of the study, the research objectives, and the organization of the study. Chapter 2 provides a review of related literature relevant to the study. The research methodology employed including the research design, target population, sampling technique utilized, data sources and types, and the data analysis approach used is included in Chapter 3. Chapter 4 talks about the research result, findings, and discussions according to the data analysis. The entire research's conclusion and recommendations will be presented in Chapter 5. The final part which is chapter 6 will give an account of the design response and the solution to the research problems indicated in the subsequent chapters. Figure 1.1 shows an illustration of the conceptual framework for the research.

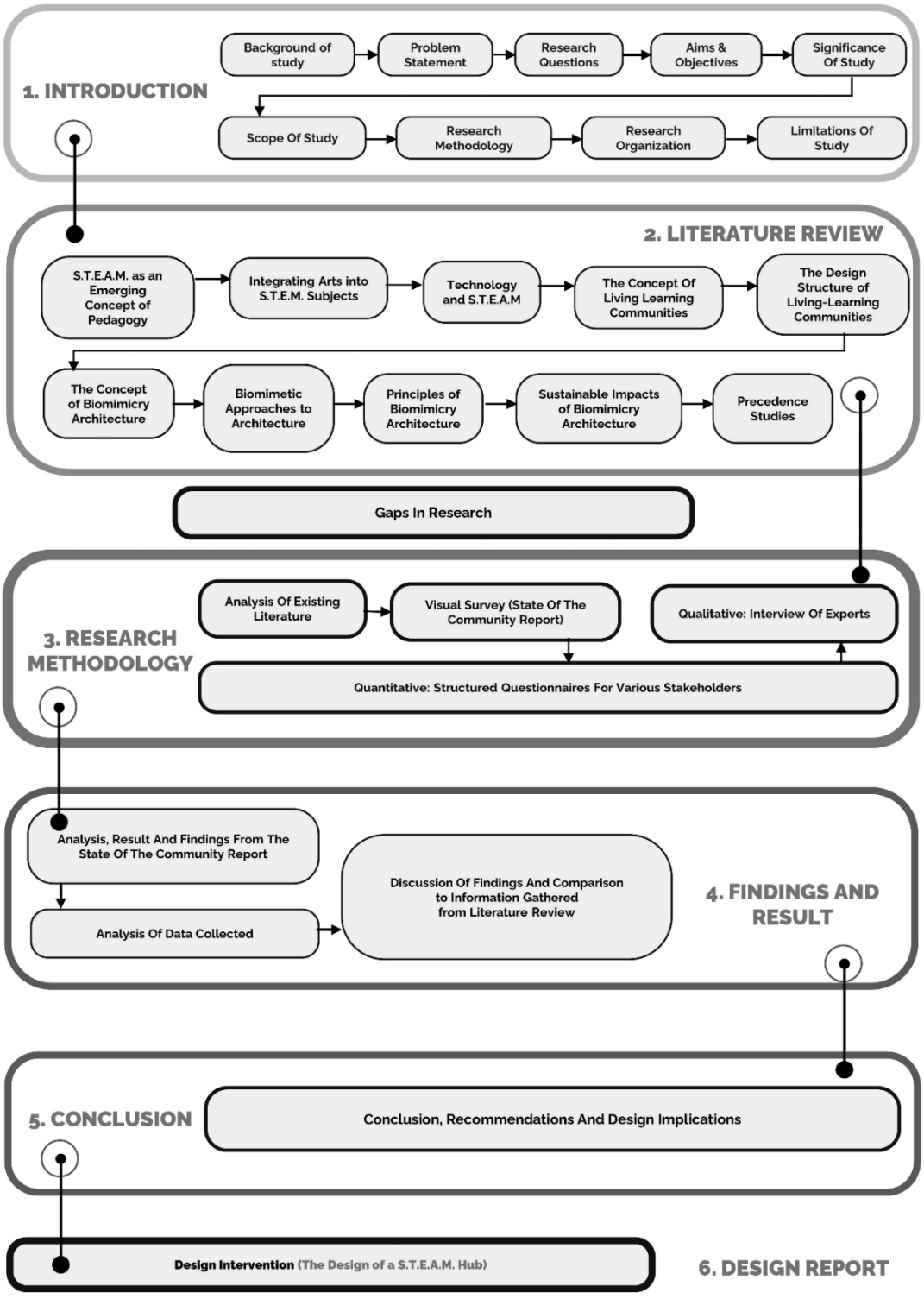


Figure 1.1.1 Research Framework (Source: Author, 2023)

1.14 CHAPTER SUMMARY

This chapter summarizes the introduction to biomimicry, Living Learning communities and S.T.E.A.M education and their potential in the design of a S.T.E.A.M Hub in Kyebi, Ghana. It covers the fundamentals behind the research in the background study from which the problem, research aim, questions, and objective were derived. The scope, methodology, significance, structure, and limitations of the research were also examined in this chapter.

CHAPTER TWO
2.0 LITERATURE REVIEW

2.1 CHAPTER OVERVIEW

This chapter, structured around three interconnected themes, provides an in-depth exploration of STEAM education, Living-Learning Communities, and biomimicry architecture. By firstly examining the current state of STEAM education, including contemporary challenges and opportunities, with a particular focus on the Ghanaian context the chapter then investigated the concept of Living-Learning Communities, analyzing their significance in fostering collaborative learning environments, improving student outcomes, and addressing educational inequalities. Subsequently, it explores biomimicry architecture, elucidating the principles of nature-inspired design and its potential applications in educational settings. By synthesizing research across these domains, the literature review establishes a comprehensive theoretical framework for the study. Through this synthesis, the chapter sets the stage for empirical inquiry into the integration of biomimicry in STEAM education within the context of Living-Learning Communities.

2.2 S.T.E.A.M AS AN EMERGING CONCEPT OF PEDAGOGY

S.T.E.A.M education is an emerging paradigm of pedagogy that tries to integrate science, technology, engineering, arts, and mathematics into a cohesive and interdisciplinary approach to learning (Hilppö et al., 2022). This method recognizes the interconnection of different subject areas and attempts to offer students with a well-rounded education that develops critical thinking, problem-solving, creativity, and innovation. According to Kastriti et al (2022), STEAM education is distinguished by its integrated approach, treating the individual subjects as a unit and teaching them coherently (Kastriti et al., 2022). It stresses the integration of information from multiple subjects, including as science, technology, engineering, arts, and mathematics, and fosters the use of methodologies and tools from these disciplines to solve real-world problems Kastriti et al (2022) added. By combining the arts into STEM disciplines, STEAM education recognizes the significance of creativity and encourages students to explore new ideas and approaches (Liao, 2016). Furthermore, STEAM education promotes teamwork and cooperative communication, which are crucial skills for both social and professional development. Overall, STEAM education strives to offer students with a holistic and practical learning experience that

prepares them for the challenges and opportunities of the 21st century according to Hilppö et al., (2022).

2.2.1 The Historical Evolution of S.T.E.A.M Education

STEAM education emerged as a new pedagogy in response to the need to increase student interest and skills in STEM fields, as discussed during the Americans for the Arts-National Policy Roundtable in 2007. The concept was developed in part to counterbalance the increased emphasis on STEM subjects and the decline in arts education in the United States in the past decades. Mejias et al. (2021) noted that STEAM, as an emerging field of theory, research, and practice, received attention for its effort to incorporate the arts into the rubric of STEM learning. As there was an active movement from STEM to STEAM education, the inclusion of creative disciplines, which can be designated by the term Arts - art, expanded and enriched this direction.

2.2.2 S.T.E.A.M Education in Ghana

In Ghana, there is a growing demand for art students to venture into STEM-related fields like engineering. However, the current senior high school curriculum in the country does not align with the advancements seen in developed nations, hindering the seamless integration of art and engineering education (Selase et al., 2023). According Nyaaba et al. (2024) there has been a neglect of STEAM initiatives within early childhood and primary education, primarily due to prevailing misconceptions about these educational levels (Nyaaba et al., 2024). Although, studies propose that the integration of STEM fields and visual arts should commence during Senior High School, providing an opportunity to blend science and mathematics subjects with courses in visual art (Owusu, 2022), Researchers argued that the detrimental effects of prioritizing upper-level STEAM education while neglecting foundational years, akin to constructing a multi-story building without strengthening its foundation Nyaaba et al. (2024) argued. This flawed approach has rendered previous STEM-related initiatives in Ghana ineffective, particularly for students from less affluent backgrounds who lack adequate support (Nyaaba et al., 2024). Emphasizing the importance of initiating STEAM education in the early years, it was suggested that it can foster gender equity, enhance critical thinking skills, and foster a positive attitude towards STEAM subjects among all young learners (Nyaaba et al., 2024).

2.2.2.1 The Misconception of Art Education in Ghana

It was advocated the integration of arts-related skills such as creativity, problem-solving, critical thinking, communication, self-direction, initiative, and collaboration into science education within the STEAM framework can be beneficial to students in aspiring to venture into STEM fields (Okwara et al., 2023). Students studying visual art are keen to dispel the myth that art is a specialized field and are eager to pursue STEM-related fields in further education according to Selase et al. (2023). Okwara et al. (2023) argues that while STEM education aims to equip learners with 21st-century skills through interdisciplinary problem-solving, it often overlooks the potential for creativity within science and the benefits of incorporating arts-based approaches. By integrating arts practices such as discovery, observation, experimentation, description, interpretation, analysis, evaluation, wondering, visualizing, exploring, and communication, STEAM offers new avenues for problem-solving and encourages positive attitudes towards science among learners (Okwara et al., 2023).

2.2.3 Significance of Art to STEM Education

Conner et al. (2017) noted that many programs argue that adding the A to STEM helps broaden participation in STEM learning. There is a growing debate among educators that "arts" should be integrated into the STEM curriculum to spur much-needed creativity and innovation (Guyotte et al., 2016; Myint Swe & Shaljan, 2021).STEAM adopts a transdisciplinary approach that incorporates the arts into science education to enhance learners' confidence, attitudes, and interests in science (Okwara et al., 2023). Studies have demonstrated that the incorporation of arts into STEM disciplines can enhance cognitive growth, increase long-term memory retention, and encourage creativity (Oner et al., 2016). Also, the incorporation of arts in STEM topics has the potential to make these fields more appealing and engaging to students Okwara et al. (2023) added. Studies have demonstrated that when the arts are introduced into science domains, pupils become more interested in STEM subjects. This is reinforced by studies undertaken by Morton et al. (2017), who believe that integrating the arts into education is a means of promoting interest in the sciences and encouraging more students to choose STEM jobs (Morton et al., 2017; Tuveri & Paolucci, 2022).

2.2.3.1 Culture Integration into STEAM Education

According to Bayode (2013), Culture integration in STEAM education using arts presents the opportunity for the incorporation of cultural perspectives, practices, and knowledge into curricula and pedagogy (Bayode, 2013). Research in this area highlights the importance of recognizing and valuing diverse cultural backgrounds to promote inclusive and equitable learning environments (Bennett, 2016). Studies have shown that integrating students' cultural experiences and identities into STEM instruction can enhance student engagement, motivation, and academic achievement (Akintoye et al., 2023, Fenyvesi et al., 2019). For example, incorporating culturally relevant examples and contexts in science lessons can make abstract concepts more relatable and meaningful for students from diverse cultural backgrounds according to Fenyvesi et al. (2019). Additionally, culturally responsive teaching practices, such as incorporating students' cultural assets and perspectives into lesson plans, have been shown to promote deeper learning and critical thinking skills (Bayode, 2023; Bennett, 2016). However, challenges such as cultural biases in curriculum materials, lack of teacher training in culturally responsive pedagogy, and systemic inequities in access to STEM education persist and need to be addressed (Bennett, 2016). Moving forward, more research is needed to explore effective strategies for integrating culture into STEM education and promoting diversity, equity, and inclusion in the STEM fields.

2.2.4 Pedagogical Approaches to S.T.E.A..M Education

As STEM education began to attract global attention, the notion of STEAM education, which stressed growing people with creative and convergent competency, also evolved (Choi et al., 2021). The adoption of STEAM teaching in preschools is still in its infancy, posing challenges for educators without clear guidelines from qualified experts according to Awang et al. (2022). There is the need for valuable insights for preschool teachers in selecting and implementing effective STEAM teaching strategies, enhancing the quality and meaningfulness of early childhood education in STEAM disciplines (Awang et al., 2022). It has been reported that non-arts instructors have faced obstacles in bringing art into the STEM curriculum to boost student creativity and innovative thinking (Ahmad et al., 2021). Incorporating the arts into STEM education can provide students with unique opportunity to enhance their creativity, critical thinking, and cooperation abilities (Liao et al., 2022).

2.2.4.1 Inquiry-Based Learning in S.T.E.A.M Education

Inquiry-Based Learning has gained significant attention as an effective instructional approach in STEAM education according to Frasinescu (2018), who deduced that it was because of the nature of the subjects being taught as students who learn through the inquiry-based approach demonstrate better understanding. Numerous research has explored the influence of Inquiry-Based Learning in various educational settings, particularly in STEM education. One study undertaken by Laursen et al. (2019) explored the efficiency of Inquiry-Based Learning in mathematics departments at four institutions and it was discovered that students in Inquiry-Based Learning courses demonstrated higher levels of engagement and problem-solving abilities compared to students in non-IBL settings (Laursen et al., 2019). Furthermore, studies indicated that the application of an inquiry-based learning method in STEAM education greatly increased students' academic achievement, inquiry learning skills, and metacognition (Durmaz et al., 2023). Additionally, the utilization of the principles of inquiry-based learning and problem-based learning in educational robotics showed efficient in a study according to Scarani et al., (2020). Students who received instruction through inquiry-based learning perform better compared to those who were educated using traditional techniques (Hsu et al., 2023). These illustrate the favourable influence of Inquiry-Based Learning on students' academic achievement in STEAM areas.

2.2.4.2 Project-Based Learning in S.T.E.A.M and its Impact

The Project-Based Learning model with the STEAM is a blend that is very suitable to complement the benefits of STEAM, providing students with an opportunity to understand the concepts of product making and design process in order to produce appropriate and relevant product results (Zhang et al., 2023). Further researches on Project-Based Learning indicates that STEAM Project-Based Learning promotes efficacy, generates meaningful learning experiences, and influences student attitudes and interests in future career pursuits (Bawaneh & Malkawi, 2023). It was suggested that STEAM educators can employ project-based learning with a set of particular learning outcomes (Admawati et al., 2018) as this approach requires teamwork, peer communication, problem-solving, and self-directed learning, incorporating rigor for all students (Hall et al., 2016). Furthermore, Project-Based Learning has been demonstrated to assist low-performing students to a greater extent and lessen the

achievement gap since the technique develops student's problem-solving skills according to Diana et al. (2021)

2.2.4.3 Impact of Innovation and Industry on S.T.E.A.M Education

In recent years, there has been an increasing emphasis on the value of innovation and industry links in S.T.E.A.M education. Several researchers have elaborated on the considerable impact of innovation and industry ties on S.T.E.A.M education (Sanabria-Z et al., 2017; Li et al., 2020) One study focused on the influence of industrial expertise on community college faculty members' teaching, particularly in the departments of science, technology, engineering, and mathematics (Wagner et al., 2021). According to Wagner (2021) faculty-industry relationships give professional learning opportunities for students, strengthening their education and preparing them for the workforce. Another study studied the interaction between higher education institutions and companies with reference to typical undergraduate courses and employability (Scarani et al., 2019). School-industry and school-community partnerships can be utilised to teach children the direct connection between their learning in school and real-world STEM professionals' job (Dare et al., 2021). This combination of industrial linkages and real-world applications make learning more relevant and authentic for students (Kelley, 2016).

2.2.5 Benefits of S.T.E.A.M Education

On one hand, S.T.E.A.M is emphasized as an extension of STEM fields for driving economic and national competitiveness, while on the other hand, S.T.E.A.M has the potential to offer new ways of doing and knowing in the arts and STEM fields, often with emancipatory and critical pedagogical approaches to learning that can be at odds with an economic focus (Mejias et al., 2021). Many programs invoke S.T.E.A.M to emphasize the role of design and aesthetics in engineering, scientific modeling, and scientific investigations. Furthermore, the literature underlines the necessity of fostering students' enthusiasm and attitudes towards science (Madani, 2020).

2.2.5.1 S.T.E.A.M Education’s Role in Fostering Innovation

In today's quickly changing world, the significance of accurate weather forecasts cannot be stressed. The incorporation of art into STEM education through STEAM has been found to serve a vital role in accelerating STEM learning (Belbase et al., 2022). Art design has been found to play a key role in accelerating STEM learning by

increasing students' comprehension from broader viewpoints and stimulating creative expression and inventive thinking (Allina, 2018). Furthermore, bringing distinctive parts of the arts into STEM education can strengthen the teaching of STEM courses and promote integrated problem-solving skills, teamwork, and interpersonal communication skills (Ghanbari, 2015). It promotes a deeper understanding from many perspectives, fosters creative expression and imaginative thinking, and boosts problem-solving skills (Admawati et al., 2018). Through the combination of various STEAM disciplines, students are encouraged to take conscious risks, work through experiential learning, persevere in problem-solving, embrace cooperation and communicate their ideas effectively (Leslie, 2014). This integrated approach not only boosts students' academic understanding but also strengthens their interpersonal skills and adaptive capacity. It stresses the integration of knowledge and abilities from multiple disciplines to offer students with a comprehensive and relevant educational experience according to Harris et al. (2017). This strategy develops creativity, critical thinking, problem-solving, and collaborative abilities. Moreover, Madden et al. (2013) argued that it emphasizes the significance of artistic expression, encourages interdisciplinary linkages, and prepares students for the difficult challenges that will be encountered.

2.2.5.2 Preparing Students for S.T.E.A.M-Related Careers

S.T.E.A.M education provides students with opportunity to engage in real-world experiences and authentic learning, connecting standards, methods, and practices across many disciplines (Manikutty et al., 2022). Through S.T.E.A.M education, students are able to apply their knowledge and abilities in an environment that mimics real-world difficulties and stimulates innovation and creativity. STEAM education highlights the interdependence of many disciplines and helps students to think critically, solve issues creatively, and effectively convey their ideas (Wang et al., 2022). This integrated approach, through STEAM education, attempts to offer students with a well-rounded and comprehensive learning experience that prepares them for the needs of the 21st century workforce Wang et al. (2019) added. According to various publications, STEAM education is vital in generating a composite workforce that possesses both creative and scientific capacities (Corlu et al., 2014; Harris et al., 2017; Leslie, 2014).

2.2.6 Technology and S.T.E.A.M

Technology plays a pivotal role in advancing education, particularly in S.T.E.A.M education (Ge et al., 2015; Kusdiyanti et al., 2019). It facilitates the integration of STEAM-related courses into learning environments, enabling students to develop a diverse range of skills and knowledge necessary for the 21st century (Lavicza et al., 2022). Beyond being an applied science, technology education is recognized as a valuable subject in its own right, allowing students to tackle real-world situations and cultivate critical thinking, problem-solving, and analytical skills (Scherer & Wiberg, 2018; Shatunova et al., 2019). In STEM education, technology integration enhances the learning experience, preparing students for future careers and higher education by engaging them in hands-on learning experiences that foster creativity, innovation, and design thinking (Sopapradit et al., 2022). Moreover, integrating technology into S.T.E.A.M education promotes a multidisciplinary approach to learning (Scarani et al., 2020). According to Zakaria et al. (2018), the integration of technology in S.T.E.A.M education offers various benefits for both instructors and students. For instance, students can utilize technology to gather and assess scientific data, create digital art projects, devise prototypes based on engineering principles, and apply mathematical concepts in coding and programming.

2.2.6.1 Emerging Technology and the Impact on S.T.E.A.M

There has been a growing emphasis on the integration of emerging technologies for S.T.E.A.M education in order to maximize the benefits of STEAM (Ge et al., 2015). The integration of the many disciplines according to Jumini et al. (2022), intends to improve students' abilities not only in science and technology, but also in the arts connected to creativity, innovation, and design. According to Conner et al. (2017), one of the reasons for the increased emphasis on STEAM education is the recognition of developing technologies and their impact on numerous professions. Emerging technologies have the potential to transform the way we approach education, particularly in the context of STEM education (Spector, 2015). These developing technologies include AI, VR, AR, robots, 3D printing, and coding, among others have the power to enhance and revolutionize the learning experience for students by delivering immersive, interactive, and hands-on experiences (Chun, 2021). For example, virtual reality and augmented reality can build virtual worlds where students can explore complicated subjects in a more engaging and participatory manner Chun

(2021) added. Already, according to Birt et al. (2017) the use of virtual reality in STEAM education might enhance students' grasp of complicated concepts and improve their spatial reasoning skills (Birt et al., 2017). Additionally, robotics and 3D printing can allow students to design, develop, and test their own products, encouraging a greater knowledge of engineering fundamentals (Sen, 2021). Finally, Leavy (2023) also noted that coding and AI can facilitate problem-solving and critical thinking abilities by giving students with the tools to examine data, design algorithms, and develop novel solutions (Leavy, 2023)

2.2.7 Challenges and Barriers in STEAM Education

Educators all around the globe are today faced with several challenges and opportunities in 21st-century education of which one of the primary challenges is the integration and execution of S.T.E.A.M education (Pugalee, 2022). Historically, the education system has mostly concentrated on teaching these courses in isolation, which might limit students' capacity to recognize the interconnectivity of various disciplines and impair their development of critical thinking and problem-solving skills (Caton,2021). Furthermore, the COVID-19 pandemic has brought additional hurdles to the delivery of STEAM education according to Kommers (2022). Educators have had to navigate the move to remote and hybrid learning environments, which faced issues in providing students with the hands-on and collaborative experiences that are crucial in STEAM education (Kommers, 20222; Ramey et al., 2021). Another problem in STEAM education is the lack of clear conceptualization and link between the disciplines as instructors often struggle to grasp how to successfully combine the many topic areas and develop a cohesive STEAM curriculum (Sánchez et al., 2019). According to Leavy et al. (2023), technologies hold great potential for enhancing the learning experience in STEAM education, but they also present challenges in terms of access, training, and integration into the curriculum and can be further magnified by the rapid advancement for example digital immersive technologies, such as virtual and augmented reality (Leavy et al., 2023). Furthermore, the shortage of trained STEAM teachers is a key limitation in establishing successful STEAM education programs. Without well-prepared and skilled STEAM teachers, children may not receive the essential direction and support to effectively engage in STEM learning (Boice et al., 2021). Moreover, there are frequently limitations in terms of resources and training for educators to properly apply STEAM education Shernoff et al. (2017) seconded. Also,

there are concerns relating the lack of understanding and support from school administrators and legislators, which might limit the implementation of STEAM education programmes (Spector., 2015).

2.2.7.1 Resource Constraints and Funding Issues

According to Carter et al. (2021), the implementation of STEAM education has several hurdles, particularly in terms of resource restrictions and financial issues. Various findings mentioned that issues resource limitations and financial concerns constitute substantial challenges to the efficient implementation of STEAM education (Bauer et al., 2020; Carter et al., 2021). One of the important resources needed for STEAM education is the involvement of university science and engineering departments since they play a significant role in giving expertise and assistance to STEAM teachers and students. (Carter et al., 2021; Madden et al., 2013). In addition to knowledge, laboratory facilities and learning media are equally vital tools for STEM education. However, according to Corter et al. (2011), lack of access to suitable laboratory equipment and restricted availability of learning material can hinder the delivery of hands-on, immersive learning experiences in STEM education (Aubel et al., 2022; Corter et al., 2011).

2.2.8 Gender and Diversity in S.T.E.A.M

In recent years, there has been an increasing acknowledgment of the need to address gender and diversity concerns in S.T.E.A.M education (Omamo et al., 2022). The participation and inclusion of women in STEM professions have been ongoing challenges in education and society. Numerous studies have demonstrated the persisting gender disparity in STEM education and professions (Vidal, 2022). The underrepresentation of women in STEAM disciplines persists around the world despite the development of gender equality in overall educational attainment (Ran, 2018). According to Kube et al. (2022), these issues of gender inequality in STEAM education have far-reaching consequences and one significant consequence is the perpetuation of gender stereotypes in these fields as these stereotypes create barriers for girls and women, impacting their confidence, self-perception, and interest in pursuing STEM subjects (Kube et al., 2022). Research has revealed that the misrepresentation of women in STEM domains effects future decisions in employment and education (Wang et al., 2017). Moreover, the learning experiences of girls and women in STEM disciplines have been significantly impacted by pervasive gender

stereotypes and the lack of representation (Kube et al., 2022). Research has indicated that girls and women are less likely to pursue STEM education and careers due to the absence of role models and the reinforcement of gender stereotypes in the area (Wang et al., 2017).

2.2.8.1 Encouraging Diversity and Inclusivity in S.T.E.A.M Fields

In recent years, there has been an increasing realization of the need to support diversity and inclusivity in S.T.E.A.M sectors in order to establish more equitable and prosperous scientific and technological communities (Wang, 2017). This emphasis on diversity and inclusivity is vital for a number of reasons. Firstly, cultural variety is crucial for innovation, creativity, discovery, and the growth of S.T.E.A.M (Martinez-Acosta et al., 2018). Different viewpoints and insights given by individuals from varied backgrounds might contribute to new ideas and techniques in problem-solving regarding S.T.E.A.M education according to Rushworth et al. (2021). Secondly, individuals of various identities and origins should be able to follow their hobbies and career aspirations without meeting systematic hurdles to achievement (Rushworth et al., 2021). Studies have demonstrated that diverse teams are more likely to create innovative ideas and have greater success in STEM professions (Graham, 2023).

2.2.9 Teacher Professional Development for S.T.E.A.M Education

Teacher Professional Development has become a vital part of S.T.E.A.M education as it strives to empower instructors in inspiring future S.T.E.A.M specialists (Jong et al., 2021). Professional development activities for teachers are vital in strengthening their knowledge and capacities, which in turn leads to enhanced student learning outcomes (Hee et al., 2016). Researchers have stressed the need of professional development in enhancing teachers' content knowledge and abilities relevant to S.T.E.AM education (Bush et al., 2016). However, there are obstacles and limits in the present professional development programs for S.T.E.A.M education according to Bryans-Bongey & Rosen (2019). Teacher confidence in STEAM education may be inadequate due to a lack of in-service training programs Kang, (2018) elaborated. One important issue is that many professional development programs exclusively focus on technical knowledge regarding programming and STEM material, omitting the necessary pedagogical expertise for effective teaching of those subjects (Neutens et al., 2022). Another issue is that professional development programs are generally undertaken in short-term intervals, which may not fully address the needs of teachers for ongoing

learning and growth (Mercan et al., 2024). In order to address these constraints and problems, demand-driven learning methodologies, reflective practice, and collaboration should be addressed in STEAM teacher training (Hu et al., 2024). Teachers typically find obstacles when it comes to integrating multiple disciplines into their STEM programmes (Herro et al., 2017). Therefore, professional development programs should offer teachers with the essential subject understanding in different STEAM disciplines, as well as pedagogical methodologies for instructing integrated STEM approaches (Bryan & Guzey, 2020). These tactics can assist teachers build their pedagogical competencies and enable them to effectively teach integrated STEM courses in diverse educational settings and scenarios. Furthermore, it is crucial for instructors to have opportunities to discuss their opinions, experiences, and approaches to STEM teaching (Çeliker, 2020). Overall, it was underlined that enough training and support for STEAM educators is needed to effectively implement STEAM education and without suitable training and support for STEAM educators, adopting STEAM education in schools can be hard (Tabiin, 2020).

2.2.9.1 Best Practices in Teacher Preparation

The adoption of STEAM education in schools sometimes confronts hurdles, including a shortage of resources and training for educators. These problems underline the need for sufficient training and support for STEAM educators. Providing training and support for STEAM educators is vital to overcome the hurdles and ensure the successful implementation of STEAM education (Hong, 2017). To ensure the efficient implementation of STEAM education, it is crucial to provide training and support for educators focused on equipping them with the knowledge and skills necessary to combine the different disciplines of STEAM effectively (Ryu et al., 2019). Additionally, the training and assistance should stress teamwork and actual real-world experiences for students (Mang et al., 2021). Without sufficient training and support, educators may struggle to incorporate the arts into STEM classroom or create integrated and meaningful learning experiences (Garcia-Senin et al., 2022). The interdisciplinary nature of STEAM education requires collaboration with teachers from different disciplines, which can be challenging due to cultural and disciplinary differences and to address these challenges, training and support for STEAM educators are encouraged to focus on building their knowledge and skills in integrating the arts into STEM instruction (Madden, 2013). Adding to that, providing educators with

resources, such as lesson plans and educational materials, that enable the integration of arts into STEM instruction is very crucial Madden, (2013) suggested. Furthermore, training and support should stress collaboration among educators from different disciplines, encouraging them to communicate effectively and work together to develop interdisciplinary learning experiences for students (Sochacka, 2016).

2.3 LIVING-LEARNING COMMUNITY FOR STEAM

The proliferation of living-learning communities catering to STEM and art-related courses in higher education has steadily increased over recent decades (Arensdorf et al., 2016). Institutions offering STEAM courses have recognized the potential advantages of living-learning communities in terms of improving retention rates and enriching student learning beyond traditional classroom settings (Stewart et al., 2021). Living-Learning Communities have gained popularity in higher education as a means to foster student engagement, academic achievement, and overall campus satisfaction (Inkelas et al., 2023). These communities aim to provide a supportive and immersive environment for students to live alongside peers who share similar academic interests or aspirations (Rehak, 2018). Initially, these communities primarily focused on providing a social and residential experience for students (Anderson et al., 2023). However, over time, the focus shifted towards incorporating academic components to support learning, as several studies have demonstrated the benefits of living-learning communities in enhancing student performance (Hill et al., 2013).

2.3.1 Living-Learning Communities: Background History

The concept of faculty staff and students living and learning together have a lengthy history, dating back to earlier universities where concentration was on social and residential experiences in the 1960s to their current incorporation of academic components (Caldwell, 2021). The idea was developed by John Dewey and Alexander Meiklejohn, who established experimental schools to put their theories about learning as a social process into practice (Choset, 2021; Love, 2012). Students lived, ate, and studied with their peers as well as faculty members in this "collegiate model" (Blimling, 2015), experiencing a holistic university experience similar to the goals of today's LLCs (Inkelas et al., 2018). Living-learning communities have shown to give several benefits for students, including better retention rates, improved GPAs, smoother transition to college, a sense of community and belonging, and enhanced overall student experience (Howell et al., 2023).

2.3.2 Design and Structure of Living-Learning Communities

LLCs have become increasingly prevalent in contemporary higher education, presenting challenges in precise definition due to their diverse configurations. They encompass a range of arrangements, from students residing together in a themed residence hall community to fully integrated curricula complemented by co-curricular activities aimed at reinforcing learning (Dunn & Dean, 2013). These communities strive to merge academic learning with residential life, fostering collaboration and holistic student development (Friswold, 2018). Extensive research has explored the impact of living-learning communities on student learning and growth, with university-community collaborations taking various forms, including service-learning initiatives (Howell et al., 2023; Wright, 2009). While residential colleges function as degree-granting entities, residential learning communities may incorporate linked academic experiences, with residential education programs offering academic initiatives within a residential context but with less integration between in-class and out-of-class activities (Inkelas et al., 2018, 2023). Following the initial design phase and establishment of course objectives, additional considerations, such as program oversight, faculty involvement, and resource allocation, are crucial for refining the vision of living-learning programs (Dunn & Dean, 2013; Inkelas et al., 2018). While general education settings remain popular for learning communities, there is a growing trend of expansion into other curricular domains (Matthews et al., 2012).

2.3.2.1 Curriculum Integration in Living-Learning Communities

When designing learning communities, higher education institutions must consider their specific needs, goals, and resources. (Otto et al., 2015). A successful learning community program requires management and supervision, preferably by a fulltime or parttime director; coordination with campus personnel responsible for scheduling classes and classroom space; a process for recruiting faculty; funding for faculty teams to compensate them for working together to integrate their courses; professional development for faculty to help them develop communities that reflect best practices; and coordination with campus personnel. (Otto et al., 2015). LLCs are most successful when they have a solid infrastructure foundation (e.g., goals/objectives, collaboration between academic affairs and student affairs, and adequate resources), as well as a supportive academic (and co-curricular environment e.g., study groups, social activities, career workshops (2021, Caldwell).

2.3.2.2 Living-Learning Communities Selection and Admission Criteria

In order to choose and admit students into Living-Learning Communities, institutions offering STEAM education often have particular criteria in place which typically focus on academic interests, involvement, and compatibility with the community's beliefs and aims (Stier, 2014). According to Purdie et al. (2011), academic interests play a major influence in the selection process for Living-Learning Communities. Students are often asked to specify their chosen academic or career pathways during the application process, and this information is utilised to match them with the appropriate Living-Learning Community (Purdie et al., 2011). Prior academic performance, like as grade point average and standardized test scores, may also be evaluated throughout the selection process (Stier, 2014). According to Choset (2021), Living-learning communities are aimed to bring together students who share similar academic interests or programs, creating a supportive and immersive atmosphere for learning. (Inkelas et al., 2023). Living-Learning Communities for women in STEM fields have been particularly successful and are considered a best practice (Wright et al., 2019).

2.3.3 Benefits and Outcomes of Living Learning Communities

Living-learning communities have been proven to be particularly useful for learners from underrepresented backgrounds, as they create a sense of belonging and support where students feel included and supported (Morgan et al., 2021). In research investigating student learning outcomes in college for on-campus students, Living-Learning Communities were found to boost academic performance, academic and social integration, and learning outcomes (Thomas, 2023). Living-Learning Communities have been proved to be successful in terms of increasing retention, enhancing GPAs, smoothing the transition to college, developing a sense of community and belonging, and improving the overall student experience (Howell et al., 2023). These communities are aimed to connect students with comparable academic interests or programs together, allowing them to live and learn in a friendly and collaborative atmosphere (Choset, 2021). Overall, studies and literature indicate that living-learning communities have a beneficial influence on student involvement, academic success, and overall campus experience (Inkelas et al., 2023).

2.3.3.1 Academic Performance and Achievements

LLC research focusing on individual STEM LLC programs has demonstrated that having a near peer mentor and peers going through the same struggles within their

major has a significant impact on women's persistence in STEM disciplines (Caldwell, 2021; hughes,2014). Academic initiatives such as living-learning communities are proposed for a variety of reasons including the need for an answer to a well-articulated problem. They could be in response to a student requirement or traced back to a faculty concept of creating environments in which learning occurs naturally (Dunn &Dean, 2013). Again, LLC students report being more challenged to improve basic skills and participating more heavily in courses as students often report that their peers and faculty encourage class attendance and participation, resulting in a more collaborative learning environment (Love, 2012; Naylor-Tincknell, 2016).

2.3.3.2 Social Integration and Community Building

Living Learning Communities (LLCs) aim to involve students residing in dormitories by organizing gatherings, conversations, or events that enable individuals with similar interests to come together in their university residences and connect with like-minded peers (Choset, 2021). One of the primary advantages of living-learning communities according to Eidum et al. (2023), is the potential for more regular informal interaction between faculty members and students. This intimate engagement with faculty members helps to enhance the students' academic experience and can lead to increased academic success. In addition, living-learning communities enable increased peer connection and social integration for students (Eidum et al., 2023). Furthermore, living-learning communities offer cocurricular learning activities that supplement the academic curriculum (Inkelas et al., 2023). These activities take place outside of the classroom and give students with additional opportunity to engage with their peers and apply what they have learned (Howell et al., 2023).

2.3.3.3 Retention rates and student success

Student learning communities are frequently cited as a high-impact practice in efforts to improve student success in higher education (Otto et al., 2015). Living Learning Communities have shown to improve student retention and academic performance, as well as overall college satisfaction and cognitive skills (Naylor-Tincknell, 2016). Students in learning communities, in particular, demonstrate improved academic performance, integration of academic and social experiences, gains in multiple areas of skill, competence, and knowledge, and overall satisfaction with the college experience (Otto et al., 2015).

2.3.4 Challenges and Barriers in Living-Learning Communities

The issue of diversity and inclusion within LLCs is a recurring theme in the literature. Inkelas (2023) conducted an exploratory case study, revealing challenges in creating inclusive environments that cater to diverse student populations. The study suggests that while LLCs aim to promote a sense of belonging, issues of representation and cultural responsiveness remain significant hurdles (Inkelas, 2023). The sustainability of LLCs is another area of concern where Terenzini et al. (2019) delved into the longevity and effectiveness of LLCs, identifying factors that contribute to their sustainability or potential downfall. Financial considerations, administrative support, and curricular integration emerged as critical elements influencing program sustainability (Johnson, 2020). Effective leadership and community engagement which involves not only administrative figures but also student leaders play a crucial role in shaping the community and are pivotal for the success of LLCs with literature emphasizing the need for intentional efforts to foster community engagement, creating a supportive living and learning environment (Dunn et al., 2020).

2.3.4.1 Funding and Resource Constraints

The financial and material resources allocated to LLCs play a crucial role in shaping the quality of the learning environment. Adequate funding is essential for implementing effective programming, maintaining facilities, and supporting the various components of a thriving LLC according to Inkelas et al. (2023). Studies indicate a positive correlation between the level of funding and the success of LLCs. Increased financial support allows for the implementation of innovative programs, faculty engagement, and student support services (Choset, 2021). These financial investments contribute to improved student outcomes, including academic performance and satisfaction Choset, (2021) added. LLCs often face financial challenges related to budget constraints, limiting the scope of programming and the availability of resources. Inkelas et al. (2020) found that financial constraints hindered the ability of some LLCs to offer diverse and impactful learning opportunities. Effective resource allocation is a critical aspect of managing LLCs. The literature suggests that improper allocation of resources, such as insufficient staffing or inadequate technology, can impede the community's ability to meet the diverse needs of its members (Magana et al., 2021). The sustainability of LLCs is closely tied to funding and while initial support may be secured, maintaining long-term financial

stability is a recurring challenge which encompass not only monetary resources but also the availability of physical spaces and ongoing administrative support (Inkelas et al., 2023).

2.3.4.2 Strategies to Address Funding and Resource Constraints

To mitigate financial limitations, researchers suggest exploring diverse funding sources, including partnerships with external organizations, alumni contributions, grant opportunities and diversification which helps reduce dependence on a single funding stream and enhances financial resilience (Inkelas et al., 2023). Efficient resource management involving strategic planning to ensure that available resources align with the community's goals the importance of ongoing assessments to identify resource gaps and reallocate funds to address pressing needs are also strategies that help to reduce the financial limitations (Magana et al., 2021). Collaboration with institutional stakeholders and advocacy for the importance of LLCs can contribute to increased financial and institutional support. Inkelas et al. (2023) suggested that strong collaboration with academic departments and campus leadership can enhance the visibility and perceived value of LLCs.

2.3.4.3 Faculty Involvement and Support

Faculty members serve as crucial catalysts for bridging the gap between academic and residential life within LLCs. Their involvement enhances the intellectual vibrancy of the community and contributes to a holistic educational experience (Buell et al.,2017; Haynes et al., 2012). Studies consistently highlight positive outcomes associated with faculty engagement in LLCs as research found that students who interacted with faculty in residential settings reported higher levels of academic engagement and intellectual development according to Inkelas et al. (2023). Faculty involvement has been linked to increased student satisfaction, academic achievement, and a sense of community Inkelas et al. (2023) elaborated. It was suggested that faculty may be hesitant to engage in LLCs without proper incentives and recognition as the lack of institutional support, such as tenure and the lack of promotion credit for involvement, may hinder faculty participation (Sipple et al., 2023). Faculty members may also struggle with defining their role within a residential context and may lack the training to navigate the unique challenges of living and learning spaces according to Sipple et al. (2023) who continued and clarified that expectations and providing training can address these concerns.

2.4 THE POTENTIAL OF BIOMIMICRY FOR S.T.E.A.M

This section delves into the exploration of biomimicry and its potential application in designing a Living-Learning Community STEAM Hub. Biomimicry, drawing inspiration from nature's ingenious designs and mechanisms, offers a promising avenue for creating sustainable and efficient built environments. As the exploration of the intersection of biomimicry and educational infrastructure is investigated in the context of Kyebi with its rich biodiversity, the aim is to uncover how principles derived from natural systems can inform the design of a STEAM Hub that fosters interdisciplinary learning, creativity, and environmental stewardship.

2.4.1 Overview of Biomimicry: A Background History

Biomimicry, derived from the Greek words bios meaning life, and mimesis meaning imitation, involves emulating or imitating natural forms, structures, and systems in design and construction for their demonstrated efficiency and effectiveness (Benyus, 1997; Rao, 2014; Spaho, 2011). This concept has garnered significant attention and importance in recent years for its potential to drive innovation in developing sustainable solutions and technologies (Ripley, 2016). At its core, biomimicry revolves around the idea of replicating nature's patterns, methods, and processes that have sustained life on Earth for billions of years (Polat, 2016).

The term biomimetics was coined in the 1950s by Otto Schmitt, an American inventor, engineer, and biophysicist credited with advancing the study of biophysics and pioneering the field of biomedical engineering (O'Shea et al., 2022). However, preceding Schmitt's work is the notable contribution of D'Arcy Thompson, a distinguished biologist and mathematician, who published his seminal work titled On Growth and Form in 1917 (O'Connor, 2018). Thompson argued for a deeper understanding of the influence of physics and mechanics on the shape and structure of organisms, emphasizing the interconnectedness between organic and mechanical forms. While Thompson did not propose a universal theory in biology or establish a direct causal relationship between emerging forms in engineering and those found in nature, his detailed examination of natural forms and their mathematical underpinnings has inspired a wide range of disciplines including biology, architecture, painting, and mathematics (O'Connor, 2018; Panchuk, 2006). Again, the idea of biomimicry dates back to prehistoric times, with evidence of humans watching and replicating nature's patterns and processes. For instance, Leonardo da Vinci studied the flight of birds and

used their wing structure to his designs for flying aircraft (Nkandu and Alibaba, 2018: Science Channel, 2011). While Buckminster Fuller is often credited with early contributions to the concept, it was Janine Benyus, a science writer and environmental advocate, who significantly shaped the modern understanding and formalization of biomimicry as a distinct field of inquiry and study (Mishra, 2018; Oguntona & Aigbavboa, 2018; Ripley, 2016). Her seminal work, "Biomimicry: Innovation Inspired by Nature," published in 1997, served as a cornerstone in consolidating various discoveries across disciplines such as engineering and agriculture, linking them to research on patterns and processes observed in the natural world (Benyus, 1997; O'Shea et al., 2022). Since then, the notion has gained popularity and has been implemented in different sectors such as architecture, engineering, material research, and product design. One of the fundamental components of biomimicry is the extraction and application of design concepts from nature to solve human difficulties (Hayes et al., 2020). This approach recognizes that nature has already created sustainable answers to complicated issues and tries to learn from and adapt these solutions for human innovation. Proponents of biomimicry say that by observing and analyzing the natural world, we can unearth unique tactics and design principles that can inform sustainable solutions in numerous sectors (Volstad et al., 2012).

The application of biomimicry in numerous industries has demonstrated considerable potential for generating innovation and addressing sustainability concerns (Oguntona et al, 2020). For example, in the realm of architecture, biomimicry has been utilized to create buildings that are more energy-efficient and responsive to their surroundings.

2.4.2 Biomimicry in Architecture

Benyoucef & Razin (2018) defined biomimicry as a novel engineering approach inspired by nature, utilized for innovation across diverse fields such as design, transportation, and architecture. Architecture, being an interdisciplinary field, draws influence from various aspects of natural, technological, and social sciences, with biology serving as a predominant source of inspiration. The framework of bio-inspired design has undergone significant evolution and diversification, largely propelled by advancements in computing technology and its integration into architectural practices (Chayaamor-Heil et al., 2018; Benyoucef et al., 2018). While architects of the past, including Le Corbusier, acknowledged the significance of biology in architecture and planning, their understanding often remained superficial, focusing on artistic

representations of nature's marvels rather than deeper structural insights (Pathak, 2019). However, architects have long been exploring alternative methods and analogies of growth and evolution, recognizing nature's efficiency in creating multifunctional structures. Consequently, designers and architects now actively seek to learn from nature to achieve optimized solutions (Pathak, 2019). El-Zeiny (2012) highlighted the global interest among architects and engineers in biomimicry, seeing it as a source of inspiration for innovative solutions and a means of fostering a more sustainable built environment. Moreover, El-Zeiny (2012) emphasized that biomimicry extends beyond mere replication of natural elements or systems; it involves a thorough examination of organisms or ecosystems, followed by a deliberate application of underlying design principles extracted from nature. Although the formalization of biomimetics as a scientific discipline is relatively recent, its principles and directives in architecture draw from a rich history of contributions spanning various biological and architectural domains (Jović et al., 2020).

2.4.3 Biomimicry Architecture in Ghana

In Ghana, a country rich in diverse ecosystems and wildlife, the application of biomimicry principles could offer unique opportunities for sustainable architecture that harmonizes with the local environment. By mimicking natural processes and structures found in Ghana's flora and fauna, architects can create buildings that are not only environmentally friendly but also culturally relevant (Oguntona et al., 2024). One potential area where biomimicry could be applied in Ghana is in the design of energy-efficient buildings that regulate temperature naturally, similar to how termite mounds in the region maintain stable internal temperatures (Leza, 2020). Additionally, the use of local materials and construction techniques inspired by natural forms could enhance the sustainability of architectural projects in Ghana (Aboulnaga, 2022). While there may be limited specific literature on biomimicry architecture in Ghana, the country's rich biodiversity and environmental challenges present a compelling case for further exploration of this innovative approach. Future research could focus on case studies or pilot projects that demonstrate the practical application of biomimicry principles in Ghanaian architecture, contributing to the country's sustainable development goals and environmental conservation efforts (Ahenkan et al.,2015).

2.4.4 Biomimetic Approaches to Architecture

A comparative literature analysis and examination of existing biomimetic technologies was conducted by M. Pedersen Zari at Victoria University in New Zealand in 2007 (Zari, 2017). According to El Ahmar (2011), various methods for biomimetic design exist, each with inherent advantages and disadvantages. These different approaches may yield significantly different outcomes in terms of overall sustainability. While some designers and scientists utilize biomimicry specifically to enhance the sustainability of their creations, in certain cases, biomimicry is merely employed as a source of novel innovation (Heyes, 2020; El Ahmar, 2011). As noted by Reap (2009), adopting a biomimetic design approach does not guarantee that the resulting product or material will be more sustainable than a conventional counterpart when evaluated from a life cycle perspective (Bar-Cohen et al., 2012; Reap, 2009). Approaches to biomimicry as a design process often categorize into two main categories: Problem-Based Approach and Solution-Based Approach (El-Ahmar, 2011; El-Zeiny et al., 2012).

2.4.4.1 Problem-Based Approach

In architecture, biomimicry serves as a problem-solving methodology for addressing diverse design challenges (Helbing, 2013). According to Fried et al. (2020), the problem-based approach in biomimicry entails identifying specific design challenges and examining how organisms or ecosystems overcome them (El-Zeiny et al., 2012; Fried et al., 2020). This approach involves defining goals and design constraints, with designers initially pinpointing the problem and then seeking biological solutions (Fried et al., 2020; Qureshi, 2022). Throughout the literature review, several terms were discovered to describe this approach, such as "Design inspired by biology" (Pedersen Zari, M., 2020), "Top-down Approach" (Verbrugghe, 2023), and "Problem-Driven Biologically Inspired Design" (Michael Helms, Swaroop S. Vattam, and Ashok K. Goel, 2009), all indicating the same concept. Figure 2.1 illustrates the steps involved in this process. The problem-based approach in biomimicry has found application in various architectural projects aimed at achieving sustainable building design. For example, a study utilized the problem-based approach methodology by identifying building behavior architectural objectives as problems and then exploring biological systems for solutions (Yen & Chang, 2018).

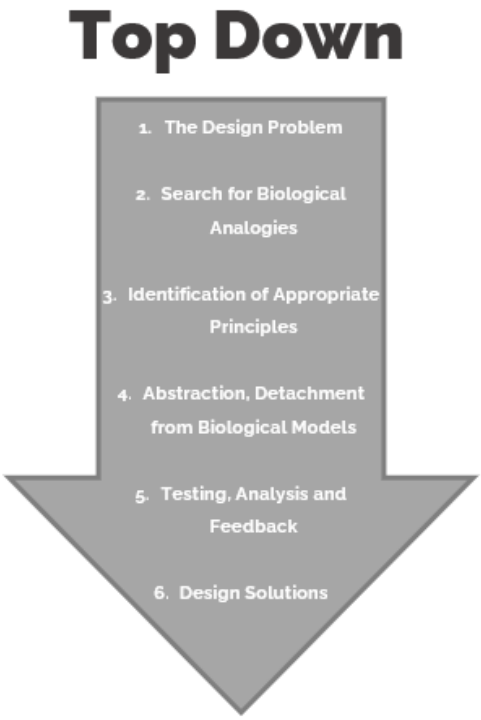


Figure 2.1Top-Down Design Approach to Biomimicry (El- Ahmar, 2011**)**

The study categorized the biological domain into two phases: an experimental phase that simulated the selected biological role model according to the selected life principles and an abstraction phase that selected the specific performance of the biological role model and implemented it in the architectural domain in the prototype phase as an architectural element such as envelope, structure, building systems, interior elements, and materials (El-Ahmar, 2011). An instance of this is the Curved Spiral Shell House (Figure 2.2) designed by Senosiain Arquitectos, drawing inspiration from a sea shell. Within the dwelling, the unconventional shapes of the exterior extend seamlessly through each space, creating a sense of continuity. The interior resembles an outdoor environment, featuring abundant plant life, organic patterns, and meandering stone paths. While the design replicates the shapes, patterns, and colors found in nature, offering potential sustainability benefits such as earthquake resistance and low maintenance, it does not fully embody biomimicry principles.



Figure 2.2 Spiral shell house, by Senosiain Arquitectos (El-Zeiny et al, 2012)

The problem-based approach in biomimicry has found application in interior architecture as well. While interior architecture often incorporates biological shapes, it must go beyond mere imitation and integrate biological principles (Manzini, 2015). A study explored various applications of biomimicry in interior architecture, emphasizing the need for a deeper integration of biological concepts (Olusegun et al., 2018).

Recognized as a valuable methodology in both architecture and interior design, the problem-based approach entails identifying specific design challenges and studying how organisms address similar problems in nature (El-Zeiny, 2012). This approach has been employed in numerous architectural projects to foster sustainable building design, showcasing biomimicry's potential in addressing design hurdles and promoting sustainable building practices. However, despite these advancements, the broader adoption of biomimicry as a design strategy remains limited (El-Ahmar, 2011). Further research is required to fully unlock the potential of biomimicry in both architecture and interior design.

2.4.4.1.1 The Biomimicry Design Spiral

The Biomimicry Design Spiral is a methodology that serves as a systematic approach to design inspired by nature. This approach involves distillation, translation, discovery, emulation, and evaluation, providing a structured framework for applying biomimicry in various design contexts (Alanbari et al., 2022). The Biomimicry Design Spiral is based on the principle of learning from nature and translating biological solutions into innovative design concepts (Benyus, 1997). It emphasizes the importance of understanding and mimicking natural systems to create sustainable and efficient design solutions (Bar-Cohen, 2012). Several studies have highlighted the significance of the Biomimicry Design Spiral in guiding the design process. For instance, a study by Hastrich (2005) emphasized the systematic nature of the Biomimicry Design Spiral as a valuable tool for solving design issues holistically (Gamage et al., 2012). The study

demonstrated how this approach can help address design challenges comprehensively by drawing inspiration from biological systems (Bar-Cohen, 2016).

Moreover, the Biomimicry Design Spiral has been applied in various fields. The Biomimicry Design Spiral, Illustrated in Figure 2.3, serves as a framework for addressing known design challenges.

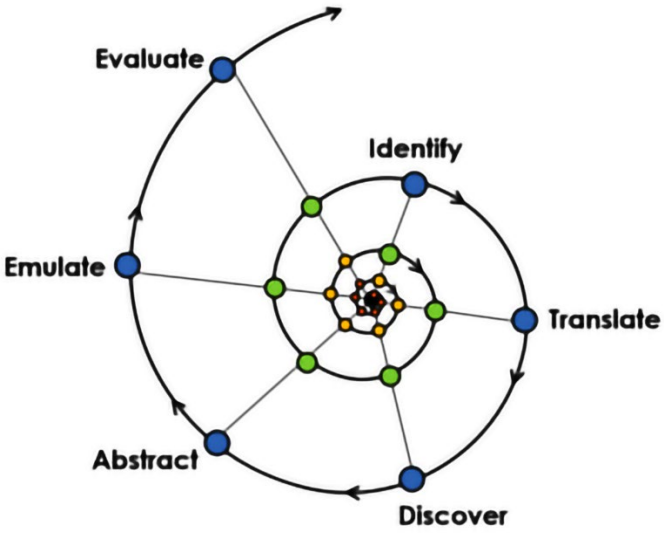


Figure 2.3 The Design Spiral by Biomimicry Institute (Carl Hastrich, 2005)

It begins with the Identify phase, aimed at pinpointing the necessary functions of the design. Following this, functions are Translated into terms applicable in the biological realm. The process then delves into Discovering strategies employed by nature to fulfill these functions, a hallmark of biomimicry. In the Abstract phase, these strategies are reverse-engineered and elucidated in terms relevant to the design profession. Subsequently, the Emulate stage involves leveraging professional expertise to devise a design solution inspired by the identified strategies. Lastly, the Evaluate step entails assessing the design solution against the original design brief and aligning it with Nature's Unifying Patterns, guiding principles for sustainability.

Yang et al. (2019) presented a case study where nature-inspired design was successfully used to develop viable product concepts, showcasing the practical application of the Biomimicry Design Spiral in the industry.

In conclusion, the Biomimicry Design Spiral serves as a valuable framework for integrating nature-inspired solutions into the design process. By following the steps of distillation, translation, discovery, emulation, and evaluation, designers can leverage the principles of biomimicry to develop innovative and sustainable design solutions across various disciplines. The systematic nature of the Biomimicry Design Spiral

provides a structured approach to biomimicry design, enabling designers to harness the efficiency and resilience of natural systems in their creations.

2.4.4.2 Solution-Based Approach

The solution-based design approach within biomimicry architecture involves identifying specific characteristics, behaviors, or functions in organisms or ecosystems and leveraging them to tackle design challenges. This methodology, also known as the "Biology to Design" approach, or the Bottom-Up approach (Jean Knippers, 2009, Nkandu et al., 2018) emphasizes using biological principles as sources for design innovation. The steps according to Nkandu et al., 2018 involved in the process are illustrated in Figure 2.4. Research conducted at the Georgia Institute of Technology by Michael Helms, Swaroop S. Vattam, and Ashok K. Goel at the Design Intelligence Lab in 2006 outlined a structured approach comprising seven distinct steps:

1. **Biological solution identification:** Designers initiate the process by identifying a specific biological solution.
2. **Define the biological solution:** This step involves clearly defining the identified biological solution.
3. **Principle extraction:** Extracting the underlying principles governing the biological solution.
4. **Reframe the solution:** Designers are prompted to reframe the solution to consider how humans perceive the utility of the biological function achieved.
5. **Problem search:** Unlike the search process in the biological domain, problem search here may involve defining entirely novel problems, diverging from the solution search step in the problem-driven process.
6. **Problem definition:** Defining the problem based on the identified biological principles and reframed solution.
7. **Principle application:** Finally, applying the extracted principles to develop innovative solutions to the defined problems.

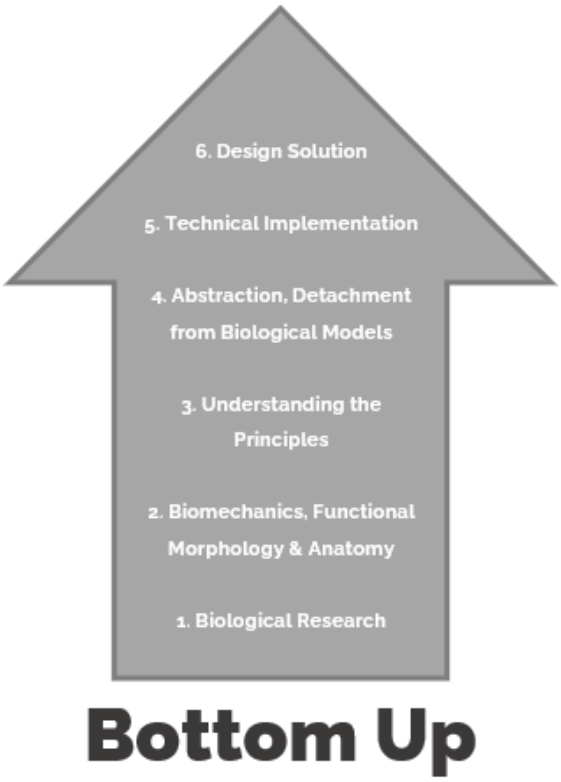


Figure 2.4 Bottom-Up Design Approach to Biomimicry (El- Ahmar, 2011)

Research by Aldersey-Williams (2004) reviews several case studies of biomimetic architectural design, showcasing the application of solution-based processes in deriving innovative design solutions inspired by nature (Uchiyama et al, 2020). A study by Vattam, Helms, and Goel (2007) delves into the problem-driven and solution-based design processes in biologically inspired design. The research provides insights into the iterative nature of the solution-based approach, emphasizing the dynamic and non-linear progression of steps involved in deriving design solutions from biological systems.

The solution-based design approach in biomimicry architecture offers a structured and innovative methodology for integrating nature-inspired solutions into architectural design. By leveraging biological principles and solutions, architects can create sustainable and efficient buildings that harmonize with the environment. The research by Vattam, Helms, and Goel (2007), and Hala S. Aamer et al. (2020) provides valuable insights into the application of solution-based processes in biomimicry architecture, highlighting the potential for creativity and innovation in sustainable design practices.

2.4.5 Levels of Biomimicry in Architecture

Biomimicry serves as a source of inspiration for architecture in three main dimensions: organism (mimicking natural forms), behavior (emulating natural processes), and ecosystem (imitating the functioning principles of ecosystems) as outlined by Jamei et al. (2021). However, the essence of biomimicry lies not merely in replicating nature but in understanding its underlying principles to address analogous technological challenges through optimized technologies (Amer, 2019; Ramzy, 2015). Learning about nature differs from learning from nature, highlighting the distinction between passive observation and active adaptation (El-Zeiny, 2012).

The framework discussed encompasses both design approaches: those directly inspired by biology and those where biological principles inform design decisions. The initial phase of this framework involves identifying the specific aspect of biology being replicated, termed here as a "level" (Pedersen Zari, M. 2007). Figure 2.5 illustrates the different levels within this framework.

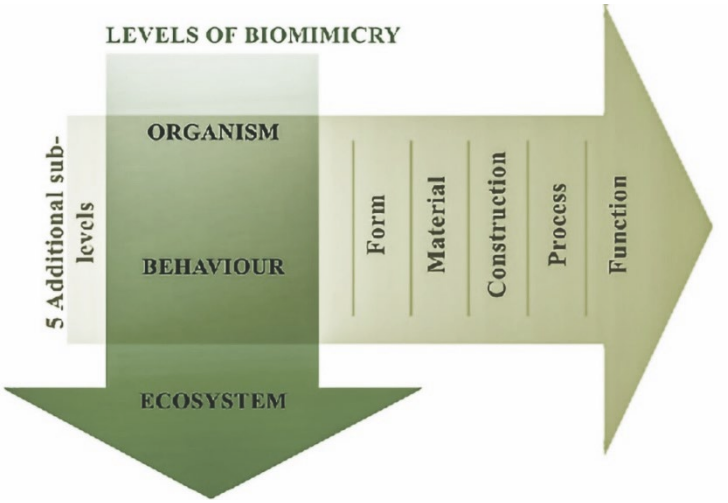


Figure 2.5 Levels of Biomimicry (Pedersen Zari, M. 2007)

An analysis of current biomimetic technologies reveals three distinct levels of mimicry: organism, behavior, and ecosystem. The organism level involves replicating specific organisms such as plants or animals, either in part or in entirety. The behavior level entails mimicking the actions or interactions of organisms within their environment. Lastly, the ecosystem level involves replicating entire ecosystems and the underlying principles that enable their successful functioning (Nkandu et al., 2018; Pedersen Zari, M. 2007).

2.4.5.1 Organism Level

At the organism level, biomimicry refers to mimicking a specified organism to emulate its characteristics, behaviors, or functions in design. This level of biomimicry is particularly relevant in architectural design, where the study of specific biological features of organisms can provide insights for creating sustainable and efficient buildings and urban environments (Pathak, 2019; Verbrugghe et al., 2023).

The literature on biomimicry has highlighted several examples of organism-level biomimicry in architectural design. For instance, the Gherkin Tower in London was inspired by the Venus Flower Basket, a deep-sea sponge with a cylindrical form and hexagonal grid structure that provides structural stability and handles wind forces efficiently (Brodrick, 2020).



Figure 2.6 The Gherkins Tower [Left] in London, UK, was inspired by the Venus' flower basket (Euplectella aspergillum) [Right] (Source: Google.com)

Architect Norman Foster designed the 2003 structure, taking inspiration from the Venus' flower basket, a species of Pacific marine sponge known as Euplectella aspergillum. The building's design replicates the shape of this sponge to harness several passive ventilation strategies, including wind deflection and ventilation through open shafts beneath each floor. Additionally, these shafts serve to release warm air in the summer, absorb solar heat to contribute to heating the structure, and illuminate various interior spaces (Primrose, 2020).

2.4.5.2 Behavioral Level

At the behavioral level, biomimicry architecture focuses on the study of the behaviors and patterns of organisms and ecosystems to develop innovative solutions for architectural design. One study by Smith et al. (2018) examines the relationship between biophilic and biomimetic approaches to architectural design as two aspects of bio-inspired design. The study argues that biomimetic design should not only be inspired by the form of nature but also by its processes and behaviors. Smith et al. (2018) further elaborate that while the organism level focuses on the characteristics and functions of individual organisms, the behavior level focuses on the patterns and processes of organisms and ecosystems. Many organisms face similar environmental challenges and need to find solutions just like humans do (Zari et al., 2020). According to Pedersen et al. (2020), these organisms operate within the environmental limits of their habitats and adapt to ecological niches, evolving both in terms of their physical characteristics and their behaviors. Organisms that play a significant role in altering habitats, either directly or indirectly influencing resource flow and environmental conditions, are known as ecosystem engineers (Pedersen, 2020). These engineers can modify habitats through their own structures or through various mechanisms. Humans are considered prominent ecosystem engineers, but studying how other species modify their environments can provide valuable insights for improving our own environmental practices stated by El-Ahmar (2011). Ecosystem engineers that alter habitat either through their own structure (such as coral) or by mechanical or other means such as beavers and woodpeckers illustrated in the Figure 2.7.

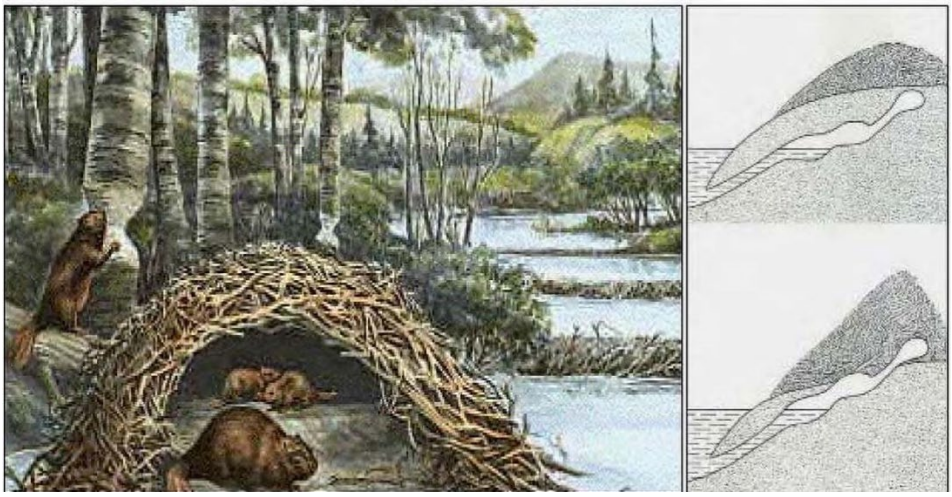


Figure 2.7 The North American beaver (Source: Pedersen Zari, M. 2007)

In a study conducted by Johnson and Lee (2020) regarding the application of biomimicry levels in design, it was discovered that only the organism level is commonly utilized for architectural solutions among the three levels of biomimicry application. The application of the other two levels remains largely unexplored. The study emphasizes the necessity to comprehend the underlying science and design phenomenology and shift away from conventional design methodologies towards more sustainable and innovative approaches.

Moreover, Brown and White (2019) delve into the utilization of biomimicry as an innovation behavior in architecture and interior design. They contend that biomimicry can lead to sustainable and innovative solutions for architectural design by imitating nature and drawing inspiration from it. An illustrative instance is the Beijing Bird Nest Stadium, showcased in Figure 2.8. The stadium's design exemplifies biomimicry as it draws inspiration from the natural form of a bird's nest.

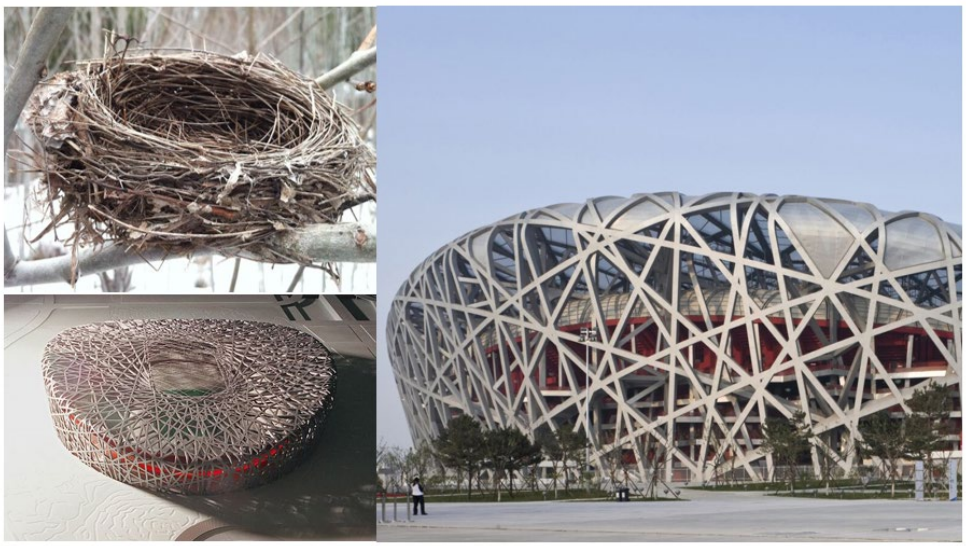


Figure 2.8 Beijing Bird's Nest stadium (Pinterest.com**)**

The stadium's design reflects the idea of nature's protection and care, while also providing a functional and sustainable space for sports and entertainment. Stadium's design is not only aesthetically pleasing but also functional, as it is designed to withstand earthquakes and also has sustainable features that make it a marvel of modern engineering.

The behavioral level of biomimicry architecture focuses on the study of the behaviors and patterns of organisms and ecosystems to develop innovative solutions for architectural design. To create designs inspired by nature, it is essential to integrate and apply the organism, behavior, and ecosystem levels in design. Biomimicry can

lead to sustainable and innovative solutions for architectural design by imitating nature and using it as a source of inspiration.

2.4.5.3 Ecosystem Level

The ecosystem level of biomimicry in architecture involves emulating entire ecosystems and their fundamental principles to serve as a foundation for design (Benyus, 1997; Dicks, 2017). This aspect of biomimicry is gaining traction in architecture and engineering due to its potential for innovation and sustainability (Dicks, 2017). Ecomimicry, as defined by various sources such as Abaeian et al. (2016), encompasses the imitation of ecosystems in design practices. Marshall (2007), on the other hand, interprets ecomimicry as a sustainable approach to biomimicry, prioritizing the well-being of both ecosystems and people over pursuits of power or profit. Moreover, proponents advocating for a shift towards regenerative design emphasize the importance of architectural approaches rooted in ecological principles (Blanco, 2021; Zari, 2018).

Ecomimicry, according to Maglic (2012), involves identifying natural elements and features to achieve results akin to those existing in the ecosystem of the design context (Maglic, 2012). Generally, inspiration from natural ecosystems can be categorized into two levels: the functional level (what do they do?) and the processual level (how do they do it?), as outlined by Zari (2018; 2020). The functional level enables the designer to understand which aspects of the local environment must be considered to ensure the designed structure harmonizes with its surroundings (Zari, 2018).

One advantage of operating within this type of biomimicry is its compatibility with other biomimetic levels, including organism and behavior (El Ahmar, 2011). Additionally, it allows for the integration of established sustainable building techniques not inherently biomimetic, such as interfaced or bio-assisted systems. These systems combine human and non-human components to mutually beneficial ends (El-Ahmar, 2011). For example, John and Nancy Todd's Living or Eco Machines replicate the natural process of wastewater treatment within ecosystems and incorporate plant integration (Gago et al., 2015).

Another benefit of this biomimetic approach lies in its potential to enhance overall environmental performance. Ecosystem-based biomimicry operates on both a metaphorical and practical functional level. Metaphorically, it enables designers to apply general ecosystem principles, even with limited ecological knowledge. Various

authors have delineated such overarching principles (Gago et al., 2015). Additionally, a comprehensive set of ecosystem principles, derived from interdisciplinary insights, is presented by Pedersen Zari and Storey (2007). By conceptualizing the built environment as a system mirroring ecosystem behavior, albeit metaphorically, there is potential to enhance its environmental performance (El-Ahmar, 2011).

An example of this approach is the Eastgate Centre in Harare, Zimbabwe (Figure 2.9), which drew inspiration from termite mounds and their modifications to their ecosystem. The concept was adapted for the Eastgate building to regulate temperature through natural ventilation and airflow, offering a sustainable cooling system for the structure (Pathak, 2019).

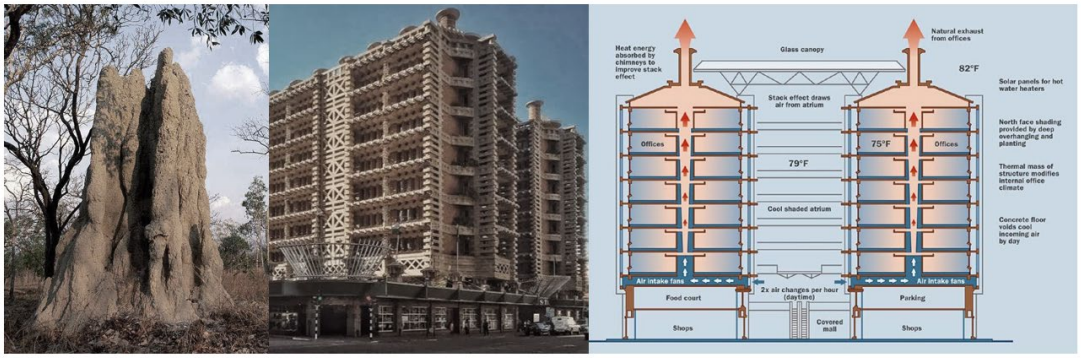


Figure 2.9 The termite mound ventilation system and the application for the Eastgate Building (https://journals.openedition.org/craup/309).

Partly inspired by ventilation and temperature regulation mechanisms observed in termite mounds, the Eastgate Centre employs passive ventilation to maintain a stable thermal environment indoors, significantly reducing energy consumption.

The ecosystem level of biomimicry in architecture holds promise for developing sustainable and innovative solutions for building behavior. By mimicking entire ecosystems and their fundamental principles, architects can design buildings that harmonize with nature and support the restoration and regeneration of ecosystems (El Ahmar, 2011).

2.4.6 Principles of Biomimicry in Architecture

Biomimicry usually applies biological principles and systems to address design challenges through the creation of materials, products, or processes according to Pawlyn (2019). In architecture, biomimicry is used to model the design of materials, structures, and systems on biological processes. The principles of biomimicry in architecture aim to enhance sustainability by emulating nature as a model and a

measure (El-Zeiny, 2012; Pawlyn, 2019). Some selected biomimicry principles were studied in the subsequent sections.

2.4.6.1 Nature as a Model

Architecture replicates the functions, shapes, and components found in nature to address challenges related to sustainability, efficiency, strength, durability, and other aspects according to Spaho (2011). Nature provides abundant examples of solutions to these challenges, developed over billions of years. These natural designs are intricately adapted to their surroundings and are optimized for energy and material efficiency as solutions to many of our design queries are likely embedded within the surrounding natural environment (Karana et al., 2019; Maglic, 2012).

2.4.6.2 Nature's Forms

Biomimicry in architecture presents a promising avenue for sustainable and efficient design by imitating the forms, processes, and systems found in nature. It is essential in biomimetic architecture to comprehend the biological role models in building behavior and ensure that the design effectively incorporates the mimicry of these biological role models, as emphasized by Spaho (2011) and Bhatia et al. (2018). Architecture that mimics natural forms underscores the extraction of structural properties inherent in these forms. Spaho (2011) continued to argue that natural structures have evolved over billions of years, demonstrating an unparalleled level of refinement through iterative processes and that present-day living structures embody nature's triumphs, with unsuccessful iterations fading into oblivion (Bhatia et al., 2018). These extant natural exemplars showcase a diverse array of resourceful materials and structural configurations capable of responding to various climatic and environmental pressures. These superior designs play a pivotal role in informing our architectural progress.

2.4.6.2.1 The Sea Urchin

The sea urchin has served as a source of inspiration for both simplistic biomorphic designs and comprehensive biomimetic architecture. Its skeletal structure, known as a 'test,' comprises interlocking plates called 'ossicles,' as seen in the Figure 2.10b, each resembling a single calcite crystal. If solid, calcite would be weighty, but the ossicles possess a porous, lightweight, and rigid composition due to their sponge-like structure (Figure 2.10a), resulting in increased effective thickness.

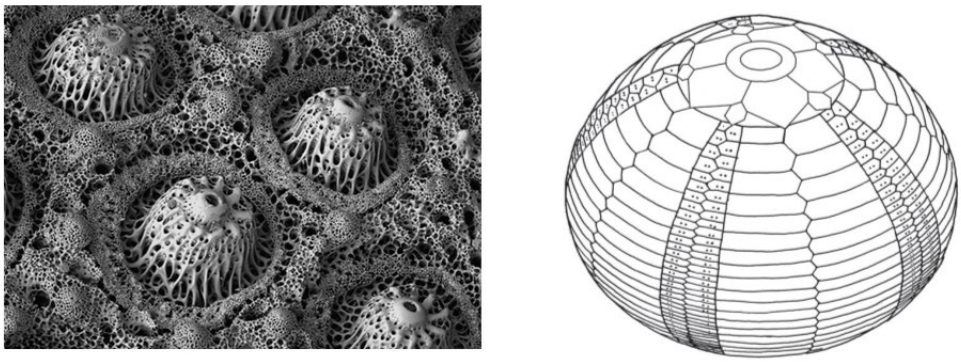


Figure 2.10 (a) (a) A close-up image of a sea urchin skeleton showing its porous and lightweight structure, (b) Structure of a sea urchin skeleton, which comprises interlocking plates made from calcite crystals. (Source: Pawlyn, 2019)

While the Doughnut House by Future Systems (Figure 2.11) drew visual cues from sea urchin skeletons, its functional structure differed significantly from that of the marine organism. In contrast, the Landesgartenschau Exhibition Hall at the University of Stuttgart in Germany (Figure 2.12) closely emulated the structure of a sea urchin, representing a pinnacle of biomimetic architecture research.

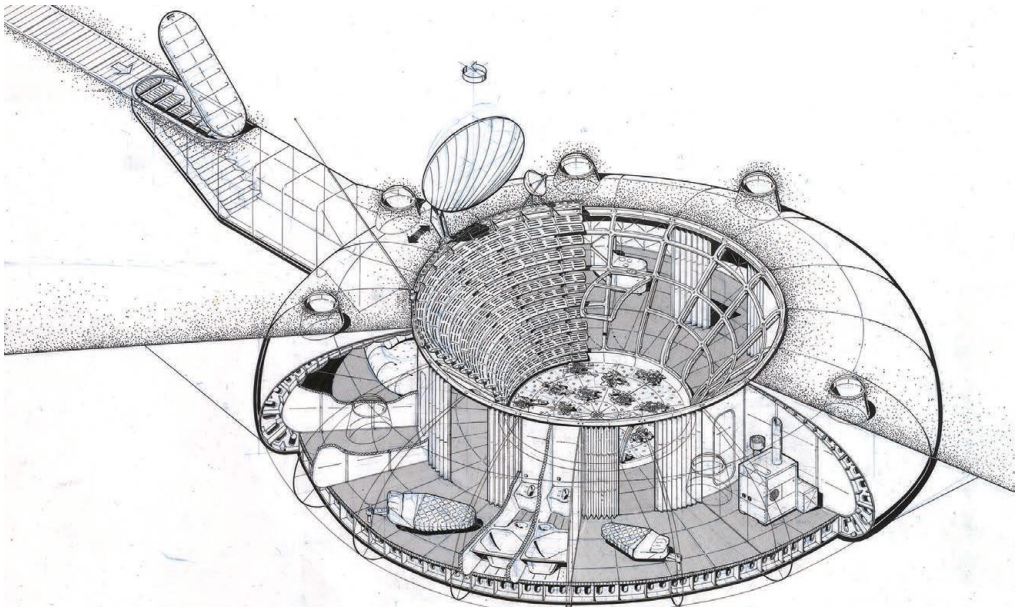


Figure 2.11 The Doughnut House by Future System – Biomorphic rather than Biomimetics (Source: Pawlyn, 2019)

This project, a collaboration between the Institute for Computational Design (ICD) led by Prof. Menges, the Institute of Building Structures & Structural Design (ITKE) led by Prof. Knippers, and the Institute of Engineering Geodesy (IIGS) led by Prof. Schwieger, drew inspiration from the interlocking ossicles of sea urchins. Constructed

from 50 mm thick plywood panels intricately connected with precise finger joints, the building exemplifies the geometric complexity observed in natural biological structures (Pawlyn, 2019).



Figure 2.12 Landesgartenschau Exhibition Hall at the University of Stuttgart – Based on the Structure of a Sea Urchin Skeleton (Source: Pawlyn, 2019)

Computational design played a crucial role in resolving this complexity to achieve the optimal form, with each panel prefabricated robotically. Despite covering an area of 250 m2, the structure boasts a relative thinness akin to that of an eggshell.

2.4.6.3 Nature's Function

Architecture emulating natural functions underscores the extraction of specific or multiple functions from nature's instances, integrating them into architectural design. These functions are harnessed to address site-specific conditions, climate variations, energy usage, and other considerations, prioritizing environmental preservation and non-pollution. Functional biomimicry influences design choices concerning form, alignment, and material preference, shaping architectural solutions (Pawlyn, 2019; Spaho, 2011).

2.4.6.3.1 Case Study: Soap Bubbles

The Eden Project (Figure 2.13), envisioned by Grimshaw, exemplifies a project that extensively tapped into biological solutions across various stages of development, from initial site assessment to strategic shaping and detailed design. Initially conceived as the world's largest greenhouse, the project faced challenges due to the site's unstable nature, situated within an active china clay pit.



Figure 2.13 Image of the Edens Project in Cornwall, England

(Source: Google.com)

To address uncertainties regarding the site's ultimate configuration, biomimicry played a pivotal role throughout the design process. Solar analysis identified the most advantageous areas for habitation, particularly the south-facing quarry walls, which could absorb and emit solar heat, thereby reducing the need for additional heating. The irregular topography and uncertain ground levels rendered conventional rectilinear designs impractical. Inspired by the structure of soap bubbles, team member David Kirkland proposed a groundbreaking solution: a series of variably sized bubbles inspired by soap bubbles interconnected along a flexible line, mimicking the site's approximate topography (Figure 2.14).

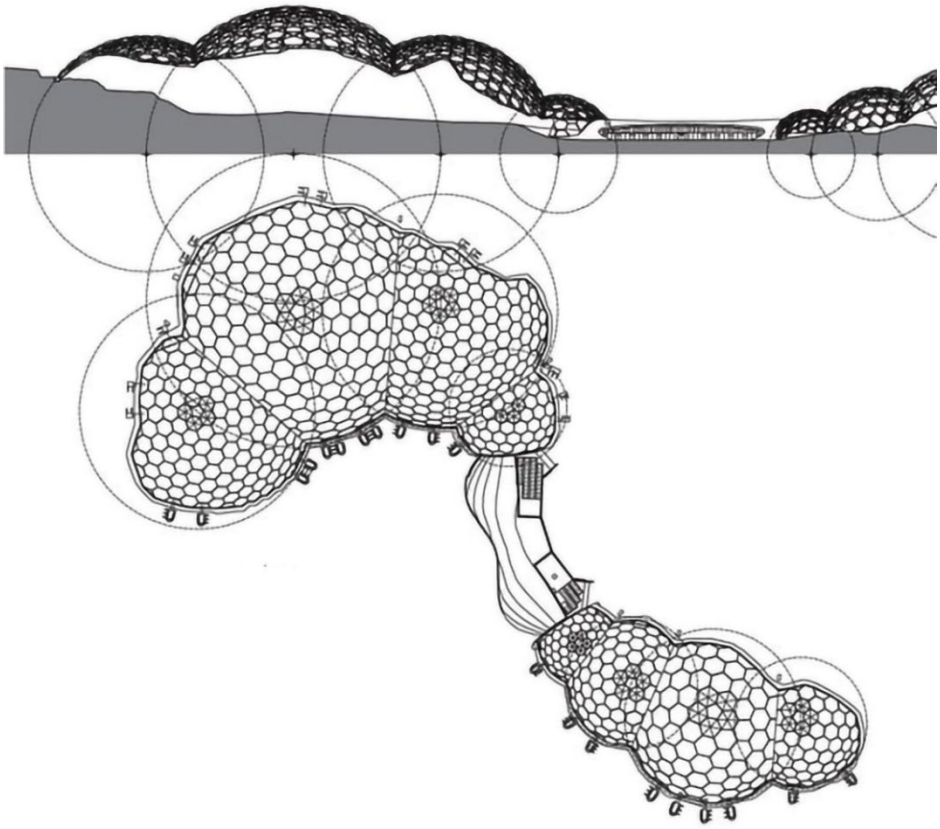


Figure 2.14 Schematic Site section and Plan of the Eden's Project (Spaho, 2011)

Through iterative experimentation with bubble arrangements, embedded within 3D terrain models (Figure 2.15), the team gradually converged on a design that mirrored the final scheme.

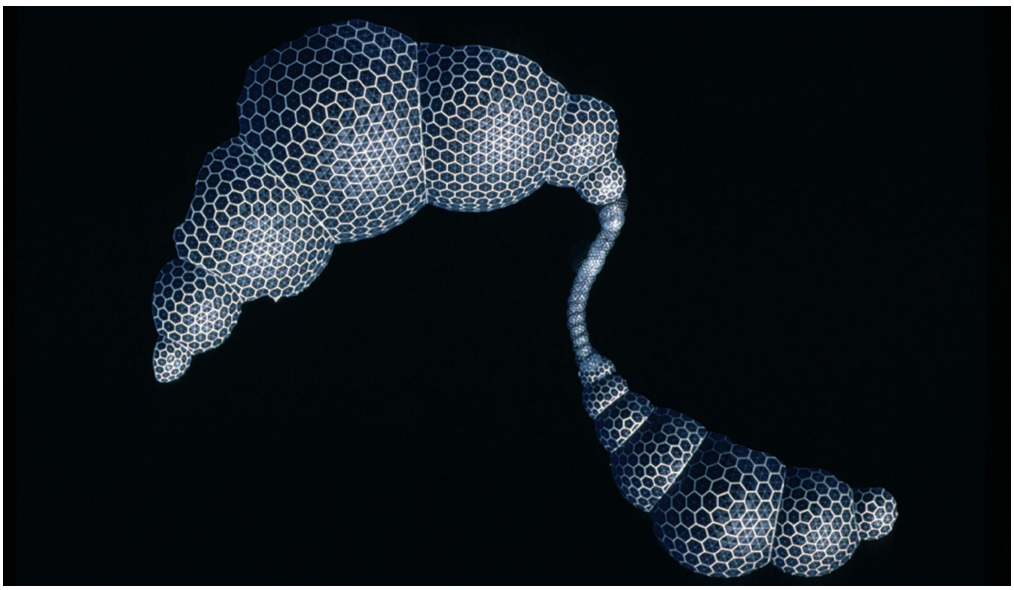


Figure 2.15 Computer-generated image showing the sections of Geodesic Structure of the Bubbles that Protruded above ground (Source: Pawlyn, 2019)

Subsequently, efforts focused on achieving optimal structural efficiency, drawing insights from natural examples ranging from carbon molecules and radiolaria through to pollen grains (Figure 2.16).

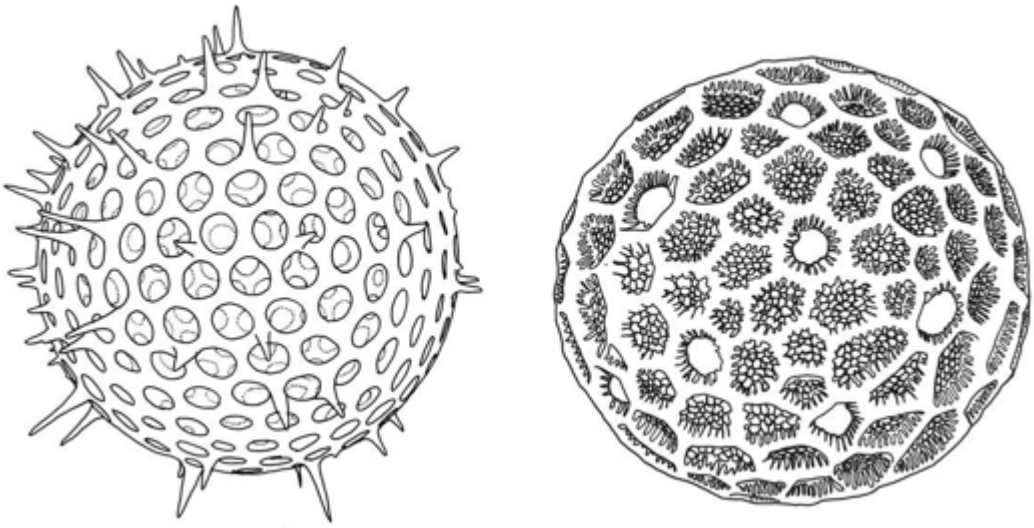


Figure 2.16 (a) Radiolarian structure (b) Pollen grain showing a geodesic structure (Source: Pawlyn, 2019)

This exploration led to the adoption of geodesic arrangements of pentagons and hexagons, pioneered by Richard Buckminster Fuller, renowned for his groundbreaking work in structural engineering. The design process commenced with conservative structural assumptions, which were subsequently refined through wind tunnel testing of scale models to ascertain wind loading (Pawlyn, 2019).

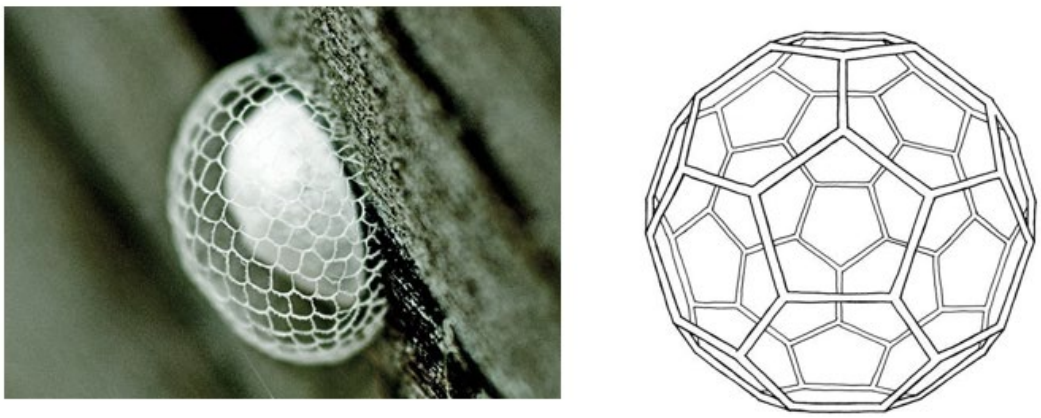


Figure 2.17(a) Protective enclosure formed by the Sisyridae sponge-fly (b) A carbon molecule known as a Buckminster Fullerene (Source: Pawlyn, 2019)

A pivotal aspect of this refinement involved maximizing the size of hexagonal elements to enhance light penetration. Due to limitations posed by glass, both in terms

of unit size and weight, alternative materials were explored, including ethylene tetrafluoroethylene (ETFE), a high-strength polymer (Figure 2.18).



Figure 2.18 ETFE pillows (Source: Google.com)

ETFE, capable of being formed into lightweight cladding elements through welding and inflation, represented a departure from conventional rigid materials, drawing parallels with Buckminster Fuller's pioneering work on inflatable structures. ETFE offered significant advantages over glass, weighing only 1% as much and enabling the creation of larger "pillows" than standard glass sheets. Thorough material testing enabled the enclosure design to be tailored to site-specific conditions, resulting in a positive feedback loop of design innovation (Spaho, 2011).

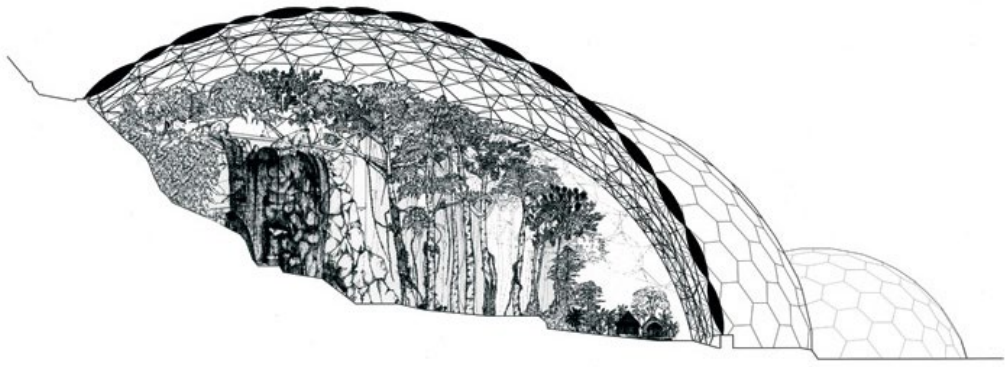


Figure 2.19 Cross section of Eden project (Spaho, 2011)

Achieving breakthroughs in material efficiency, such as larger pillows reducing steel usage, facilitated reductions in resource consumption and cost, yielding a scheme that utilized a fraction of conventional resources and incurred significantly lower construction expenses. Moreover, the biome's superstructure weight was less than the air it enclosed, reflecting a remarkable achievement in resource optimization. (Spaho, 2011). With advancements in materials technology and insights gleaned from biology,

further strides in resource efficiency could be anticipated in future endeavors. For instance, emerging technologies like 3D printing hold promise for manufacturing steel tubes with optimized stress distribution, mirroring biological principles of material utilization.



Figure 2.20 Interior of the Humid Tropics Biome (Source: Google.com)

Unlike historical precedents characterized by domineering architectural interventions, the biomimetic approach embraced by the Eden Project fostered a more harmonious relationship with the landscape. The biomes, accommodating the site's existing topography with minimal excavation, symbolize a more respectful coexistence between human activities and the natural environment (Spaho, 2011).

2.4.6.4 Nature's Parts

Creating architectural designs inspired by nature involves identifying structural, formal, or functional characteristics from natural phenomena and incorporating them into particular building elements (Spaho, 2011). This process might involve completely replacing building skins and mechanical systems or adding an extra layer to existing structures. The primary goal is to elevate building performance, resulting in enhanced efficiency and harmonious integration with the surrounding environment.

2.4.6.4.1 Skeletons

While bamboo exemplifies straightforward tubular structural engineering, bones offer a more intricate study. Bones often exhibit mechanisms for resolving asymmetrical forces. In Figure 2.21a, the stress lines in a femur are depicted, while Figure 2.21b presents an X-ray image of the same bone.

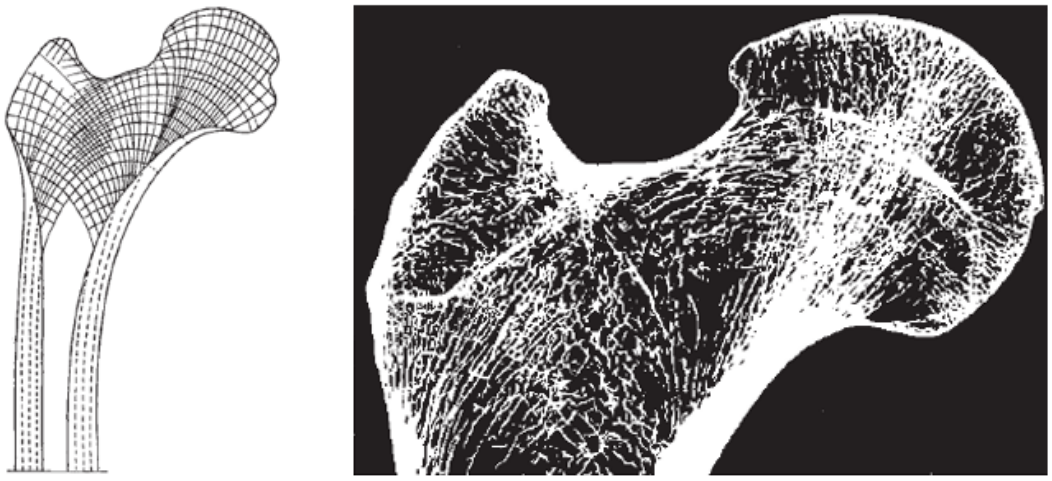


Figure 2.21 (a) Diagram showing the lines of stress passing through a bone+ (b) X-ray through a bone showing the arrangement of bony trabeculae
(Source: Pawlyn, 2019)

Pawlyn (2019) highlights the precise correlation between the density of bone filaments and stress concentration, where areas experiencing high stress exhibit a proliferation of material, while voids are present elsewhere. D'Arcy Wentworth Thompson's seminal 1917 work "On Growth and Form" extensively documented such observations, noting, for instance, the similarity between a vulture's metacarpal (Figure 2.22) and a Warren truss, as Pawlyn (2019) stated. Vultures, subjected to intense selective pressure to achieve high strength with minimal weight, demonstrate remarkable adaptations.



Figure 2.22 Vulture's metacarpal, which is effectively identical to a Warren truss (Source: Pawlyn, 2019)

Birds, overall, have evolved in response to weight-related selective pressures, with various species showcasing different interpretations of the principle "materials are expensive and shape is cheap." Avian skulls (Figure 2.23), such as those of crows and

magpies, serve as engineering marvels, wherein the effective thickness of the skull is increased while reducing weight (Pawlyn, 2019).

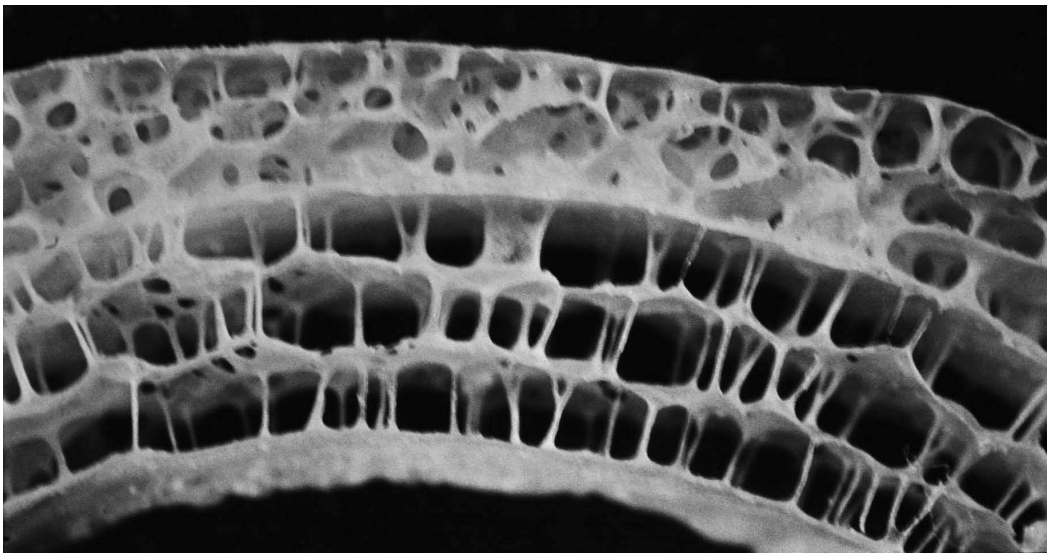


Figure 2.23 Section through the skull of a magpie showing thin domes of bone connected together with struts and ties (Source: Pawlyn, 2019)

This structure resembles a space-frame, with two layers of structural members connected by struts and ties, further enhanced by adopting a dome shape for increased efficiency. Architect Andres Harris drew inspiration from this principle for a canopy structure, leveraging a comprehensive understanding of how bone tissue forms around pressurized cells, creating air voids between solid surfaces (Mohammed, 2019; Pawlyn, 2016). This insight suggests the possibility of constructing the canopy in a manner akin to nature, utilizing a network of inflated void formers around which suitable materials could be cast.

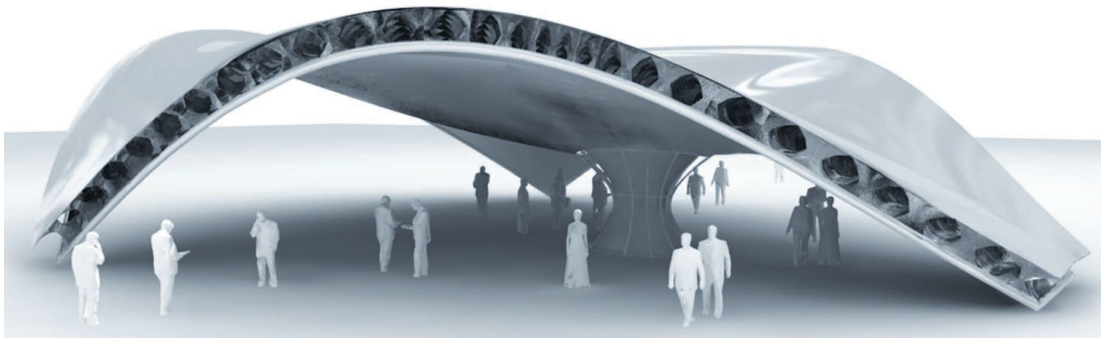


Figure 2.24 Canopy structure designed by architect Andres Harris, using the same structural principles as those found in bird skulls (Source: Pawlyn, 2019)

Skeletons have long captivated architects, ever since Thompson highlighted parallels between structures like the Forth Road Bridge and the form of dorsal vertebrae found in horses.

2.4.6.5 Adaptive Design/Additive Manufacturing

At the nano-scale, self-assembly plays a pivotal role in natural processes. Molecular self-assembly entails molecules arranging themselves in an ordered manner or folding into macromolecular structures without external direction (Pawlyn, 2019). Mimicking this process presents a significant opportunity, particularly in the realm of growing materials for construction through accretion or self-assembly, mirroring natural phenomena (Pawlyn: 2019; Zhang, 2018). Originally termed as 'rapid prototyping' or 'rapid manufacturing' (RM), and now commonly known as '3D printing' or 'additive manufacturing' (AM), this technology marked a breakthrough for designers during the digital revolution. According to Pawlyn (2016), it enables the direct transformation of a three-dimensional computer model into a physical prototype with exceptional precision, bypassing the labor-intensive conventional prototyping process. Notably, AM facilitates a semblance of bottom-up manufacturing akin to natural processes, allowing precise positioning of material as required.

2.4.6.5.1 Bacterial Growth – Fungal Mycelia

The Living has ventured into exploring bacterial growth as a means of material growth, specifically employing fungal mycelia to bind discarded corn stalks into bricks with adequate compressive strength for construction purposes (Pawlyn, 2019). These bricks were utilized in a temporary installation named 'Hy-Fi,' resembling chopped sections of highly magnified mycelia (see Figure 2.25).



Figure 2.25 'Hy-Fi' by The Living, constructed using bricks that were grown using fungal mycelia (Source: Pawlyn, 2019)

Upon dismantling, the bricks were composted, seamlessly reintegrating into the biological cycle. Similarly, other initiatives, such as Gramazio Kohler Architects' 'Flight Assembled Architecture,' have utilized drones to assemble structures. This approach, utilizing micro-agents to precisely position small components, arguably brings us closer to the self-assembly observed in biology according to Pawlyn (2019). Despite the significant difference in scale, it represents a notable departure from conventional methods reliant on large components assembled by human agents.

2.4.7 Sustainable Materials

Materials possessing the ability to detect and react to alterations in their surroundings are commonly labeled as 'smart.' In the context of architecture, systems often employed exhibit this trait at the building level (Gamage, 2012). However, it's crucial to differentiate between these conventional systems and truly 'smart' materials. While typical systems typically comprise a sensor, a processor, and an actuator, 'smart' materials amalgamate the sensor and actuator into a single entity, eliminating the need for a processor (Pawlyn, 2016). An example of this concept is the pine cone (Figure 2.26), initially investigated at the Centre for Biomimetics at Reading University.

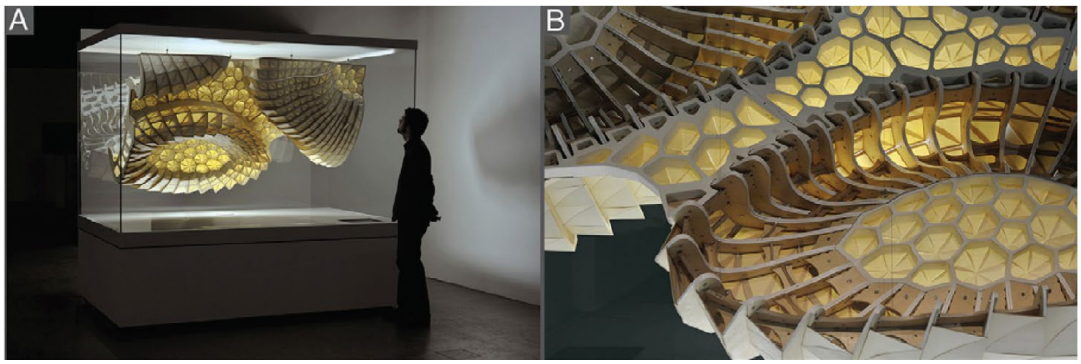


Figure 2.26 'HygroScope - Meteorosensitive Morphology', Centre Pompidou, Paris, by Achim Menges and Steffen Reichert – materials that respond to changes in humidity without a separate sensing and processing system

(Source: Pawlyn, 2019)

While attached to the tree, the pine cone remains firmly shut; however, as it falls and dries out, it gradually unfurls, eventually dispersing its seeds. This unfurling mechanism arises from the pine cone's scales, which consist of sandwich structures composed of two materials exhibiting distinct reactions to humidity (Pawlyn, 2019). As one material undergoes more significant shrinkage than the other in response to drying, it induces a bending effect akin to a bimetallic strip. This principle of hygroscopic actuation was later expanded into a multilayered textile featuring numerous small flaps. These flaps would open in response to the wearer perspiring, subsequently closing once the skin beneath cooled down.

According to Pawlyn (2019), many items are typically produced following a 'cradle to grave' approach, meaning they are manufactured with a varying lifespan before being disposed of, often ending up in landfills or being incinerated. What's commonly referred to as 'recycling' often involves 'downcycling,' a process where materials undergo progressive degradation until they eventually become waste. Downcycling essentially postpones the moment when these resources are discarded as waste.

2.4.7.1 Use of the Right Materials

According to Pawlyn (2019), the concept of Cradle to Cradle emphasizes that merely being 'less harmful' does not equate to being 'beneficial'. For example, while efforts are made to reduce formaldehyde content or increase recycled materials in plastics, the ultimate goal should be to design products that are completely free of toxins and are fully recyclable (Pawlyn, 2019)

2.4.7.1.1 Concrete

Concrete is widely utilized globally, with an annual pouring volume of 15 billion tonnes expected to persist as less developed countries construct essential buildings and infrastructure. However, cement poses a challenge as it impedes complete reintegration into the technical cycle, leading to gradual downcycling of aggregates. Yet, there are potential solutions, such as geo-polymer cements, pozzolanic cements, and naturally occurring cementitious compounds found in conglomerate rocks. Biomineralisation sequesters an atom of carbon with every atom of calcium in the process of forming calcium carbonate (Figure 2.27). Cement production, by contrast, releases a molecule of carbon. Innovations spearheaded by Brent Constantz indicate progress towards mimicking the mineralization processes observed in corals and marine organisms, which absorb carbon during mineral formation.

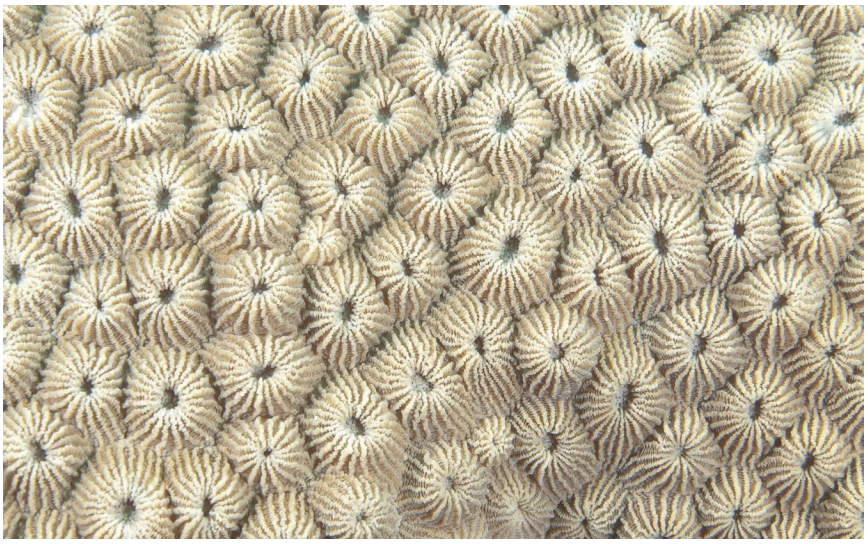


Figure 2.27 Biomineralisation as performed by corals and other marine organisms (Source: Pawlyn, 2019)

Constantz's work has focused on developing carbon-positive aggregates, offering promising prospects for quicker deployment and increased carbon sequestration. The potential of such advancements is substantial, particularly in countries like China and India where significant concrete usage persists. These innovations exemplify a growing field of 'drawdown technologies,' which could play a vital role in mitigating climate change by reducing and potentially reversing atmospheric carbon dioxide buildup.

2.4.7.1.2 Glass

Glass is widely used in modern construction, and Graham Dodd from Arup suggests a method to manufacture environmentally friendly C2C double-glazed units by drawing inspiration from biomimicry. Nature exhibits various color effects, such as the iridescence of the blue Morpho butterfly's wings (Figure 2.28), not through pigments or coatings but via 'structural color,' which refracts and scatters light. Similarly, for glass, it may be feasible to create a nanostructure within the glass itself to achieve similar effects as low-emissivity coatings.



Figure 2.28 The iridescent color of the blue Morpho butterfly as a result of a microstructure that creates a color effect through refraction instead of a pigment (Source: Pawlyn, 2019)

Another aspect to address in glazing is the challenge of recyclability, which can be tackled by implementing a thermoplastic seal that is easier to remove and recycle. While the thermal performance of such units may not match conventional ones, it's crucial to recognize that reducing energy consumption and carbon emissions, while significant, isn't the sole challenge. Some of the most sustainable solutions may not necessarily be the ones with the lowest carbon footprint (Pawlyn, 2019).

2.4.7.1.3 Metals

Common building materials often receive finishes like paints and seals, hindering their reuse and recyclability and posing pollution risks upon disposal. Unlike biological materials capable of self-repair, most construction materials remain inert. To address

this, promoting the use of weather-resistant metals like aluminium, stainless steel, and Corten steel is advisable. Additionally, leveraging technological advancements like foamed metals and honeycomb structures can significantly enhance resource efficiency. Exploring alternatives inspired by biological color creation may offer paint-free solutions for various products (Pawlyn, 2019)..

2.4.7.1.4 Timber

Timber faces similar coating challenges to metals, with traditional finishes posing pollution risks upon disposal. Utilizing cellulose in 3D printing offers a groundbreaking approach to reimagining wood. In its conventional forms, timber is best chosen for its inherent weather resistance, such as oak, larch, and western red cedar, or by opting for products treated with non-toxic methods like Thermowood or Accoya. Example of the use of Accoya is the Exchange building (Figure 2.29) at Darling Square, New South Wales in Australia known as The Hive, by Kengo Kuma. Thermowood utilizes intense heat treatment to deter microbial decay, while Accoya achieves similar results through acetylation, using harmless acetic acid to stabilize moisture levels. These methods enable timber to reenter the biological cycle at the end of its lifespan (Pawlyn, 2019).



Figure 2.29 The use of Accoya on the façade of the Exchange building (The Hive) by Kengo Kuma (Source: Google.com)

2.4.7.1.5 Rammed Earth

Rammed earth, an ancient building material, has regained popularity due to its minimal environmental impact. Studying how animals use earth without modern tools offers insights (Pawlyn, 2019).. For instance, the muddauber wasp adeptly compacts mud using thixotropy, reducing viscosity through vibration for efficient construction. Similarly, certain birds combine mud with plant fibers for enhanced strength, resembling reinforced concrete. Inspired by these natural processes, Italian company WASP inspired Trigonopsis, developed a clay-based 3D printer, Big Delta, capable of printing houses. For what is often regarded as a rather crude material, the results are striking (Figure 2.30).

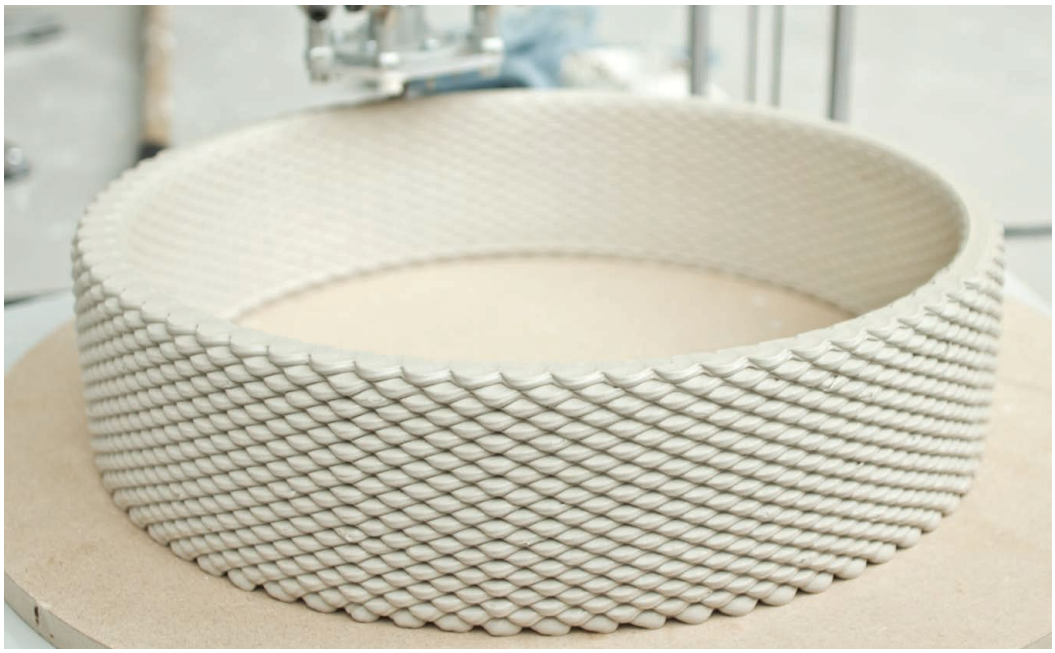


Figure 2.30 3D-printed ceramic by Olivier van Herpt showing the beauty and precision (Source: Pawlyn, 2019)

This approach not only leverages local materials but also embodies the resourcefulness of natural builders. Embracing this biomimetic philosophy could revolutionize rural construction practices according to Pawlyn (2019).

2.4.8 Environmental and Sustainable Impacts of Biomimicry

Nature has long served as a primary source of inspiration for architects and scientists alike, influencing the design of structures, building materials, environmental systems, and aesthetics (Mohammed et al., 2014). With billions of years of evolutionary refinement, nature offers a wealth of solutions to contemporary challenges in sustainable design, making it a natural source of learning (Nkandu & Alibaba, 2018).

Biomimicry emerges as a compelling alternative in the quest for sustainable building design and technology, harnessing inspiration from nature to drive architectural innovation (Rao, 2014).

Biomimicry as a design approach can be broadly categorized into two groups: Firstly, identifying human needs or design problems and seeking solutions from organisms or ecosystems—a process termed as design looking to biology. Secondly, recognizing specific characteristics, behavioral patterns, or functions in organisms or ecosystems and translating them into human designs—referred to as biology influencing design (Mohammed et al., 2014). By imitating nature's functions, forms, and parts, architecture addresses various challenges such as sustainability, efficiency, strength, and durability (Spaho, 2011).

The rationale behind this approach lies in aligning human creations with the natural world, thereby enhancing acceptance and sustainability (Mohammed et al., 2014). Buildings increasingly integrate with nature, supporting natural processes rather than disrupting life-sustaining ecosystems—an approach crucial for reducing ecological footprints (Rao, 2014). Through biomimicry, architectural designs respond to site conditions, climate variations, energy demands, and other factors while minimizing environmental harm (Spaho, 2011).

Functional-biomimicry guides decisions regarding a building’s form, orientation, and material selection, ensuring coherence with natural systems (Spaho, 2011). Looking ahead, aspiring architects and designers are tasked with creating bio-inspired design adaptations that emulate nature's ingenuity, facilitating sustainability in future buildings (Rao, 2014).

2.4.8.1 Zero-Waste Systems

Natural systems operate in closed loops, where waste is nonexistent and everything serves as a nutrient. These regenerative ecosystems, powered by solar energy, offer valuable insights for reimagining our buildings and cities. Transitioning from linear resource use to closed-loop models stand as a crucial transformation that be must achieve to create more sustainable buildings (Pawlyn, 2019).

The Mobius Project, developed by Exploration, integrates food, energy, water, and waste in synergistic cycles (Figure 2.31). Inspired by initiatives like the Tunweni Brewery and the Cardboard to Caviar Project, it features a restaurant, food production

(fish, vegetables, mushrooms), waste management (anaerobic digestion), water treatment, and energy generation. By consolidating these cycles, outputs from one part of the system can serve as inputs for another, fostering efficiency. For instance, the building can process biodegradable waste using anaerobic digestion, with methane derived used for power and heat in the greenhouse.



Figure 2.31 The Mobius Project – a scheme that brings together cycles of food, energy, water and waste in synergistic ways (CGI by Filippo Privitali)

The restaurant minimizes waste by sourcing produce locally and utilizing food scraps for fish or compost. Surplus fertilizer aids in rehabilitating urban brownfield sites. Similarly to Graham Wiles' enhancements to the Cardboard to Caviar Project, the Mobius Project could refine further (Pawlyn, 2019).

For instance, flue gases from methane combustion can be repurposed for building materials through accelerated carbonation. The project fosters community engagement and reconnects individuals with food while addressing urban sustainability challenges. Success relies on scaling elements economically and functionally, considering external factors like pollution and nutrient loss. Projects like the Mobius Project offer opportunities to transition from linear to closed-loop systems, addressing urban sustainability holistically.

2.4.8.2 Water Management

Several projects have drawn inspiration from biological water harvesting methods, notably the Seawater Greenhouse (Figure 2.32). by Charlie Paton inspired by how the desert beetle harvests water in its environment



Figure 2.32 (a)The Seawater Greenhouse in Oman as it looked on completion Day (b)The Seawater Greenhouse one year later (Source: Pawlyn, 2019)

This innovative structure achieves significant irrigation savings by harnessing seawater evaporation driven by wind. At the front, evaporators create a cool, humid environment for crops, while at the back, a second evaporator raises air temperature and humidity (Pawlyn, 2019). Vertical polythene pipes act as condensation surfaces, resembling the beetle's shell, collecting water droplets for irrigation (Figure 2.33).

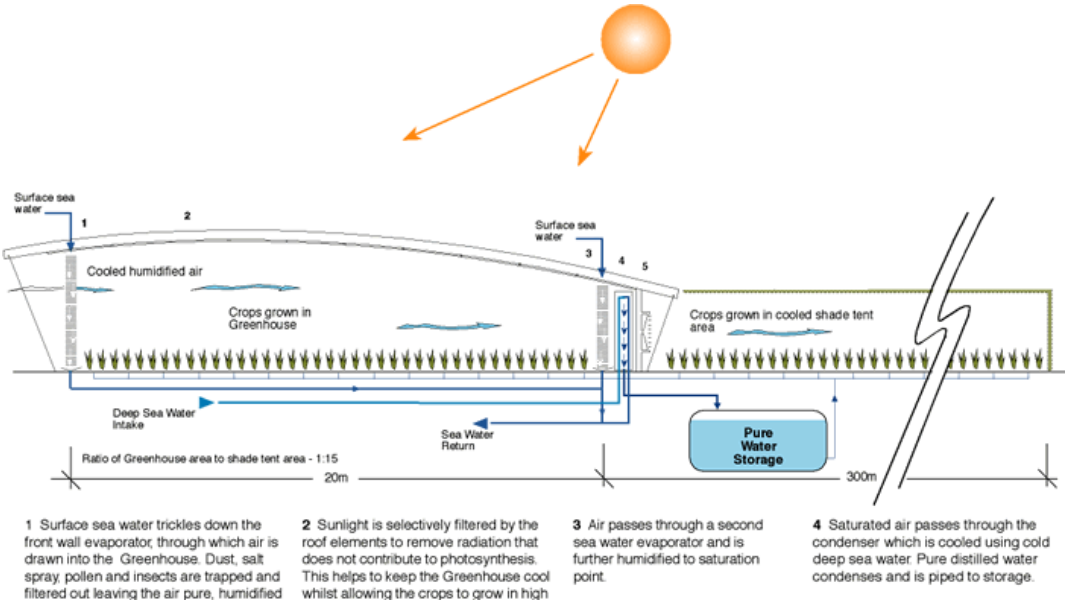


Figure 2.33 How the seawater greenhouse works (Source: Greenprophet.com).

This design effectively mimics and amplifies the beetle's water harvesting conditions, transforming saline water into fresh water using solar energy, wind, and minimal pumping. In many cases, innovative strategies for managing excess water offer numerous advantages, including reduced construction costs, minimized flood risk, enhanced biodiversity in water habitats, and groundwater replenishment. For construction in India's Lavasa region, known for its heavy rainfall of 11 meters annually, Biomimicry 3.8 and HOK architects embraced a holistic approach. They closely examined the local ecology and water flow patterns (Figure 2.34).

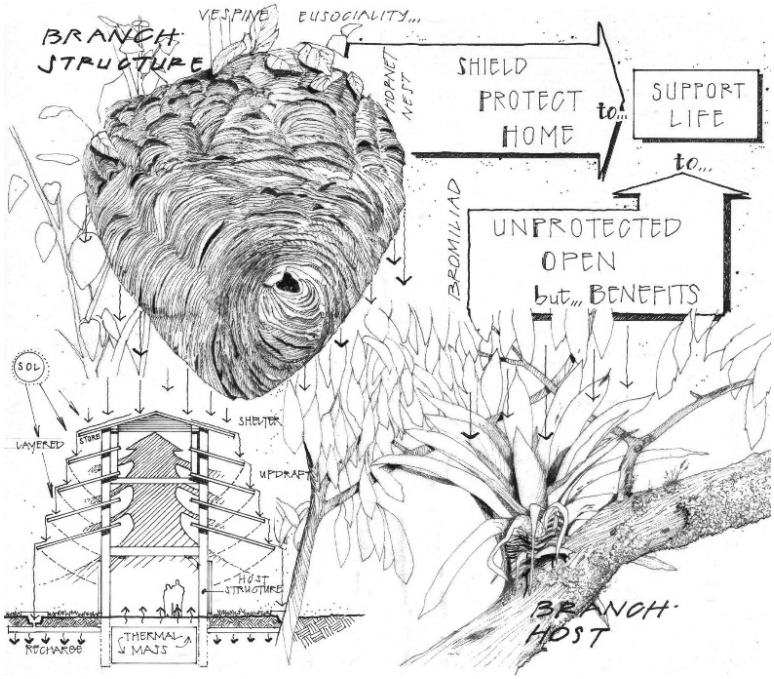


Figure 2.34 Sketch of the Lavasa project by architects HOK

(Source: Pawlyn, 2016)

The sketches show how locally adapted species, such as the bromeliad, provided a number of sources of design inspiration, including the idea of cascading roof surfaces to catch and evaporate rainfall. In natural forests, up to 30 percent of rainfall is retained in the canopy, evaporating back into the atmosphere, acting as atmospheric pumps that propel water inland (Pawlyn, 2019). Inspired by this, the project aimed to maintain these natural cycles by emphasizing evaporation. This influenced the architectural design, resulting in cascading roof surfaces made of absorbent materials, unlike conventional structures. These roofs maximize evaporation instead of efficiently channeling rainwater into gutters and downpipes. The stormwater management strategy extended to all urban surfaces to minimize runoff and promote groundwater recharge.

2.4.8.3 Thermal Control

The Plant Biomechanics Group at the University of Freiburg, known for their biomimetic innovations, developed the Flectofin shading system, inspired by the Bird of Paradise flower. This system, co-created with ITKE and the Institute for Textile Technologies, mimics the flower's motion to efficiently provide solar shading. By studying the flower's design, which features a perch that bends when birds land, activating petal movement to expose pollen, the group extracted the idea of a flap capable of a 90° rotation (Spaho, 2011). This characteristic is ideal for solar shading, offering unobtrusive views when not needed and full protection when required. After several prototypes, Flectofin was implemented as a large-scale shading system in soma's Thematic Pavilion at the 2012 Expo in Yeosu, South Korea (Figure 2.35) that uses thematic Pavilion by soma, using a kinematic facade inspired by early research on the Flectofin as a dynamic part of the facade that controls solar gain. Additionally, a method inspired by the ancient Persians' ice-making technique and the fog-basking beetle's cooling mechanism was developed by engineer Salmaan Craig using BioTRIZ methodology (Figure 2.36).

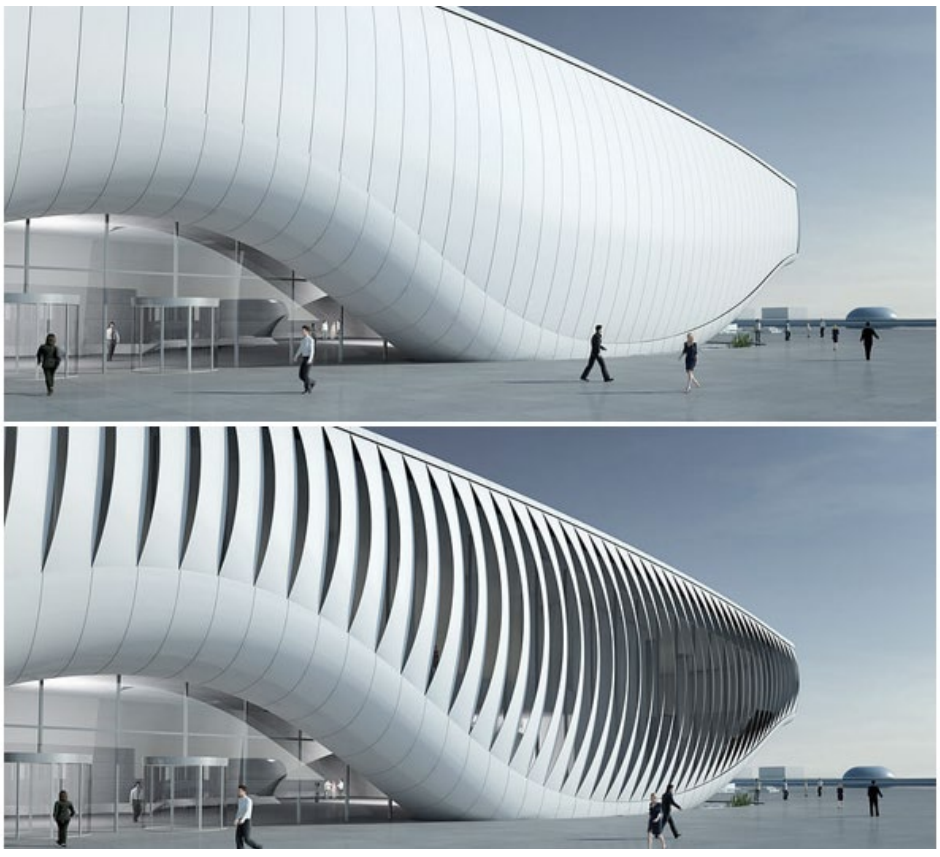


Figure 2.35 Thematic Pavilion by soma, uses a kinematic façade

(Source: Google.com)

Unlike conventional solutions that manipulate energy, this approach focused on structural modifications. It involved insulating a concrete roof against sunlight while enabling infrared heat radiation at night through transparent apertures.

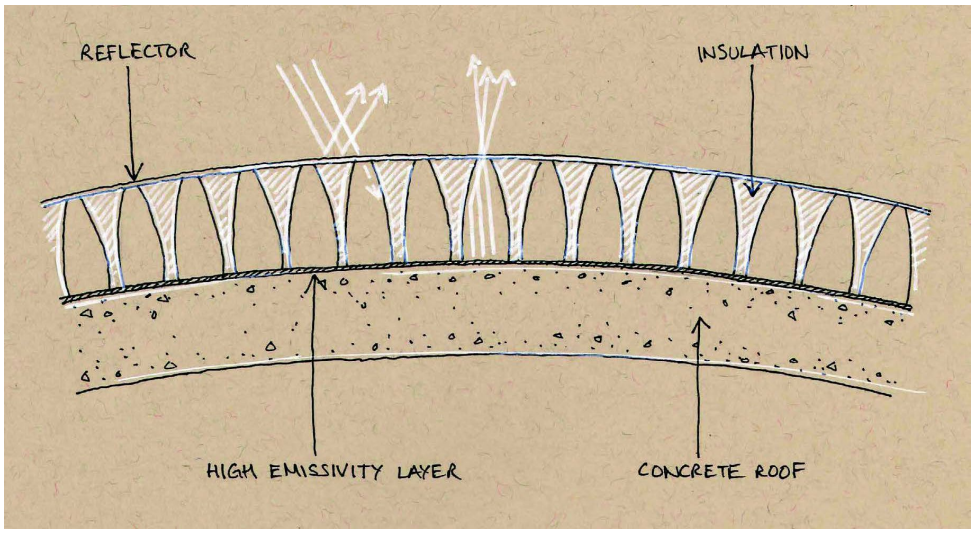


Figure 2.36 Roof system designed by Salmaan Craig using BioTRIZ

(Source: Pawlyn, 2019)

Test panels demonstrated a significant temperature reduction, with the concrete acting as a heat store during the day. Craig estimates that this biomimetic roof could keep concrete 4.5°C cooler than standard roofs in Riyadh, Saudi Arabia. Finally, evaporation, a natural cooling mechanism observed in plants, was explored for its effectiveness. Plant leaves control evaporation through microscopic pores, allowing them to dissipate heat and maintain cooler temperatures (Pawlyn, 2019).

2.4.8.4 Energy Efficiency

Biomimicry has been utilized in designing various renewable energy technologies, resulting in comparable enhancements to those observed in building technologies. Biomimicry offers solutions to address the issue of excessive wind speed, which often necessitates the shutdown of less advanced wind turbines to prevent damage. Many leaves, for instance, adapt their orientation or roll up in high winds to minimize wind loading on trees (Pawlyn, 2019). Advanced wind turbines now incorporate computer-controlled systems to adjust blade angles, and future designs may include blades that flex under wind loading to reduce resistance and allow turbines to continue operating in strong winds. Inspired by palm trees that bend in hurricane-force winds, a team in the US aims to develop turbines with flexible blades, potentially reaching an

impressive scale of 50 MW with 200 m long blades. Biomimetic research at the California Institute of Technology has shown that mimicking fish swimming in shoals (Figure 2.37) can significantly increase wind energy extraction.



Figure 2.37 (a) Shoaling fish swim in formations that optimize the use of eddy Currents (b) Scientists have applied the principles inn vertical wind turbines for a demonstrated substantial increase in energy generation (Source: Pawlyn, 2019)

In offshore wind turbine installation, a new "suction bucket" foundation method, inspired by razor clams burying themselves in the seabed, has been developed to efficiently secure turbines to the seabed. Solar technologies have also benefited from biomimetic breakthroughs, such as lenses and mirror layouts inspired by sunflowers (Figure 2.38), leading to increased efficiency and reduced land requirements.



Figure 2.38 Concentrated solar power (CSP) mirrors laid out with phyllotactic geometry to optimize energy generation (Source: Pawlyn, 2019)

Future biomimetic applications may include self-cleaning surfaces and scratch-proof coatings for solar mirrors based on the sand skink's adaptation to sand. Artificial photosynthesis research holds promise for further advancements in solar technology. Biomimetic windows that mimic the efficiency of leaves or forests in processing sunlight across their surface area are becoming increasingly feasible (Pawlyn, 2019). The potential of clear solar-energy windows offers significant resource gains, akin to the potential impact of widely implementing biomimetic concrete.

2.4.8.5 Comparison of Biomimetic Design to Conversional Practices

In recent years, there has been a growing interest in biomimetic design as a tool for sustainable and innovative solutions in several sectors, including architecture and product design (Kozlov, 2019). According to Webb (2021), numerous studies have emphasized the potential benefits of applying biomimetic concepts into design approaches, as it enables for a deeper knowledge and emulation of natural systems to tackle complicated design challenges. For example, in the realm of architecture, biomimicry has been employed to develop structures that are not only visually beautiful but also energy efficient and responsive to their surrounding environment (Han et al., 2017). Conventional design processes, on the other hand, tend to rely on existing design frameworks and approaches that may not stress sustainability or ecological considerations (Bhattacharjee et al., 2020).

While conventional design practices have their merits and have yielded successful outcomes in the past, biomimetic design offers a new perspective and approach that has the potential to revolutionize the way we think about design and its relationship with nature (Goloshubin & Pavlova, 2022; Zari, 2020). By looking to nature as a source of inspiration and guidance, biomimetic design fosters a shift towards more integrated and sustainable design solutions. By understanding the ideas and techniques found in nature, designers can produce new solutions that are both efficient and environmentally sustainable (Arango-Santander, 2022). Moreover, biomimetic design enables for the construction of products and buildings that are better adaptable to their surroundings and can potentially promote human well-being (Sabaa et al., 2022).

2.4.9 Challenges and Future Directions of Biomimicry

Overall, biomimicry has the potential to profoundly impact modern architecture by delivering sustainable and inventive answers to design difficulties. However, there are still obstacles to overcome in properly incorporating biomimicry into architectural

design. These problems according to Sadegh et al. (2022) include inadequate knowledge and understanding of biological systems among architects and designers, as well as the necessity for interdisciplinary collaboration between biologists, engineers, and architects. The concept of biomimicry is sometimes misrepresented as creating buildings that resemble natural organisms, i.e., buildings shaped like shells, which is a different design approach known as Biomorphology according to Amer (2019). Despite these challenges, the prospects are great. Biomimicry has the ability to generate more sustainable and environmentally-friendly designs in architecture. These designs can promote energy efficiency, reduce material usage, and improve overall functionality. Additionally, biomimicry can also enhance the aesthetic appeal of building projects by combining natural patterns and forms (Sadegh et al., 2022). In order to fully fulfil the promise of biomimicry in architecture, there has to be a larger emphasis on research and teaching in this discipline. Architects and designers need to have a profound understanding of biological systems and processes in order to properly use biomimicry principles. Furthermore, there is a need for increased collaboration amongst diverse disciplines to stimulate innovation in biomimetic design (Butt, 2022). Architects, biologists, engineers, and other professionals should work together to exchange knowledge and ideas and produce integrated solutions that mix biology and architecture. This partnership can lead to significant advancements in sustainable design and establish a more harmonious balance between human-built buildings and the natural environment (Webb, 2021).

2.4.9.1 The Potential of A.I in Biomimetic Designs

In recent years, developments in technology and the synthesis of bio-sustainable materials have further driven the development of biomimicry (Kekic et al., 2020). These improvements have enabled for the incorporation of biomimetic techniques and mechanisms into architectural designs, resulting to more efficient and sustainable solutions in building systems and energy efficiency. One new area of technology that has the potential to dramatically advance biomimetic design is artificial intelligence (AI). The implementation of biomimicry concepts in architectural design can lead to a more sustainable approach, as it aims to understand and imitate the rules that govern natural systems (Sarwate & Patil, 2016). By incorporating a deep understanding of biology and ecology into architectural design, biomimetic designs have the potential to produce a constructed environment that contributes to the health of human

populations while promoting positive integration with natural carbon cycles (Chàfer et al., 2020).

According to Kadar et al. (2020), Artificial Intelligence (AI) which is an umbrella term that sums together a set of technologies that perform human-like cognitive processes such as thinking and learning and solves problems through pattern recognition, prediction, optimization, and recommendation generation, utilizing data provided by sensors under video, image, audio, text formats, could be extremely beneficial in the application of biomimicry in architecture (Kadar et al., 2020).

Artificial intelligence has the potential to change biomimetic design by enabling more advanced study and interpretation of natural systems. Artificial intelligence has the potential to dramatically boost biomimetic design in various ways (Bansal, 2020). Firstly, AI according to Hassan et al., (2022) can aid in the collection and analysis of data from natural systems, helping designers comprehend and reveal hidden patterns, correlations, and principles that can be applied to architectural design. Also, AI can enable designers to simulate and optimize biomimetic designs by constructing computational models that imitate the behavior and performance of natural systems (Bansal, 2020). By using artificial intelligence, designers may explore a greater range of options and iterate designs more efficiently. Overall, the integration of artificial intelligence into biomimetic design has the potential to dramatically enhance the sustainability and efficiency of architectural systems (Ding et al., 2022).

By using AI's computing strength and capacity to process vast volumes of data, designers can reveal intricate patterns and correlations in natural systems that may have previously been overlooked (Bansal, 2020). These findings can then be integrated into biomimetic designs, leading to more sustainable and efficient architectural solutions (Hassan et al., 2022). In conclusion, artificial intelligence has the ability to dramatically advance biomimetic design in architecture by helping designers to optimize designs, evaluate and interpret data from natural

2.4.9.2 Importance of interdisciplinary collaboration in advancing biomimicry

The approach to not only create aesthetically pleasing designs, but also to incorporate sustainable and efficient solutions that mimic the functionality of natural systems is a necessity as it is also crucial and can be achieved through interdisciplinary collaboration between various scientific disciplines and fields of innovation (Ding et al., 2022). Biomimicry in architecture requires the expertise of biologists, engineers,

designers, and other professionals who can contribute their knowledge and insights to the design process according to Butt et al. (2022) who continued to elaborate that biomimicry is not limited to one specific field, but rather encompasses a wide range of disciplines that can contribute to its advancement in architecture. For example, architecture may draw from the knowledge and insights of materials science and mechanical and structural engineering to produce innovative building materials and construction procedures that mirror the qualities of natural materials and structures (Butt et al., 2022). Additionally, biology can provide inspiration for efficient energy systems, ventilation tactics, and organic designs that enhance natural light and air circulation in buildings (Mohammed, 2023). Moreover, interdisciplinary collaboration in biomimicry can lead to the development of sustainable design solutions that address important environmental and societal concerns (Gruber et al., 2017). For example, by researching how birds build their nests or termites develop their mounds, architects might learn about efficient and adaptive construction strategies that minimize waste (Verbrugghe et al., 2023).

2.5 THE LIVING-LEARNING COMMUNITY STEAM HUB

The Living-Learning Community STEAM Hub is envisioned as a dynamic establishment offering a spectrum of programs and activities tailored to foster interdisciplinary learning and community engagement. These initiatives include S.T.E.A.M. Summer Camps aimed at nurturing young learners' curiosity and creativity through hands-on projects and experiments (Kney et al., 2016; Oner et al., 2016). Additionally, S.T.E.A.M. Teacher Development Programs will provide professional development opportunities for educators to enhance their pedagogical skills and integrate STEAM principles into their teaching practices (Jong et al., 2021). Art and Science Workshops will encourage participants to explore the intersections of art and science, fostering innovative thinking and collaboration (Sochacka et al., 2016; Myint Swe & Shaljan, 2021). STEM Inspired Art Exhibitions will showcase the creative expressions of learners, demonstrating the integration of science, technology, engineering, and mathematics concepts into artistic endeavors (Lyons, 2018). The Hub will also host a Coding and Robotics Club, offering opportunities for learners to develop coding skills and engage in robotics projects (Ge et al., 2015; Sopapradit et al., 2022; Zakaria et al., 2018)). Technical and Vocational training programs will provide practical skills development in various technical fields, promoting workforce

readiness. Arts Projects that will involve local residents in collaborative artistic endeavors, fostering community cohesion and cultural exchange is also a consideration (Akintoye, 2023). Lastly, Cultural Training Programs will celebrate Ghanaian heritage and traditions, promoting cross-cultural understanding and appreciation (Bayode, 2023).

Through these diverse programs and activities, the STEAM Hub aims to cultivate a vibrant learning community and inspire sustainable innovation in Ghana as existing literature has emphasized the importance of integrating biomimetic principles into the design of the Hub, leveraging nature-inspired solutions to promote sustainability and environmental stewardship (Mohammed et al., 2014; Pawlyn, 2019; Rao, 2014; Spaho, 2011). Furthermore, the Hub will serve as a catalyst for community empowerment, fostering meaningful interactions between educators, students, and community members. Through innovative design and pedagogical approaches, the STEAM Hub aims to cultivate a culture of creativity, critical thinking, and experiential learning, thereby shaping the future of education in Ghana.

2.5.1 Design Guidelines for a Living-Learning Community STEAM Hub

Given the absence of a case study for the Living-Learning Community STEAM Hub, it is imperative to propose a literature informed design guidelines aimed at fostering a dynamic and sustainable environment for education and community engagement. There were considerations regarding principles and strategies for integrating biomimicry, innovation, and cultural integration into the design of the hub. By examining existing research and best practices, we aim to provide a comprehensive framework for creating a vibrant and inclusive space that promotes learning, creativity, and environmental stewardship. Let us embark on this journey to reimagine the future of education and community development through thoughtful design and collaboration.

Table 2.1 Living-Learning Community STEAM Hub Design Guidelines

STREETSCAPE
1. Site Integration • **Incorporate natural landscaping:** Utilize indigenous vegetation and water features to create a biodiverse environment. • **Enhance ecological harmony:** Mimic local ecosystems to promote connectivity with nature and support local biodiversity.
2. Biophilic Design • **Integrate nature into the streetscape:** Incorporate natural materials and living walls to foster well-being and connection with the environment. • **Create inviting outdoor spaces:** Design green pathways and rest areas for relaxation, reflection, and engagement with nature.
BUILDING DESIGN
1. Adaptive Facades • **Optimize energy efficiency:** Implement dynamic shading systems and passive ventilation strategies to minimize solar heat gain and enhance natural ventilation. • **Inspired by natural systems:** Design facades that respond to environmental conditions and promote occupant comfort and well-being.
2. Flexible Learning Spaces • **Promote collaboration and creativity:** Create adaptable indoor environments with movable partitions and modular furniture for diverse educational activities. • **Support experiential learning:** Design multifunctional spaces that can accommodate workshops, events, and interactive exhibits.
INNOVATION
1. Biome-inspired Architecture • **Celebrate local biodiversity:** Incorporate biomorphic forms and textures inspired by the unique ecosystems and cultural heritage of the region. • **Create a sense of place:** Design buildings that reflect the identity and values of the community, fostering a connection to the natural and cultural landscape.

2. Educational Outreach

- **Engage the community:** Host interactive exhibitions, workshops, and events that showcase innovative biomimetic solutions and promote STEAM education.
- **Inspire creativity and curiosity:** Provide hands-on learning opportunities and educational resources to empower learners of all ages to explore and innovate.

SUSTAINABILITY

1. Water Management

- **Minimize water consumption:** Install rainwater harvesting systems and green roofs to capture and reuse water onsite.
- **Promote ecological balance:** Utilize permeable paving and biofiltration swales to manage stormwater runoff and enhance water quality**.**

2. Energy Efficiency

- **Reduce energy demand:** Integrate daylighting, natural ventilation, and renewable energy technologies to minimize reliance on non-renewable resources.
- **Harness natural resources:** Utilize solar panels and wind turbines to generate clean energy and reduce carbon emissions.

COMMUNITY AND VIBRANCY

1. Cultural Integration

- **Celebrate diversity:** Embrace cultural traditions and heritage in the design and programming of the hub, promoting inclusivity and social cohesion.
- **Foster cross-cultural exchange:** Create opportunities for students, educators, and community members to share knowledge.

2. Collaborative Spaces

- **Promote social interaction:** Design communal gathering areas, outdoor plazas, and shared amenities that encourage spontaneous interactions and networking.
- **Support community engagement:** Provide platforms for collaborative projects, events, and initiatives that empower individuals to contribute to the vibrancy and vitality of the community.

2.5.2 Precedence Study for Living-Learning Community STEAM Hub

This section offers a comprehensive examination of a precedent study focusing on the development of a Learning Hub. Herein, we delve into the planning and implementation process of this educational facility. Subsequently, the following subsection addresses key considerations essential to the design and development of similar facilities.

2.5.2.1 The Hive – NTU Learning Hub

Thomas Heatherwick, in collaboration with CPG Consultants, designed "The Hive" at Nanyang Technological University as part of NTU's campus transformation plan. Completed in 2015, this innovative Learning Hub promotes collaborative learning to enhance educational outcomes. Recognized for its sustainable design, the Learning Center received the 2013 BCA Green Mark Platinum Award (WikiArquitectura, 2023)



Figure 2.39 The Hive at Nanyang Technological University

(Source: Heatherwick Studio, 2017)

A. LAND USE

The primary site of Nanyang Technological University spans 200 hectares (Figure 2.40), rendering it Singapore's most expansive university campus.

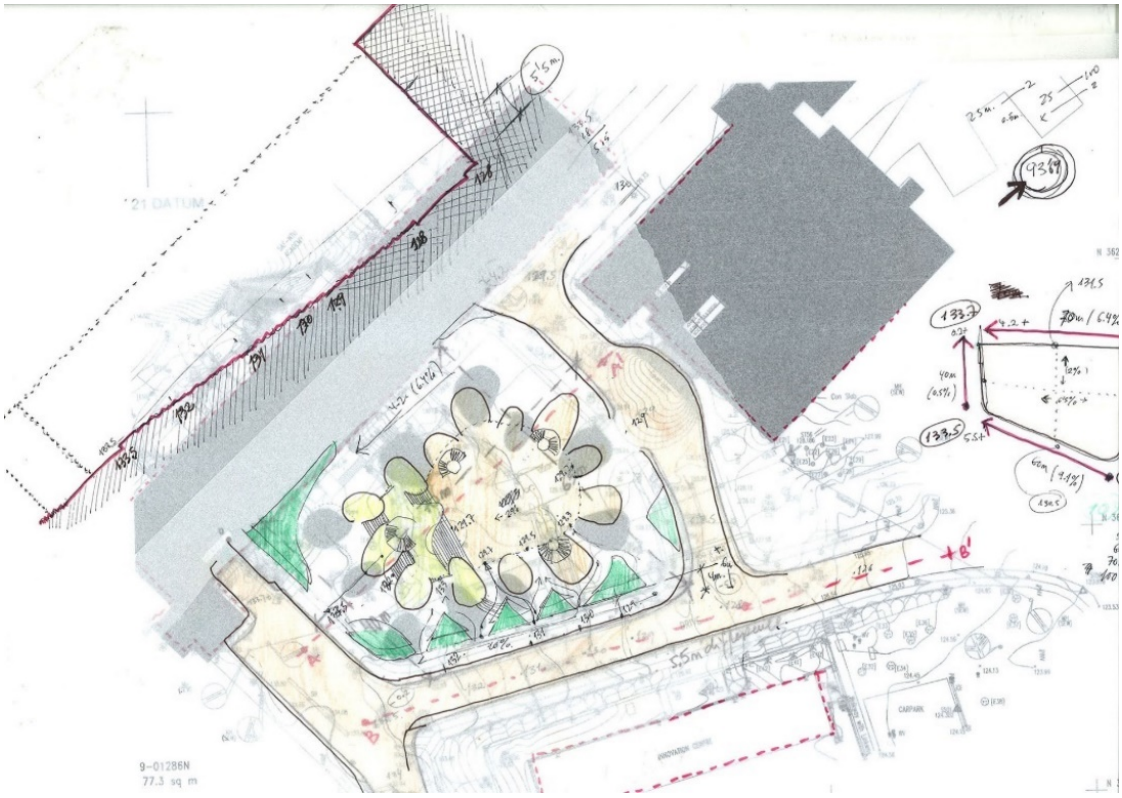


Figure 2.40 Conceptual sketch of the Site in Context

(Source: https://www.heatherwick.com)

Situated at 50 Nanyang Avenue in the western area of the city, the campus is undergoing redevelopment, which includes the creation of the Learning Hub, envisioned as a versatile facility catering to NTU's 33,000 students (Heatherwick Studio, 2017).

B. BUILDING DESIGN

The architects noted that advancements like the Internet and affordable computers have transformed students' learning habits, rendering traditional university buildings less appealing and isolating. Therefore, the design sought to reimagine university architecture , emphasizing social connectivity and collaborative learning experiences (Figure 2.41), according to Heatherwick Studio (2017).

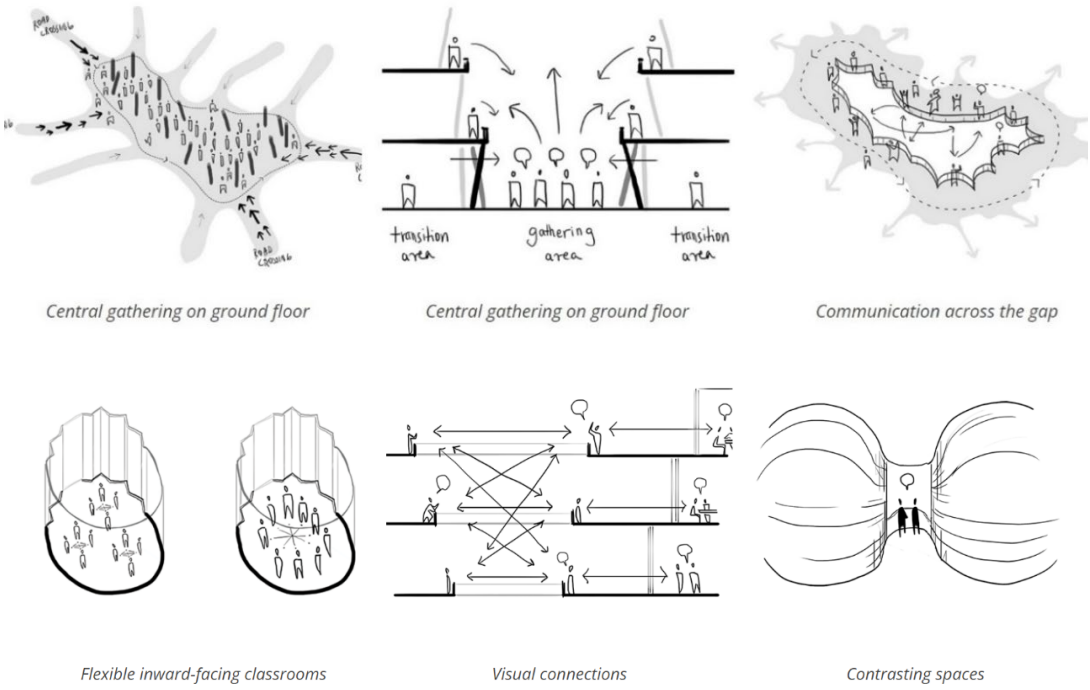


Figure 2.41 Schematic Sketches of design considerations

(Source: Annabielski (2017) https://morphogenesis16.wordpress.com)

The resulting structure integrates social and educational areas, fostering a vibrant atmosphere conducive to interactions. Comprising twelve towers of rounded tutorial rooms, the building converges towards a central atrium, offering fifty-six tutorial spaces without traditional boundaries. The building was conceptualized as a cluster of conical towers encircling a spacious atrium (Figure 2.42), aiming to eliminate lengthy corridors typically found in conventional educational structures.

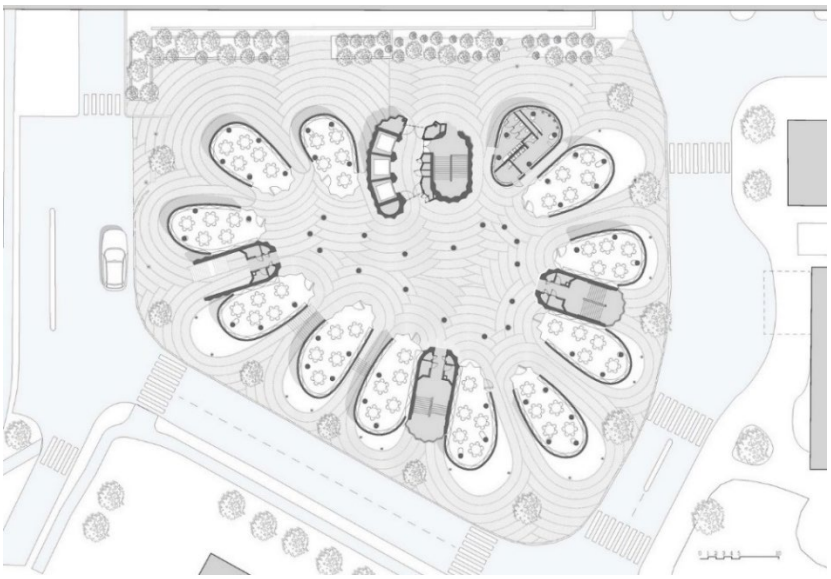


Figure 2.42 Ground floor plan of "The Hive" (https://www.heatherwick.com**)**

This innovative design integrates learning areas with communal spaces, such as balconies, gardens, and outdoor walkways, to facilitate frequent interactions among students and faculty. Departing from conventional classroom layouts, the center aspires to create a fluid environment (Figure 2.43) where educators and learners interact on equal footing, fostering a culture of collaboration and sociability conducive to diverse interactions among students, faculty, professionals, and researchers.

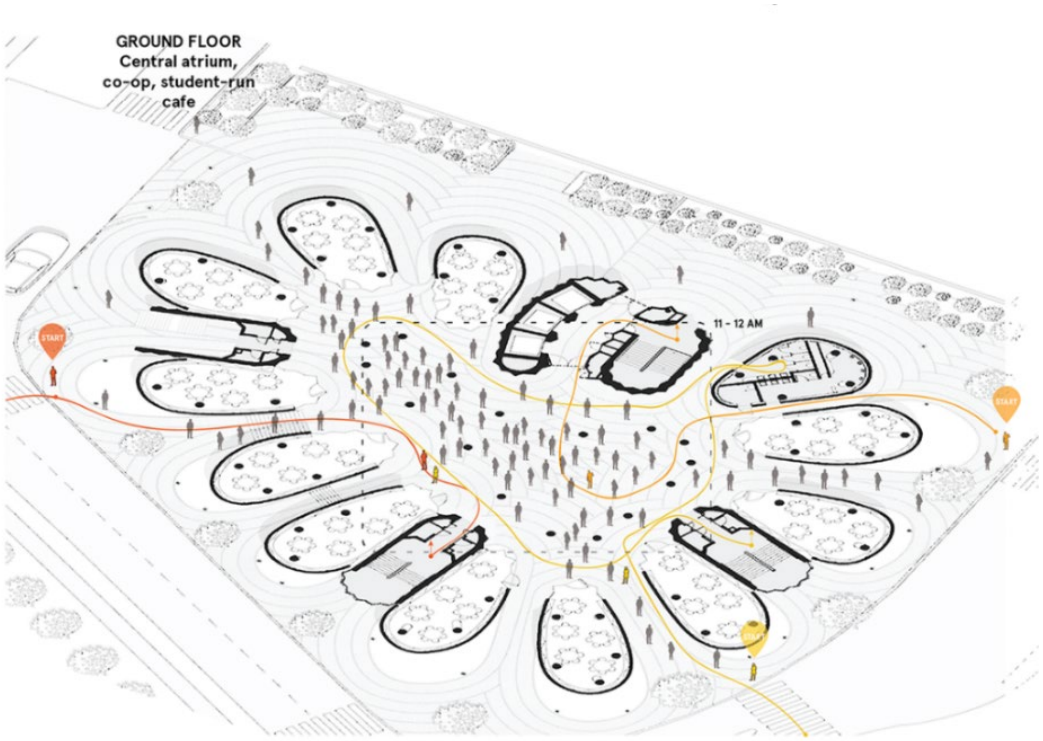


Figure 2.43 Floor plan showing fluid environment that encourages movement

(Source: Annabielski (2017) https://morphogenesis16.wordpress.com)

These modern classrooms prioritize interactive small group instruction and active learning, with adaptable configurations (Figure 2.44). Accessible from the atrium, the rooms are surrounded by shared spaces, promoting connectivity and providing areas for gatherings.



Figure 2.44 A small group adaptable learning space (https://www.heatherwick.com)

NTU's Senior Associate Provost, Professor Kam Chan Hin, highlights the hub's role in fostering interdisciplinary interactions, nurturing innovation across disciplines.

C. CONSTRUCTION

The Learning Hub, comprised of handcrafted concrete towers encircling a central space (Figure 2.45), blends learning and social environments through various communal areas like nooks, balconies, and gardens (WikiArquitectura, 2023).

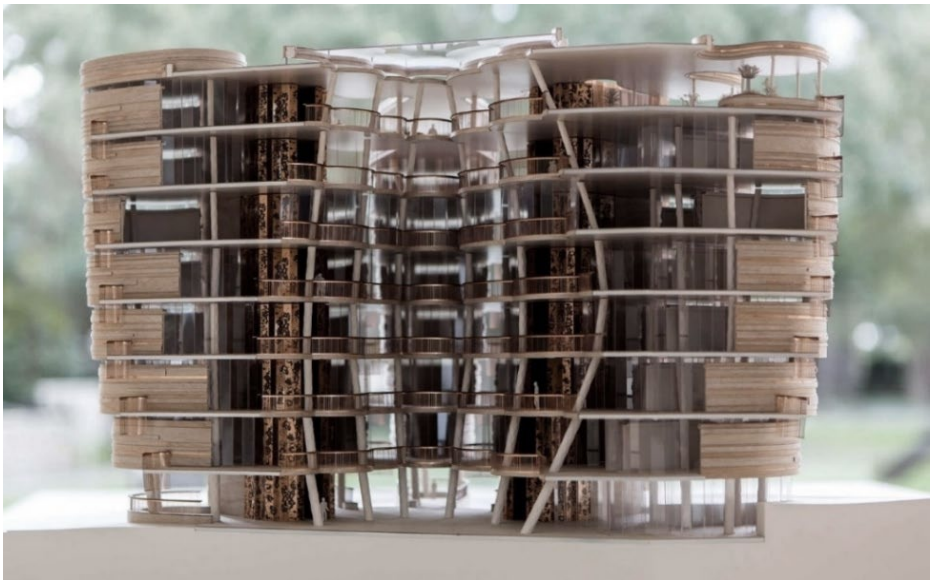


Figure 2.45 Sectional model of "The Hive" showing the atrium and structural members (https://www.heatherwick.com)

The architect's express gratitude for the opportunity to collaborate with NTU on this innovative project, which required meticulous adherence to Singapore's strict building

codes and sustainability standards. To enhance the aesthetic appeal of concrete, the team embedded 700 drawings into the cores (Figure 2.46), creating a visually stimulating environment inspired by science, art, and literature.



Figure 2.46 Visually stimulating drawings on concrete wall

(https://www.heatherwick.com)

Additionally, unique textures and patterns were meticulously crafted into the concrete elements, giving the building an organic, handmade appearance (Figure 2.47). Sustainability was a key focus, with the building achieving Green Mark Platinum status for its passive cooling systems and energy-efficient design. Structural innovation, such as tilted columns and column-free frames, provided both stability and architectural interest (Annabielski' 2017).

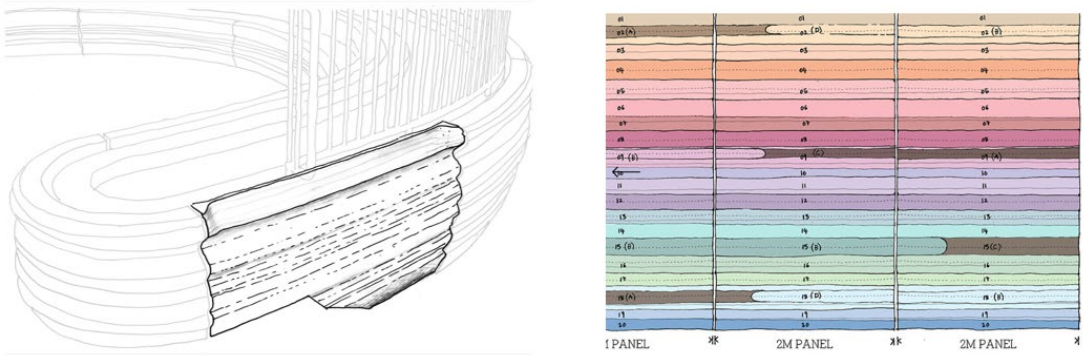


Figure 2.47 Unique textures and patterns crafted into the concrete

(https://www.heatherwick.com)

The foundation system, featuring perforated piles and flat plate systems, minimized noise impact and ensured structural integrity. In order to reduce solar heat absorption, Heatherwick Studio implemented slender bands of glazing along the edges of each

classroom. While curved glass was deemed too costly and a faceted look was undesirable, the architects opted to arrange the flat panels in a zigzag configuration. The use of tall windows facilitates connectivity between the classrooms and the central atrium (Annabielski' 2017).

Overall, "The Hive" Learning Hub epitomizes innovative educational architecture, designed to foster interaction and engagement among students and faculty. Its unconventional structure, featuring handmade concrete towers surrounding a central atrium, redefines traditional learning environments. With a focus on sustainability and aesthetic appeal, the Hub it serves as a symbol of modern educational ideals and architectural innovation (Annabielski' 2017).

2.6 RESEARCH GAP

In recent years, there has been increasing recognition of the importance of interdisciplinary education in nurturing well-rounded learners equipped with the skills needed for the 21st-century workforce (Hilppö et al., 2022; Liao, 2016; Okwara et al., 2023). And while this has led to the growing appreciation of the importance of STEAM education in nurturing future-ready skills in the Ghanaian context (Nyaaba et al., 2024; Owusu, 2022; Selase et al., 2023), there is a lack of comprehensive research on the effectiveness of Living-Learning Communities in promoting STEAM learning outcomes, especially in under-resourced communities like Kyebi. Furthermore, while there is considerable literature on biomimicry in architecture and sustainable design (O'Connor 2018; Pawlyn, 2016; Spaho, 2011) , its application within educational facilities, especially those fostering interdisciplinary learning, remains relatively unexplored as there appears to be a dearth of studies focusing specifically on the integration of biomimicry principles within the context of Living-Learning Community STEAM Hubs, particularly within the Ghanaian educational landscape. Additionally, there is a notable gap in understanding the practical implications and challenges of implementing biomimetic design solutions in educational infrastructure, particularly in regions with limited resources and varying environmental contexts. Addressing these gaps is crucial for advancing both theoretical understanding and practical implementation strategies in the realm of educational architecture and STEAM pedagogy.

2.7 THEORETICAL FRAMEWORK

The theoretical framework for this thesis encompasses the integration of several key concepts to guide the exploration of biomimicry in the design of a Living-Learning Community STEAM Hub within the Ghanaian context. At its core lies STEAM education, emphasizing interdisciplinary learning and the fusion of Science, Technology, Engineering, Arts, and Mathematics to cultivate critical thinking and innovation among learners (Hilppö et al., 2022; Liao, 2016; Nyaaba et al., 2024; Okwara et al., 2023: Owusu, 2022). Building upon this foundation are the principles of Living-Learning Communities (Chenneville, 2021; Engberg et al., 2011; Shushok, 2008; Stewart et al., 2021), which provide immersive and collaborative environments fostering shared learning experiences. Central to the framework is the concept of biomimicry, drawing inspiration from nature to solve design challenges and promote sustainability (Benyus 1997; O'Connor 2018; Pawlyn, 2016; Rao,2014; Spaho, 2011). By integrating biomimetic principles into the STEAM Hub design, the aim is to create environmentally sustainable educational spaces that harmonize with the natural environment (Ahenkan et al.,2015). Moreover, the framework considers the socio-cultural context of Ghana, including cultural norms, educational policies, and socio-economic factors, to ensure the effective implementation of biomimetic design strategies within the Ghanaian educational landscape. Through the synthesis of these theoretical perspectives, the framework provides a holistic approach to exploring innovative and sustainable educational environments in Ghana.

2.8 CONCEPTUAL FRAMEWORK OF LITERATURE REVIEW

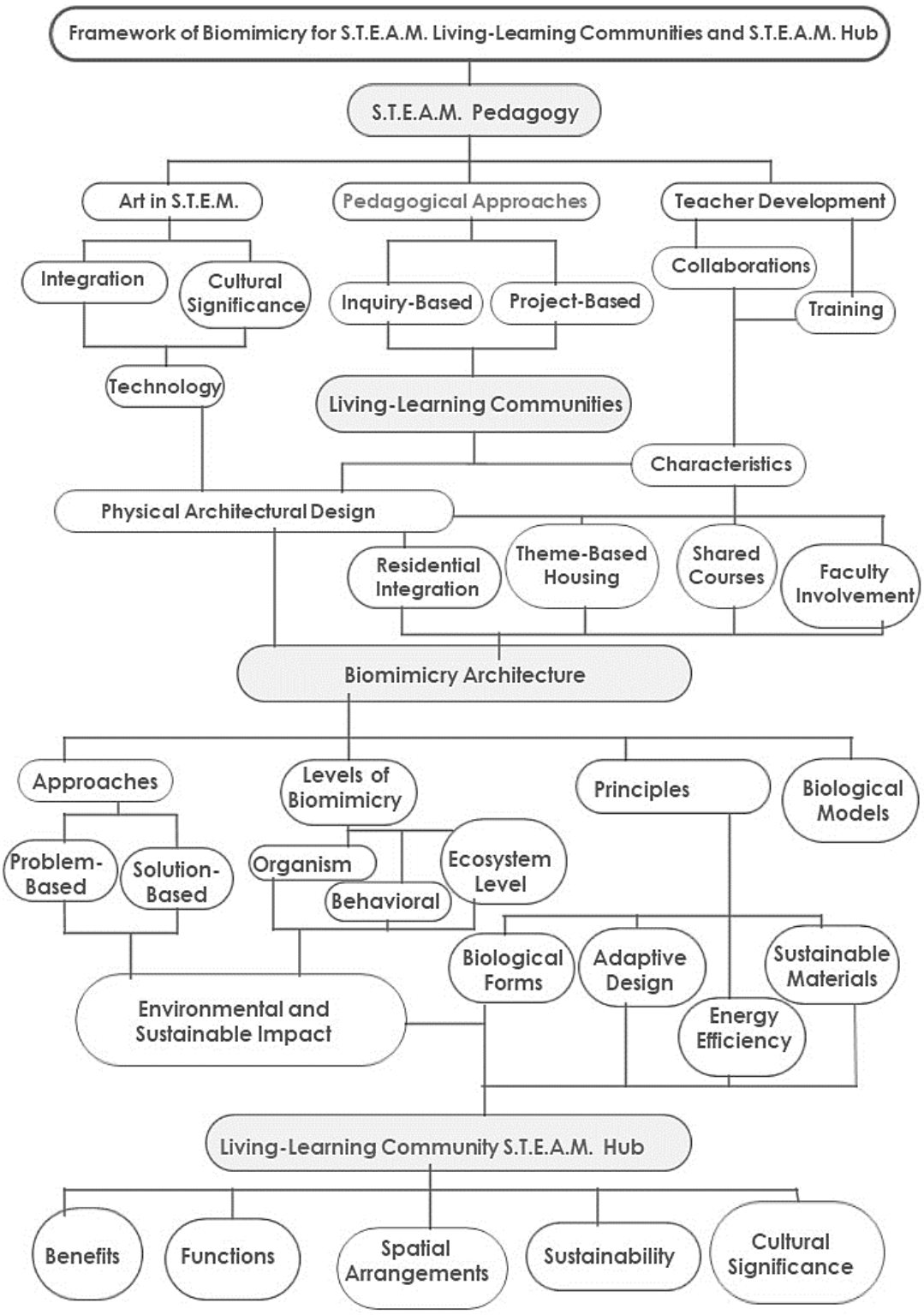


Figure 2.48 Conceptual Framework of the Research

(Source: Author's Construct, 2024)

2.9 CHAPTER SUMMARY

The chapter examined the evolution of S.T.E.A.M education, pedagogical techniques, integrating arts, teacher professional development, gender and diversity, innovation, and technology in S.T.E.A.M. It also analyzed obstacles and barriers in steam education. The chapter also discussion on Living-Learning Communities, their design, benefits, problems, and cross-institutional comparisons. This chapter finally provided an in-depth investigation of biomimicry in architecture, concentrating on its worldwide and Ghanaian historical context, numerous levels, concepts, biological models, environmental and sustainable impacts, case studies, and best practices. It also explored the significance of Artificial Intelligence in biomimetic designs and the possibility for multidisciplinary cooperation. Some cases and precedent study of learning hub design were also conducted in the chapter.

CHAPTER THREE
3.0 RESEARCH METHODOLOGY

3.1 CHAPTER OVERVIEW

This chapter presents an outline of the methodology employed in the study, including a philosophical framework for qualitative research, a delineation of the research design, and an elucidation of the data collection technique utilized. Additionally, it furnishes an overview of the data sources, sampling methodologies, and methods employed for determining the sample size. The chapter also encompasses a discussion of the various methodologies and types of data gathering methods employed in the research, an exposition of the data analysis process, and an evaluation of the study's reliability and validity, particularly in ethical terms. Finally, the chapter is summarized to encapsulate its key points.

3.2 RESEARCH PROCESS

Research can be defined as the systematic process of data gathering and rational analysis for a specified objective, utilizing methods that have been purposefully established for reliably and validly acquiring information (Chen, 2015; Opoku et al., 2016). A research process, according to Samani (2016), is a structured method for achieving the research's defined aims and goals (Samani, 2016). The research process framework of Saunders et al. (2009, 2016) was utilised as a guide to this research procedure. The research onion illustrates the different paradigms, options, tactics, and steps used by scholars during the research process. A depiction of the research onion proposed by Saunders et al. is presented in Figure 3.1

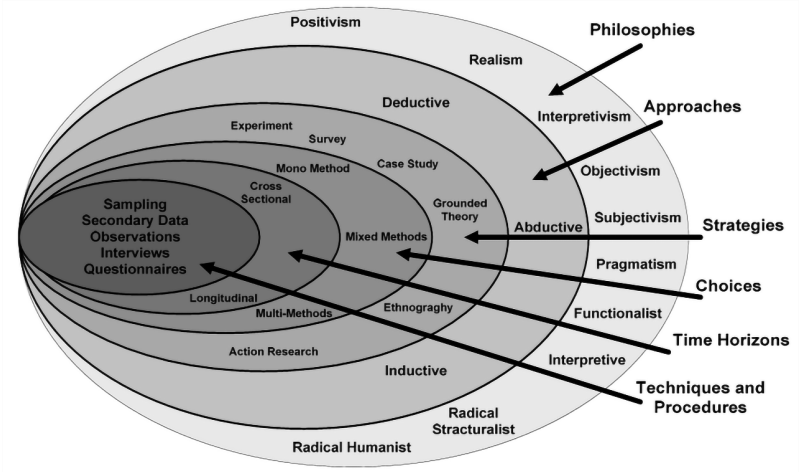


Figure 3.1 Research Process Onion (Saunders et al., 2009).

The research process onion provides a structured approach to identify and address the significant limitations that must be considered before initiating any research endeavor. Its layered structure serves as a foundational framework for assessing various aspects, including the researcher's philosophical orientation, the chosen research approach, suitable research strategies, the timeline under review, and the adopted data collection techniques (Melnikovas 2018; Orth et al., 2021; Saunders et al., 2016).

In this study, the research is categorized into nine sections; the first of which was the formulation of the research problem, which was followed by a comprehensive literature review that evaluated the available literature on the research topic. The third phase involved determining the research question, and objectives. Following the selection of the research philosophy and research design, a decision on the sample design was determined. The research was then carried out utilizing the relevant data collection methods. The acquired data were processed, analyzed, and evaluated, with the results and recommendations presented. Lastly, the preparation of the final report and a design proposal brings the process to a conclusion.

3.3 RESEARCH PARADIGM

Research philosophy is the system of beliefs and assumptions about the evolution of knowledge, as it is precisely what is being done pursuing research, seeking understanding in a particular topic (Saunders et al., 2019). Whether one is aware of them consciously or not, at the various stages of any research, a variety of assumptions are made (Burrell, 2016) and these as suggested by Saunders et al. (2019), include inference about realities that are encountered in the research (ontological assumptions), about human knowledge (epistemological assumptions), and about the extent and ways the researcher's values affect the research process (axiological assumptions). The four basic philosophies that were considered for the research positivism, constructivism, transformative worldview, and pragmatism. For a positivist, knowledge can only be true, untrue, or meaningless (Veal, 2017). In contrast to the positivist method is constructive research, which has to do with most qualitative research, the assumption is that reality is a social construct, meaning that there is no single, observable reality (Merriam, 2015; Veal, 2017). According to Kelemen and Rumens (2019), pragmatism concepts are relevant solely when it comes to supporting actions. Pragmatism seeks the reconciliation of both objectivism and subjectivism,

facts and values, accurate and rigorous knowledge, and varying contextualized experience since reality matters to the pragmatist as a practical (Saunders et al., 2019) Transformative research primarily centers on addressing the needs of individuals, making researchers advocates for their concerns. This type of research incorporates various viewpoints, including philosophical perspectives, discussions on race, critical theory, disability theory, and feminist theory (Romm, 2015).

Following a thorough examination of the research objectives, it was determined that a blend of quantitative and qualitative methodologies was imperative for this study. Consequently, the transformative philosophy was selected from among the available research paradigms as it is an umbrella term that encompasses paradigmatic perspectives that are meant to impact change and are participatory, and inclusive (Romm, 2015). Transformative paradigm adopts a constructivist ontology which recognizes the social constructed nature of reality. In epistemological sense, transformative research is shaped by the experiences, perspectives, and social positions of individuals and communities involved in the research according to Romm (2015)

3.4 RESEARCH DESIGN

According to Makombe (2017), the research design is defined as the plan or proposal required to conduct a study in which philosophical worldviews or paradigms, research methods, and techniques are defined (Creswell, 2014; Makombe, 2017). Research designs is categorized by researchers into three main types: quantitative, qualitative, and mixed methods (Tran, 2016). Research design as suggested by Roller et al. (2015), is the plan for a study that depicts the general framework used for data collection (Roller et al., 2015; Sileyew, 2019). The research design is always more focused on the what of the research subject than the why of the research Babbie (2020) added.

The study employed a mixed-methods research approach, incorporating both quantitative and qualitative data collection and analysis techniques. This approach allowed for a nuanced exploration of the multifaceted aspects of STEAM, Living-Learning Communities and biomimicry within the context of S.T.E.A.M. Living-Learning Communities. This integration leveraged the strengths of each method while mitigating the inherent weaknesses associated with relying solely on one approach (Johnson and Onwuegbuzie et al., 2011). The selection of this research design aligned with the chosen transformative paradigm that encompasses paradigmatic perspectives according to Romm (2015), and allows for the mixed-method approach.

3.4.1 Research Purpose

According to Saunders et al. (2016) researchers have recognized three main objectives for research namely explorative, descriptive, and explanatory. The research design chosen is primarily exploratory. It involves a case study methodology, with Kyebi serving as the specific case under investigation. The case study design facilitated an in-depth examination of S.T.E.A.M education in Kyebi, implementation strategies, and impacts of a Living-Learning Community S.T.E.A.M. Hub incorporating biomimicry principles. The research utilized an exploratory approach as the research aimed to identify what is happening, acquire new insights, ask questions, and respond to issues of qualitative nature as stated by Saunders et al. (2016). This, according to Kogan et al. (2014), is suitable in situations when there is not enough prior research or theories which is the case of the potential of using biomimetic principles in design of a Living-Learning Community S.T.E.A.M Hub in Kyebi, Ghana.

3.4.2 Research Approach

According to Saunders et al. (2019), it may be more appropriate to conduct research deductively rather than inductively if the researcher could describe what is happening rather than be more interested in understanding why something is happening. An abductive approach moves back and forth instead of moving from theory to data (as in deduction), or data to theory (as in induction), thus integrating deduction and induction (Shepherd et al., 2017). An abductive approach may be appropriate for a study in which there is a plethora of knowledge in one context but significantly limited in the context which is being researched, allowing the researcher to alter an existing theory (Saunders et al., 2019). Tavory et al. (2014) suggested that since a well-established abductive approach is most likely to be supported by transformative paradigm due to its flexibility, it can be utilized from several different research philosophies by researchers.

This research adopted the abductive approach integrating both deduction and induction since it seeks to investigate the potential of a Living Learning Community S.T.E.A.M. Hub incorporating biomimicry principles by a deductive approach using quantitative analysis and by inductive approach through qualitative analysis in the form of interviews to derive solutions to short comings in terms of incorporating biomimicry architecture in Ghana and its potential in designing a Living-Learning Community S.T.E.A.M. Hub in Kyebi.

3.4.3 Research Strategies and Methods

Research strategy, according Denzin et al. (2012), is the bridge between the research philosophy and methodologies used for collecting and analyzing the data (Denzin and Lincoln, 2012). According to Saunders et al. (2019), the right research method should be selected based on the research questions and objectives, the depth of existing knowledge on the topic area being explored, the available time and resources, and the researcher's underpinning philosophies. Action Research, Experiments, Case Study, Ground Theory, Ethnography, and Archival Research are some of the prevalent research methodologies available according to Makri et al. (2021)

From the various strategies, this research adopted a combination of action research and the case study strategy following the fact that action research articles are authored by those who had the original intention of effecting change whilst undertaking their research which corresponds with the transformative paradigm (Ollila et al., 2020). The research employed a case study approach to conduct a comprehensive investigation of the impacts of integrating biomimicry principles into a Living Learning Community S.T.E.A.M. Hub within a real-life setting. Following Opoku et al. (2016) perspective, a case study offers an empirical investigation into real-life contexts of contemporary phenomena, particularly when the boundaries between the phenomenon and context are blurred.

In summary, the mixed-methods approach offers the flexibility needed to capture the complexity of your research topic. It allows for a more robust investigation, combining the strengths of both quantitative and qualitative research methods to provide a comprehensive and well-rounded understanding of the potential of biomimicry in S.T.E.A.M. living learning communities in Ghana, with a specific focus on Kyebi.

3.4.4 Time Horizon

To complete the research design, Saunders et al. (2019) noted that it is important to decide whether the research aims to gather data at a specific period (cross-sectional study) or over multiple points of time (longitudinal study). This research adopted the cross-sectional approach to investigate the most recent data that was collected from the February to April, 2024.

3.5 SAMPLING AND POPULATION

Sampling according to Taherdoost (2016), is when researchers investigate a fraction or a sample of a larger group of valid participants and the results are used to establish

a statement that applies to the entire target population or group. A sample frame according to Newby, 2014 is any element of the target population that may be identified and reached to collect research data (Newby, 2014).

3.5.1 Study Population

In research, the population refers to the entire group of individuals or instances under study, representing the larger group of interest. There are two main types of populations: the target population, encompassing the group the researcher aims to study and generalize findings to, and the accessible population, which is a subset of the target population that the researcher can realistically reach and study, considering constraints like time, budget, or logistical challenges (Majid, 2018).

The research participants consist of the stakeholders identified in the literature review. This encompasses S.T.E.A.M. educators in Ghana, biomimicry experts such as architects and lecturers from the Department of Architecture at KNUST, S.T.E.A.M. students in prominent universities in Ghana, the Education Directorate of Kyebi and the local people of Kyebi.

3.5.2 Sampling Technique

The selection of the sampling method for this study is guided by its specific aims. Two primary categories are distinguished: probability sampling and non-probability sampling, as outlined by Groat and Wang (2013) and Rahi (2017). Probability sampling guarantees equal chances of selection for each unit, whereas non-probability sampling does not entail predetermined odds for unit selection, as emphasized by Rahi (2017).

A mixed-method sampling technique which involves the combination of well-established techniques in a creative way to respond to the research questions presented by mixed-method research designs, was adopted for the research. A combined method of purposive and snowball sampling techniques was utilized to develop the sample for the research under discussion. According to purposive sampling which is under the non-probability category of sampling techniques, sample participants based on their knowledge, expertise and relationship regarding the research topic (Emmel, 2013). According to Crossman (2020), snowballing sampling is the non-probability sampling technique (including purposive sampling) in which research starts with a smaller population of known individuals and develops the sample by requesting those initial respondents to suggest others who could be included in the survey (Crossman, 2020).

3.5.3 Sample Size Determination

Because a sample size is dependent on the data analysis type, the precision, and accuracy of the research, and the variables being assessed, the population for the research must first be defined to precisely identify the type of sampling size required for a given study (Singh, 2014). Moreover, Conroy (2015) suggests the sample size be more than 100.

The study meticulously deliberated on the sample size as it significantly influences all statistical techniques employed. The Taro Yamane formula was applied for known populations, while the Cochran's formula was utilized for populations with unknown characteristics. As of 2013, the population of Kyebi Municipal was about 12,000 (Marful et al., 2019). Since the total population is outdated, a projected population, using the exponential growth rate (Ma., 2020), for 2024 was calculated and the sample size was determined using the Taro Yamane formula (Uakarn et al., 2021) using a confidence level of 90% for this calculation.

For the Exponential Growth rate:

PN = PO x (1+ r) N

Where PN = Projected Population after N years

PO = Initial Population (i.e. Population a decade ago)

r = Annual Growth Rate (expressed as a decimal)

N = Number of years of projection

In the case of Kyebi,

PN = 2024 (11 years)

PO = 11, 677 (2013)

r = 2% (0.02)

N = 11 years

P (2024) = 11,677 x $(1+ 0.02)^{11}$

P (2024) = 14, 519 (projected population of Kyebi in 2024)

Using the Taro Yamane formula

$$n = \frac{N}{1+Ne^2}$$

Where n = sample size

N = population size = 14,519. e = error (0.10)

Confidence level = 90% or e= level of precision is set to 0.1

$$n = \frac{14{,}519}{1+14{,}519(0.1)^2}$$

N ≈ 99 A sample size of 92 local residents of Kyebi

Because the total population of the target stakeholders (students and educators) in Ghana is unknown, the Cochran formula was be used for the quantitative data.

$$n = \frac{Z^2 x\ (p)(1-p)}{e^2}$$

n = Sample size, z = Standard normal deviation set at 90% (1.65), p = Estimated proportion of attitude within population (0.5), q = (1-p) = (0.5), e = Confidence interval (0.1)

$$n = \frac{1.65^2 x\ (0.5)(0.5)}{(0.1)^2}$$

n ≈ 68, A sample size of 68

A summary of the total sample size with the various stakeholders for the research is presented in Table 3.1.

Table 3.1 Summary of total sample size

TARGET POPULATION	POPULATION SIZE	FORMULA	SAMPLE POPULATION
Local Residents **GES, Local Chiefs**	12000	Yamane	99
Student (Tertiary)	Unknown	Cochran	68
Built environment professionals	Unknown	Purposive	20
S.T.E.A.M. Advocates	Unknown	Purposive	10
TOTAL		**197**	

(Source: Author's Construct,2024)

3.6 DATA SOURCES AND COLLECTION

Data collection according to Muhammad et al. (2016) is the systematic process that involves the acquiring and measuring of the information on variables of interest to answer a research question, test a hypothesis and evaluate results.

The research objectives stated in earlier sections of this research constituted the foundation for acquiring data. From the definitions provided by Best (2014), primary and secondary data were employed to address the specific research issue at hand. The survey, aiming to contribute to existing knowledge, gathered primary data from respondents, while additional secondary data was extracted from literature and previous studies. In this study, primary data was mainly utilised and was acquired through the author's field survey.

The data collection methods encompassed observations, photography, and questionnaire surveys. The use of questionnaires targeted relevant groups to ensure comprehensive and necessary responses. The judicious integration of these two data sources ensured the study's comprehensiveness, relevance, and reliability of findings and recommendations.

The subsequent Table 3.2 illustrates the research objectives, their corresponding data collection points, and the instruments employed for data collection.

Table 3.2 Data Sources and Instruments

RESEARCH OBJECTIVES	DATA REQUIRED	DATA SOURCE	INTRUMENTS
1. Identify how S.T.E.A.M. education is currently progressing in Ghana.	1. Current state of S.T.E.A.M. Education in Ghana.	1. Literature 2. Sampled Respondents 3. Interviews	1. Literature Review 2.Questionnaires 3. Interview Guides
2. Investigate the potential of Living-Learning Communities for S.T.E.A.M.	1. State of Kyebi 2. The need for an LLC	1. Literature 2. Sampled Respondents 4. Interviews	1. Literature Review 2.Questionnaires

	S.T.E.A.M. Hub in Kyebi		3. Interview Guides
3. Examine the challenges and opportunities in implementing biomimicry in S.T.E.A.M. living-learning communities in Kyebi.	1. Opportunities 2. Implementation Strategies 3. Challenges	1. Literature 2. Sampled Respondents 3. Interviews	1. Literature Review 2.Questionnaires 3. Interview Guides
4. Apply the concept biomimicry to design a sustainable Living-Learning Community S.T.E.A.M. Hub in Kyebi.	1. Design guidelines 2. Design Brief	1. Literature 2. Sampled Respondents 3. Interviews	1. Literature Review 2.Questionnaires 3. Interview Guides
State of community report	*Biodiversity of Kyebi, Topography of site*	*Field Survey, Google maps, Drone Images*	*Visual Survey (Photos, Observation, Sketches)*

The distinctive characteristics of the research necessitated the utilization of both primary and secondary data. To accommodate time limitations, the qualitative and quantitative data gathering processes was carried out simultaneously. The structured questionnaires and interview guides were predominantly employed for the field survey, while photographs were utilised for the case study to record the present state of Kyebi. Additionally, the study area was evaluated using existing urban maps and Google Maps.

3.6.1 QUESTIONNAIRES (Construction and Structure)

Structured questionnaires were utilized as the main research instrument for the first section of this research. The questionnaires were divided into five (5) parts, each

addressing a different component of the study based on the research objectives. A prologue introducing the research was added as part of the questionnaires to give the respondents a fair idea of what the survey aims to accomplish. The first part of the questionnaire captured general information about the participants, ranging from the name of their university, and their level of education. Part two of the questionnaire centered on the current state of S.T.E.A.M. education in Ghana. Part three focused on investigating the perspectives of educators, students, and community members on the potential of Living-Learning Communities for S.T.E.A.M. The fourth part eexamined the challenges and opportunities in implementing biomimicry in S.T.E.A.M. living-learning communities in Kyebi. Finally, part five focused on determining how biomimicry can be applied to design a sustainable S.T.E.A.M. Living Learning Community in Kyebi. Each of the aforementioned variables has majority of sub-questions with a five-point scale to deduce the opinions of the respondents and some open-ended questions for more details.

Some of the questionnaires were distributed and data collected for the research using an online survey platform accessible via URL links while some of the forms were printed out were convenient. Google Forms was used for the construction of the instrument.

3.6.2 INTERVIEWS

An interview, according to Rowley (2012), is a social interaction in which participants cooperate to offer retrospective and prospective accounts or versions of their past or future acts, experience, emotions and ideas. The methods for obtaining those experiences include open-ended, unstructured techniques that may seem more like a friendly discussion than a data-gathering interview (Roulston et al., 2018) to highly structured protocols with predefined and standardized questions from which an insignificant variation occurs.

Interviews with various stakeholders including educators, students, biomimicry specialist who are architects, traditional council in Kyebi and the municipal assembly will be conducted for this study to collect qualitative data informed by the literature review, with a focus on the impact and potential of biomimicry in S.T.E.A.M. living learning communities in Kyebi and suggestions from the participants on their expectations regarding the design of the S.T.E.A.M. Hub. Interviews with focus

groups will be conducted first, followed by a few selected one-on-one interviews for some more information especially from experts.

3.7 DATA ANALYSIS TECHNIQUES

This research adopted the mixed-method approach for its data analysis considering there are three outlined choices in the research process onion including the Mono, Mixed, and Multi-method of quantitative and qualitative research choice (Saunders et al., 2016). A structured, close-ended questionnaire-based survey was administered via survey links. A Likert scale which is a rating scale that researchers use to rate opinions, attitudes, or the behaviour of people according to Bhandari (2020) was utilized for this research with a numeric range from 1 to 5 arranged in the order of; 1- Strongly Disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, and 5 – Strongly Agree.

According to Cohen et al. (2017), qualitative data analysis entails organizing, accounting for, and making meaning of data according to the participant's interpretation of the circumstance, recognizing patterns, themes, groups, and regularities.

During this research, after the collection of the raw data, the data was organized and analyzed. For the analysis of closed-ended questionnaires, the Statistical Package for Social Sciences (SPSS) now known as IBM SPSS Statistics will be analyzed by descriptive statistics using frequency tables and from these, the data will be presented in pie diagrams and bar graphs.

The data acquired from interviews were analyzed using thematic content analysis based on the research objectives. Vaismoradi et al. (2016) suggest that thematic analysis is utilized when data is organized into themes and sub-themes, enabling comparison and simplification of data. This method yields outcomes suitable for quantitative measurement, aiding in the research process.

The combination of both methods will enable a comprehensive interpretation of the findings, providing a holistic understanding of the potential of biomimicry in S.T.E.A.M. living learning communities.

3.8 ETHICAL CONSIDERATION

The researcher has an ethical responsibility to protect the rights and welfare of the participants in the study (McMillan & Schumacher, 2011). Before the data collection begun for this research, the questionnaires were reviewed by the academic supervisor and accepted with an introductory cover letter attained from the University Department

of Architecture to introduce the researcher to the local authorities and seek their assistance during the research period.

In addition, participants were fully informed about the objectives of the research and reassured that their responses will be treated confidentially and used specifically for academic purposes specific to the research. Apart from the aforementioned, participants will not be physically or psychologically mistreated or abused throughout the research. In contrast, there will be an attempt to create and maintain an atmosphere of comfort.

3.9 THE METHODOLOGICAL LIMITATIONS

The study acknowledges potential limitations, such as the generalizability of findings beyond the specific context of Kyebi and the subjective nature of qualitative data. These limitations were considered in the interpretation of results from the findings.

3.10 RESEARCH METHODOLOGY FRAMEWORK

The methodological approach utilized in conducting this study is encapsulated within the framework presented in Figure. This framework serves provides the specifics pertaining to the research paradigm to the data analysis techniques employed.

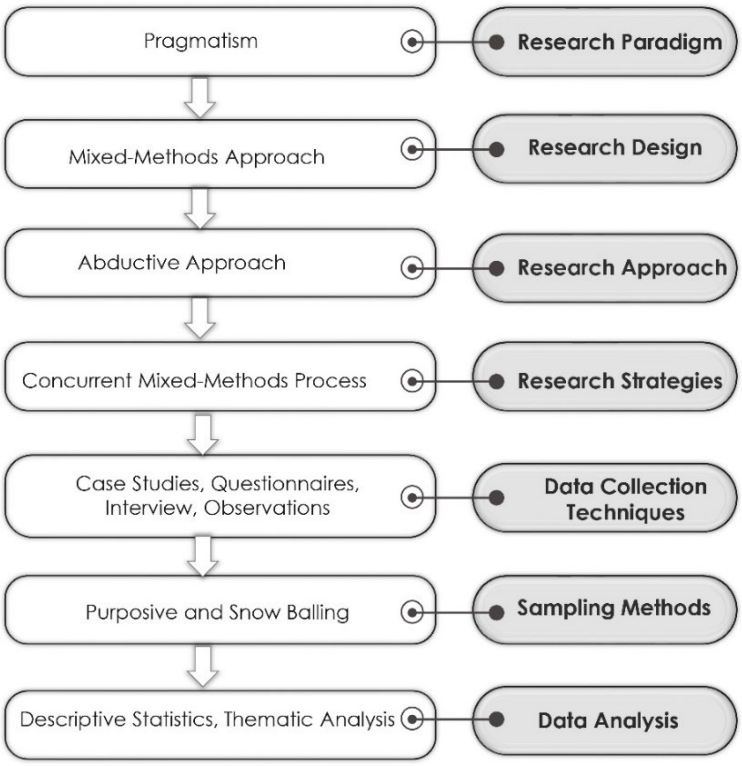


Figure 3.2 Research Methodology Framework (Source: Author's Construct, 2024)

3.11 CHAPTER SUMMARY

This chapter outlined the research design that guided the research relating to the exploration of the potential of biomimicry for S.T.E.A.M. living learning communities in Ghana, with Kyebi as a focal point. The chapter began by restating the purpose of the research and providing a philosophical positioning of the research and a description of the research design. The research population and determined sample size were highlighted from the projected population of Kyebi in this chapter. The multi-method approach and data collection techniques utilizing a questionnaire and interviews were also discussed. The chapter further presented a summary of how the data would be presented and analyzed. Lastly, the ethical considerations for the study were also highlighted.

CHAPTER FOUR

4.0 FINDINGS AND DISCUSSIONS

4.1 CHAPTER OVERVIEW

This chapter presents the findings and analysis of data collected during the research, employing descriptive analysis and frequency techniques. The Statistical Package for the Social Sciences (SPSS), version 26, was utilized for statistical chart generation and standard deviation calculations. Descriptive statistics, including mean, median, mode, variance, standard deviation, and skewness, were used to summarize the dataset and assess its distribution normality. Data from a questionnaire consisting of five sections, focusing on respondents' backgrounds and research objectives, was analyzed separately for local residents, students, S.T.E.A.M. educators/advocates, and built environment professionals to allow for varied opinion comparisons. Additionally, qualitative analyses from interviews with stakeholders were analyzed to understand their opinions on S.T.E.A.M. education, Living-Learning Communities, and the potential of Biomimicry architecture for S.T.E.A.M. Hub design, and related issues. Findings are contextualized within existing literature to highlight similarities and differences with previous studies.

4.2 DEMORAPHIC PROFILE OF RESPONDENTS

The demographic information served to contextualize the participants' backgrounds. A heterogeneous cohort of respondents was purposefully selected from the sample population to ensure representation of various characteristics inherent in the target population. This deliberate sampling strategy facilitated the capture of a diverse range of perspectives. Employing a questionnaire containing a blend of open and close-ended questions, the survey sought to elicit responses that encompassed both quantitative and qualitative data.

The study categorized the target population based on the demographic information provided in section 1 of the questionnaire, ensuring the validity and reliability of the collected data. Participants were divided into two groups: one comprising respondents from the Kyebi locality and the other representing stakeholders from outside Kyebi, as outlined in Tables 4.1 and 4.2, respectively.

Table 4.1 Profile and The Respondent Rate of The Respondents from Kyebi

RESPONDENTS (Kyebi)	NUMBERS SENT	NUMBER OBTAINED	RESPONSE RATE (%)
Local Residents	89	89	100
Traditional Council	2	2	100
Municipal Assembly (GES)	1	1	100
Educators	5	4	80
STEAM Advocates	2	2	100
Total	**99**	**98**	**98.98%**

(Source: Author's Construct,2024)

Table 4.1 outlines the composition of local residents surveyed, primarily comprising students and educators from various educational institutions, such as Junior High Schools, Senior High Schools, a Vocational/Technical School, and a Teacher Training College in Kyebi. Additional data was gathered from tertiary students engaged in distance learning programs through the snowballing method. Data collection involved the use of questionnaires, predominantly featuring closed-ended questions, resulting in a 100% response rate due to the respondents' accessibility. Interviews were conducted with representatives from Kyebi's traditional council to explore cultural influences on education. Further interviews were held with the Educational Directorate of the Kyebi Municipal Assembly, educators, and S.T.E.A.M. Advocates to delve deeper into their perspectives, ensuring comprehensive insights. The local respondents demonstrated a response rate of 98.98%.

Table 4.2 Profile and The Respondent Rate of the other Stakeholders

RESPONDENTS (Others)	NUMBERS SENT	NUMBER OBTAINED	RESPONSE RATE (%)
Tertiary Students	68	48	70.59
STEAM Educators/ Advocates	10	9	90
Built Environment Professionals	20	14	70
Total	**98**	**72**	**73.47%**

(Source: Author's Construct,2024)

Table 4.2 delineates the second participant category, predominantly comprising tertiary students from universities, notably KNUST, in addition to build environment professionals and STEAM educators/advocates. Data collection methodologies varied, employing questionnaires for students and a combination of questionnaires and interviews for STEAM educators and built environment professionals. This approach was selected to ensure adaptability, improve clarity in responses, and explore diverse perspectives comprehensively. Data from tertiary students outside Kyebi were incorporated to align with the study's inclusive program objectives spanning multiple educational levels. Despite their absence within Kyebi, their insights remained pertinent to the research objectives.

Table 4.3 illustrates an overview of the respondents representing diverse stakeholder groups. The predominant stakeholders, comprising 56.3% of the total population, are the residents of Kyebi, who hold significant relevance to this study. Tertiary students from outside the community constitute 30.4% of the respondents and are deemed highly pertinent to the research objectives. Additionally, 7.6% of the participants belong to the built environment sector, primarily architects, selected for their familiarity with biomimicry architecture principles.

Table 4.3 Overall Stakeholder Distribution Chart

	Frequency	Percent	Valid Percent
Resident of Kyebi	89	56.3	56.3
Educator	5	3.2	3.2
KNUST Student	48	30.4	30.4
S.T.E.A.M. Advocate	4	2.5	2.5
Built environment Professional	12	7.6	7.6
Total	**158**	**100.0**	**100.0**

(Source: Author's Construct,2024)

4.2.1 Demographic Profile of Kyebi Locals

As presented in Table 4.4, educators make up 13.5%, tertiary students represent 3.4%, teacher training students comprise 27.0%, vocational/technical students account for 13.5%, senior high school students constitute 33.7%, and junior high school students comprise 9.0% of the participants from Kyebi.

Table 4.4 Demographic Profile of Kyebi Locals

	Frequency	Percent	Valid Percent
J.H. S	8	9.0	9.0
S.H.S	30	33.7	33.7
Vocational/Technical	12	13.5	13.5
Teacher Training	24	27.0	27.0
Tertiary	3	3.4	3.4
Educator	12	13.5	13.5
Total	**89**	**100.0**	**100.0**

(Source: Author's Construct,2024)

This data showed a notable presence of senior high school students and teacher training students, which was deliberate since they comprise the major target group for the research. Their willingness to participate indicates they have considerable interest in community development initiatives within the education sector.

4.2.2 Demographic Profile of Tertiary Students

The demographic profile of tertiary student participants mainly from KNUST indicates a diverse representation across various academic disciplines. Specifically, the Faculty of Built Environment comprises the largest proportion of participants at 29.2%, followed by the Faculty of Arts with 14.6%. Additionally, the Faculty of Electrical and Computer Engineering and the Faculty of Mechanical and Chemical Engineering each represent 10.4% of the participants, same as the Faculty of Educational Studies. The School of Medicine and the Faculty of Allied Health Sciences both contribute 8.3%, reflecting interest and engagement from students in healthcare-related fields. A summary of the data is presented in Table 4.5

Table 4.5 Demographic Profile of Tertiary Students

	Frequency	Percent	Valid Percent
Faculty of Built Environment	14	29.2	29.2
Faculty of Educational Studies (FES)	5	10.4	10.4
Faculty of Arts	7	14.6	14.6

Faculty of Civil and Geo-Engineering	4	8.3	8.3
Faculty of Mechanical and Chemical Engineering	5	10.4	10.4
Faculty of Electrical and Computer Engineering	5	10.4	10.4
Faculty of Allied Health Sciences	4	8.3	8.3
School of Medicine and Dentistry	4	8.3	8.3
Total	**48**	**100.0**	**100.0**

(Source: Author's Construct,2024)

This distribution highlights the interdisciplinary nature of the research topic. The significant representation from the Faculty of Built Environment highlights the relevance of the study's focus on biomimicry principles and sustainable design within the context of the Living Learning Community S.T.E.A.M. Hub.

4.2.3 Demographic Profile of STEAM Educators/Advocates

In Table 4.6, the demographic profile of STEAM educators/advocates reveals a notable presence of educators, constituting 55.6% of the participants. This high proportion indicates a strong representation from professionals directly involved in teaching and promoting S.T.E.A.M. education. Additionally, STEAM advocates account for 44.4% of the participants, demonstrating a significant engagement from individuals passionate about advocating for interdisciplinary education and its integration into various educational settings.

Table 4.6 Demographic Profile of STEAM Educators/Advocates

	Frequency	**Percent**	**Valid Percent**
Educator	5	55.6	55.6
S.T.E.A.M. Advocate	4	44.4	44.4
Total	**9**	**100.0**	**100.0**

(Source: Author's Construct,2024)

This distribution suggests a shared commitment among educators and advocates to explore innovative approaches and strategies for enhancing S.T.E.A.M. education delivery and fostering a supportive ecosystem for interdisciplinary learning.

4.2.4 Demographic Profile of Built Environment Professionals

The demographic profile of Built Environment Professionals reveals a diverse representation of professionals contributing to the discourse on S.T.E.A.M. education and biomimicry in design. Architects constitute the majority at 50.0%. Engineers and Urban Planners each represent 16.7% of the participants. Additionally, Environmental Designers and Building Construction Specialists contribute 8.3% each. A summary of the data is presented in Table 4.7

Table 4.7 Demographic Profile of Built Environment Professionals

	Frequency	Percent	Valid Percent
Architect	6	50.0	50.0
Urban Planner	2	16.7	16.7
Building Construction Specialist	1	8.3	8.3
Engineer	2	16.7	16.7
Environmental Designer	1	8.3	8.3
Total	**12**	**100.0**	**100.0**

(Source: Author's Construct,2024)

This diverse representation underscores the interdisciplinary nature of the research, emphasizing the collaboration between professionals from various built environment disciplines to explore innovative approaches to design and education. The balanced distribution of participants across different professional roles signifies a collective effort to integrate biomimicry principles and promote sustainable design practices within educational settings.

4.2.5 Demographic Profile of Interviewees

Table 4.8 summarize the demographic data of the interviewees. Educators from Kyebi represent the largest portion at 33%, indicating a significant involvement from local

educators invested in shaping educational practices within their community. Traditional council members of Kyebi contribute 17%, demonstrating the engagement of local leadership in discussions concerning educational development and community initiatives.

Table 4.8 Demographic Profile of Interviewees

	Frequency	Percent	Valid Percent
Traditional Council (Kyebi)	2	17	17
Educator (Kyebi)	4	33	33
GES (Kyebi)	1	8	8
S.T.E.A.M Advocates (Kyebi)	2	17	17
Built Environmental Professional	2	17	17
STEAM Advocate	1	8	8
Total	**12**	**100.0**	**100.0**

(Source: Author's Construct,2024)

Additionally, Built Environment professionals and STEAM Advocates each represent 17%. Representatives from the Ghana Education Service (GES) constitute 8% of the interviewees, reflecting the involvement of government bodies in educational policy discussions. The balanced representation of stakeholders from various sectors highlights the inclusive approach taken to gather insights and perspectives from diverse perspectives, ensuring a comprehensive understanding of the challenges and opportunities in implementing S.T.E.A.M. education initiatives within the Kyebi community.

4.2.6 Gender Distribution of Respondents

The collection of gender data in the research is vital for promoting equity and inclusivity within the STEAM field as understanding gender-specific differences in learning styles allows for tailored interventions, optimizing educational outcomes for all participants. In the Ghanaian context, where societal norms intersect with gender dynamics, such data provides insights into the influence of socio-cultural factors on attitudes and behaviors related to STEAM education and LLCs. From the data collected as represented in the Figure 4.1, the percentage of male and female

participants were close as the male made-up 51.27% whilst the female was 48.73%. as illustrated in Figure 4.1.

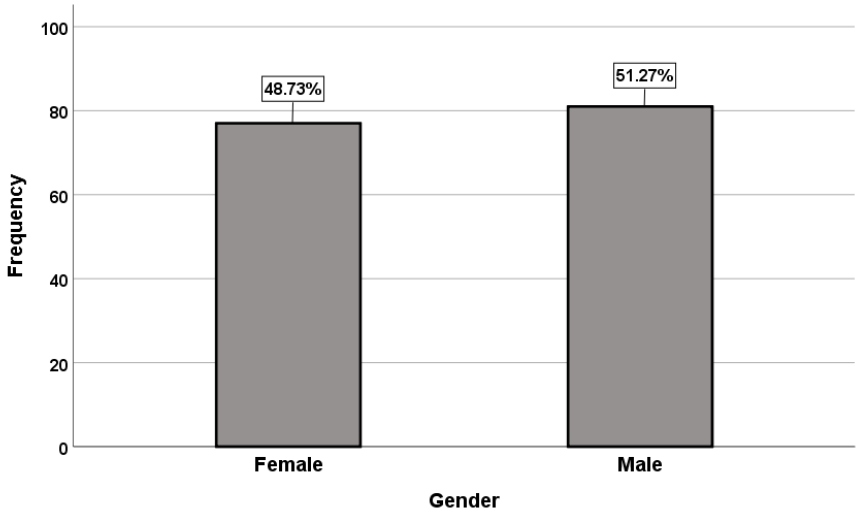


Figure 4.1 Overall Gender Distribution of the Respondents

(Source: Author's Construct,2024)

The close percentages ensure that the research findings are reflective of both male and female perspectives, enhancing the validity and comprehensiveness of the study's conclusions. It also signifies that the research captures a diverse range of experiences and insights from participants. The same thing applied to the participants of the interviews conducted as seen in the Figure 4.2.

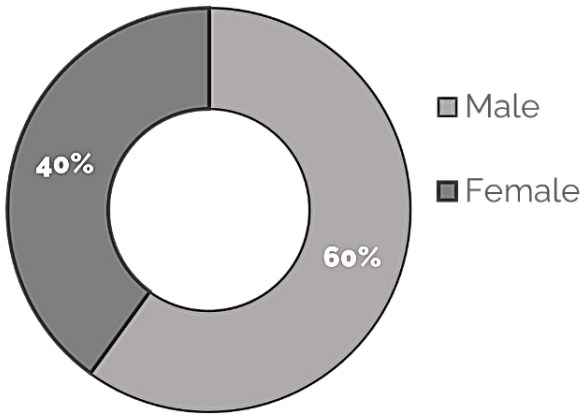


Figure 4.2 Overall Gender Distribution of the Interviewees

(Source: Author's Construct,2024)

Among the nine interviews conducted, 60% of the respondents were male. This distribution is influenced by engagements with representatives from the Kyebi traditional council on culture and STEAM education and architects with expertise in

biomimicry architecture. The remaining 40% of interviewees were predominantly female, comprising educators and STEAM Advocates.

4.2.7 Respondents' Level of Familiarity with Research Topics

Assessing respondents' familiarity with the research topic using the Likert scale (1=Not familiar at all, 2=Slightly familiar, 3=Moderately Familiar, 4= Very Familiar, and 5=Extremely familiar) provided a foundational knowledge and enabled tailored analyses, aiding in the identification of knowledge gaps within the participant cohorts for targeted interventions. This is to ensures data integrity, validates findings, and enhances research outcomes by capturing nuanced perspectives while guarding against inaccuracies.

From Figure 4.3, the data reveals a significant lack of familiarity among respondents with biomimicry architecture, Living-Learning Communities (LLCs), and S.T.E.A.M. education. Approximately 70% of respondents reported being not familiar at all with biomimicry architecture, indicating a considerable gap in understanding this innovative design approach. Similarly, 75% of respondents indicated no familiarity with LLCs, suggesting limited awareness of collaborative educational environments.

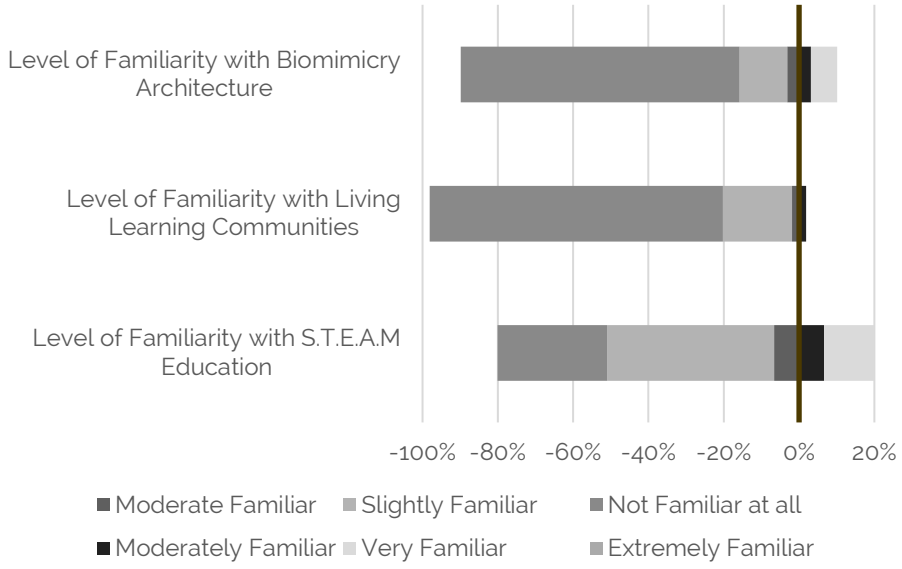


Figure 4.3 Respondents' Level of Familiarity with Research Topics

(Source: Author's Construct,2024)

For S.T.E.A.M. education, 30% of respondents reported being not familiar at all, indicating a moderate level of awareness compared to the other concepts. However, the majority of respondents still demonstrated limited familiarity with S.T.E.A.M.

education. Interviews were conducted with experts on the topics to make up for the gaps in knowledge by the participants.

4.2.7.1 Respondents' Level of Familiarity STEAM Education

Table 4.9 provides a general summary of the overall frequency distribution of respondents based on their level of familiarity with STEAM education. The data reveals that the largest proportion of respondents, comprising 44.3%, were "Slightly familiar", followed by 29.1% who indicated "Not familiar at all" . Additionally, both "Moderately Familiar" and "Very Familiar" categories were selected by 13.3% of the respondents each. Notably, none of the respondents selected the highest level of familiarity, "Extremely familiar".

Table 4.9 Respondents Level of Familiarity with the STEAM Education

Level of Familiarity	Frequency	Percentage %	Valid Percentage%	Cumulative Percentage %
1. Not Familiar at al	46	29.1	29.1	29.1
2. Slightly Familiar	70	44.3	44.3	73.4
3. Moderately Familiar	21	13.3	13.3	86.7
4. Very Familiar	21	13.3	13.3	100
Total	158	100	100	

(Source: Author's Construct,2024)

Among built environment professionals, 50% reported being not familiar at all with S.T.E.A.M. education, indicating a significant lack of awareness within this demographic. In contrast, educators/advocates demonstrated a higher level of familiarity, with 80% reporting being very familiar, suggesting a stronger understanding and engagement with S.T.E.A.M. education concepts. Tertiary students exhibited a mixed level of familiarity, with 35% reporting not being familiar at all and 20% being very familiar, indicating a need for targeted educational initiatives to enhance understanding among this group. Similarly, Kyebi locals displayed varying degrees of familiarity, with 60% being slightly familiar and only 5% very familiar, indicating a moderate level of awareness overall. A summary of the data is summarized in Figure 4.4. educators/advocates, tertiary students, and Kyebi locals.

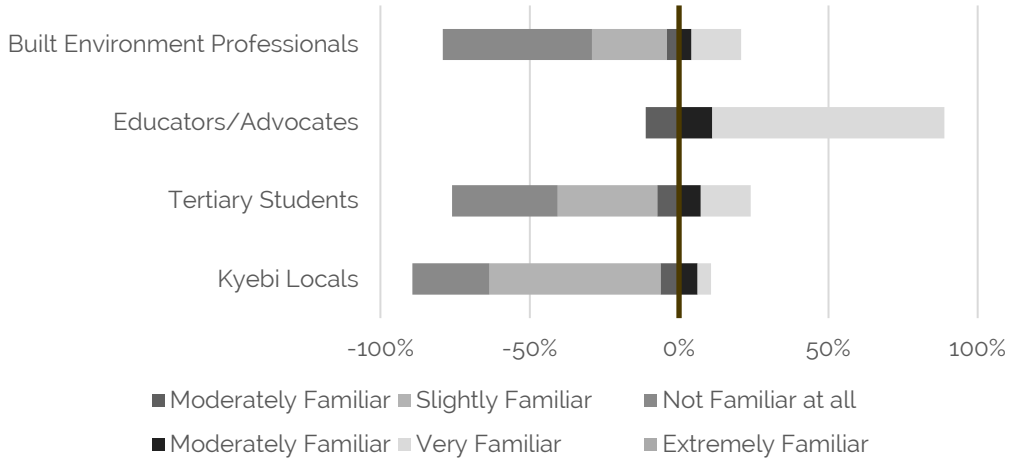


Figure 4.4 Respondents' Level of Familiarity STEAM Education

These findings suggested that STEAM educators and Advocates opinion on the data relating to STEAM education will hold more validity to the research. Also interviews with experts in STEAM education will be very critical for the research.

The distribution of responses in Figure 4.5 indicates that the majority of respondents have a limited to moderate level of familiarity with STEAM education, with higher percentages observed in the lower categories of the Likert scale. Notably, there were no responses in the "Extremely familiar" category, suggesting a lack of highly knowledgeable individuals in the field of STEAM education. Among the 158 respondents surveyed, a notable concentration was observed towards the lower end of the scale, with 29.1% selecting "Not familiar at all" and 44.3% choosing "Slightly familiar." Conversely, fewer respondents indicated higher levels of familiarity, with 21 selecting "Moderately Familiar" and an equal number choosing "Very Familiar."

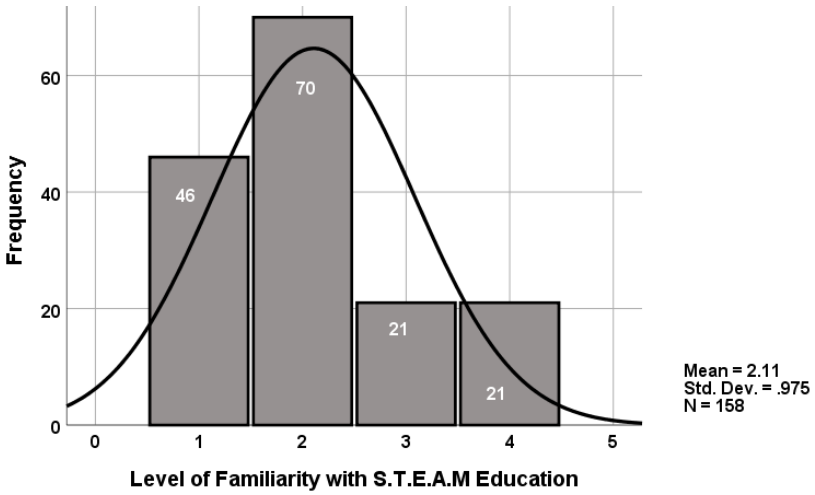


Figure 4.5 Respondents Knowledge of STEAM Education

(Source: Author's Construct,2024)

The calculated mean value of 2.11 suggests an average rating closer to "Slightly familiar," indicating a baseline awareness of STEAM education among respondents. The standard deviation of 0.975 suggests a moderate level of consistency in respondents' ratings, with responses clustered relatively close to the mean, as represented by the bell curve on the histogram in Figure 4.4. Overall, these findings underscore the need for further education and awareness initiatives to enhance familiarity and understanding of STEAM concepts among the surveyed population.

4.2.7.2 Respondents' Level of Familiarity Living-Learning Communities

Table 4.10 presents general summery of the frequency distribution of respondents' familiarity with Living-Learning Communities. The majority of respondents, comprising 77.8%, selected "Not familiar at all", indicating a significant lack of awareness or understanding of Living-Learning Communities among the surveyed population. Additionally, 18.4% of respondents chose "Slightly familiar", suggesting a small proportion with some basic knowledge or awareness of Living-Learning Communities. Only a minimal percentage of respondents, 3.8%, indicated "Moderately Familiar" , while there were no respondents who selected "Very Familiar" or "Extremely familiar" categories.

Table 4.10 Respondents Familiarity with the Living-Learning Communities

Level of Familiarity	Frequency	Percentage %	Valid Percentage%	Cumulative Percentage %
1. Not Familiar at all	123	77.8	77.8	77.8
2. Slightly Familiar	29	18.4	18.4	96.2
3. Moderately Familiar	6	3.8	3.8	100
Total	158	100	100	

(Source: Author's Construct,2024)

In Figure 4.6, the data reveals varying levels of familiarity with Living-Learning Communities (LLCs) among different respondent groups, including built environment professionals, educators/advocates, tertiary students, and Kyebi locals. Among built

environment professionals, a significant majority (60%) reported being not familiar at all with LLCs, indicating a substantial lack of awareness within this demographic. Similarly, educators/advocates exhibited a high level of unfamiliarity, with 55% reporting no familiarity at all, suggesting a need for increased awareness and education regarding the concept of LLCs within this group. Tertiary students also displayed a considerable lack of familiarity, with 65% reporting no familiarity at all, highlighting a potential gap in understanding among this demographic. Kyebi locals demonstrated the highest level of unfamiliarity, with 85% reporting no familiarity at all, indicating a widespread lack of awareness about LLCs within the local community.

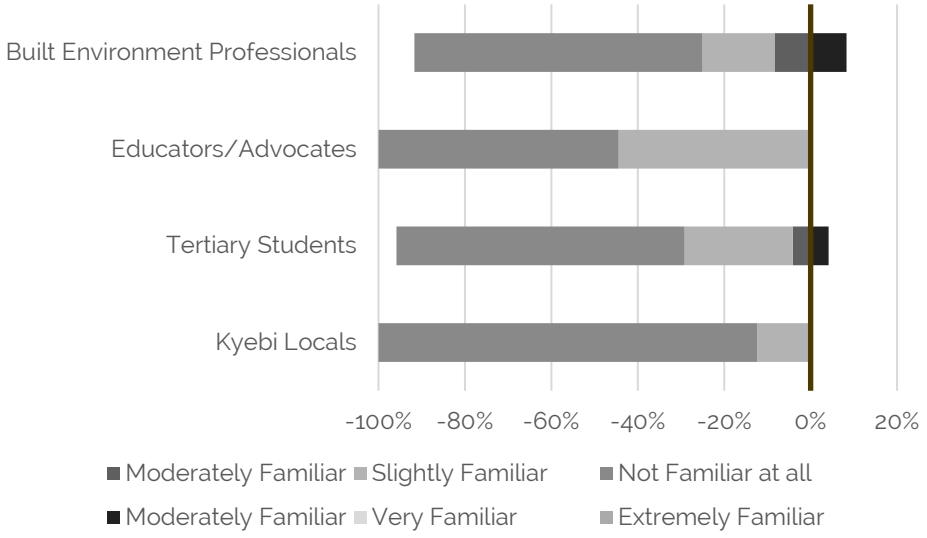


Figure 4.6 Respondents' Level of Familiarity Living-Learning Communities

(Source: Author's Construct,2024)

The data from Figure 4.7 reveals a notable gap in familiarity with Living-Learning Communities among respondents, with the majority showing a lack of awareness or knowledge about this concept.

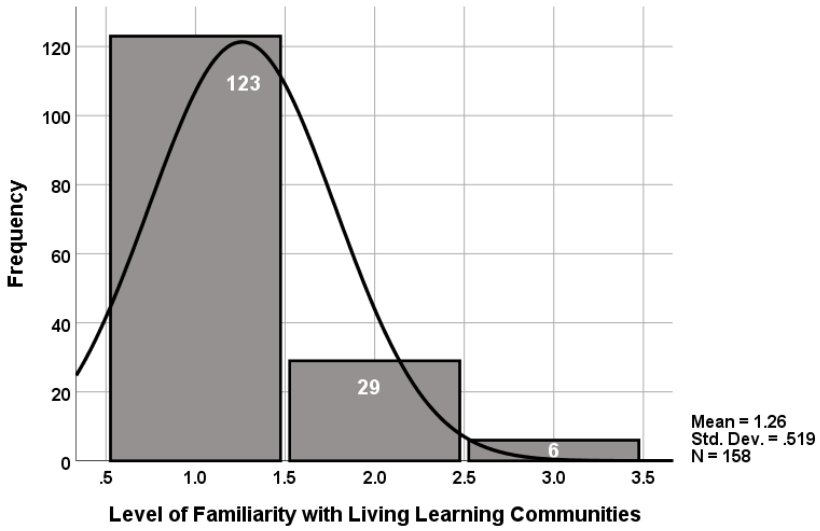


Figure 4.7 Respondents Familiarity Living-Learning Communities

(Source: Author's Construct,2024)

The distribution highlights a significant concentration of respondents towards the lower end of the familiarity spectrum, with 77.8% selecting "Not familiar at all" (1). Only a small proportion indicated higher familiarity levels, suggesting a need for increased education and awareness initiatives to promote understanding and engagement with Living-Learning Communities. The calculated mean value of 1.26 indicates that respondents' familiarity leans heavily towards the lower end of the Likert scale. Additionally, the low standard deviation of 0.519 suggests a relatively low level of variability in familiarity levels among respondents, with responses clustered closely around the mean. This is evidence of the gap in research regarding LLCs in Ghana.

4.2.7.3 Respondents' Level of Familiarity Biomimicry Architecture

From the data gathered, the majority of the respondents (74.1%) selected "Not familiar at all", indicating a widespread lack of awareness. 12.7% chose "Slightly familiar" (2), 6.3% "Moderately Familiar" (3), and 7.0% "Very Familiar" (4), with no respondents selecting "Extremely familiar" (5). This underscores a notable gap in familiarity, with most respondents lacking awareness of Biomimicry Architecture. Table 4.11 reveals a general summary of the respondents' familiarity with Biomimicry Architecture.

Table 4.11 Respondents Level of Familiarity with Biomimicry Architecture

Level of Familiarity	Frequency	Percentage %	Valid Percentage %	Cumulative Percentage %
1. Not Familiar at all	117	74.1	74.1	74.1
2. Slightly Familiar	20	12.7	12.7	86.7
3. Moderately Familiar	10	6.3	6.3	93.0
4. Very Familiar	11	7.0	7.0	100
Total	158	100	100	

(Source: Author's Construct,2024)

Limited responses in higher familiarity categories suggest a need for increased education and awareness initiatives to promote understanding and engagement with Biomimicry Architecture. Moreover, the relatively low percentages in these categories highlight the potential for further exploration of factors contributing to low familiarity levels and the development of targeted strategies to address them effectively. Overall, this analysis emphasizes the importance of increasing awareness and understanding of Biomimicry Architecture to foster innovation and sustainability in architectural design practices.

In Figure 4.8, the data highlights varying levels of familiarity with Biomimicry architecture among different respondent groups, including built environment professionals, educators/advocates, tertiary students, and Kyebi locals. Among built environment professionals, a notable portion (10%) reported being not familiar at all with Biomimicry architecture, while the majority exhibited varying degrees of familiarity, with 30% slightly familiar, 30% moderately familiar, and 30% very familiar. This suggests a relatively higher level of awareness and understanding of Biomimicry architecture within this demographic, reflecting potential expertise in sustainable design principles.

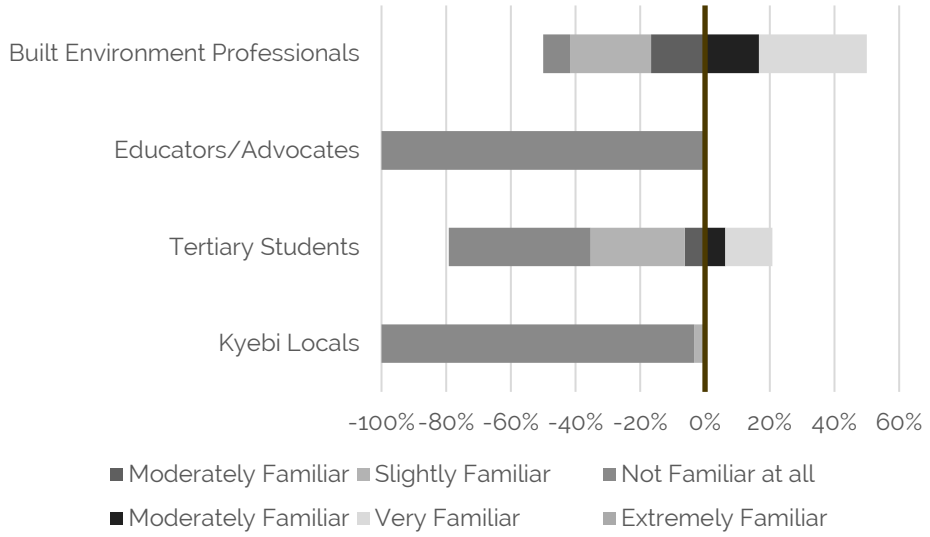


Figure 4.8 Respondents' Level of Familiarity Biomimicry Architecture

(Source: Author's Construct,2024)

However, it is noteworthy that all educators and advocates reported not being familiar at all with Biomimicry architecture, indicating a significant gap in knowledge and awareness among this group. Similarly, tertiary students demonstrated a notable lack of familiarity, with 40% reporting no familiarity at all, suggesting a need for increased education and exposure to Biomimicry concepts within academic curricula. Kyebi locals also displayed a high level of unfamiliarity, with 95% reporting no familiarity at all, underscoring the need for community outreach and educational initiatives to promote awareness and understanding of Biomimicry architecture at the local level.

Figure 4.9 illustrates a histogram chart of respondents' familiarity with Biomimicry Architecture, indicating a predominant concentration towards lower familiarity levels. Specifically, 74.1% of respondents selected "Not familiar at all" (1), while 12.7% chose "Slightly familiar" (2), 6.3% "Moderately Familiar" (3), and 7.0% "Very Familiar" (4), with no respondents selecting "Extremely familiar" (5). The mean value of 1.46 suggests low average familiarity with Biomimicry among respondents.

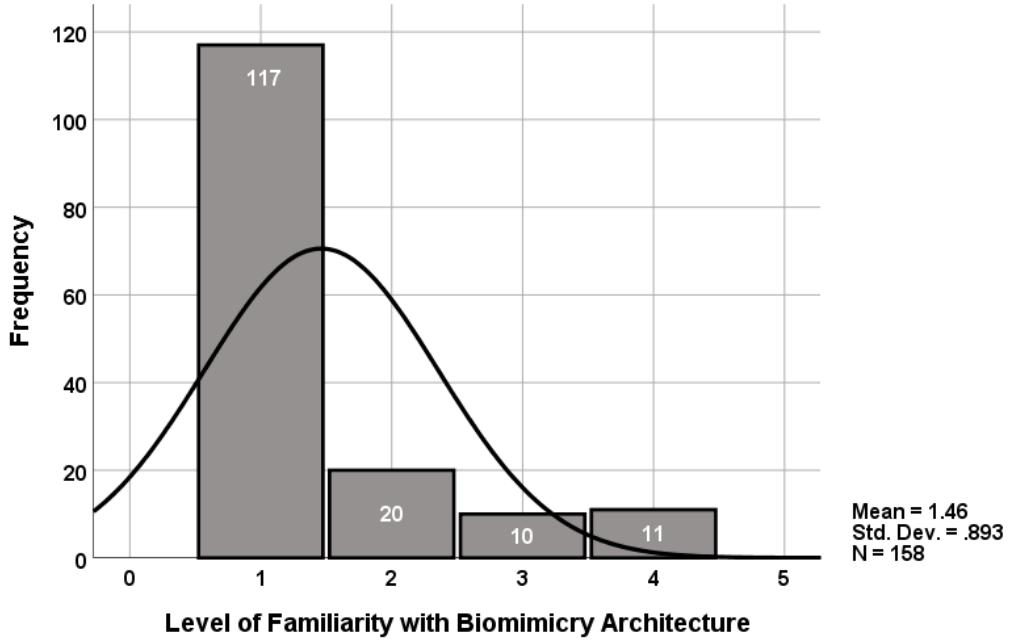


Figure 4.9 Respondents Knowledge of Biomimicry Architecture

(Source: Author's Construct,2024)

The relatively low standard deviation of 0.893 suggests moderate consistency in respondents' familiarity levels, with responses clustered closely around the mean, as depicted in Figure 4.9. These findings also underscore the significant gap in familiarity with Biomimicry Architecture, highlighting the need for increased education and awareness initiatives to promote understanding and engagement with this innovative approach.

Table 4.12 summarizes the level of familiarity with STEAM education, Living-Learning communities, and Biomimicry Architecture. STEAM education has a mean familiarity level of 2.11, Living-Learning communities have a mean familiarity level of 1.26, and Biomimicry Architecture has a mean familiarity level of 1.46. These statistics are evidence of the varying levels of familiarity across the three topics and highlight the importance of targeted strategies to enhance awareness and knowledge among the surveyed population.

Table 4.12 Summary of the Mean and Standard Deviation of Level of Familiarity

		S.T.E.A.M Education	Living Learning Communities	Biomimicry Architecture
N	Valid	158	158	158
	Missing	0	0	0
Mean		2.11	1.26	1.46
Median		2.00	1.00	1.00
Std. Deviation		0.975	0.519	0.893

(Source: Author's Construct,2024)

Table 4.12 shows varying familiarity levels among respondents for each topic. STEAM education is the most familiar, with a mean familiarity slightly above the midpoint of the Likert scale. Living-Learning communities have lower familiarity compared to STEAM education, with a mean below the midpoint and a narrower spread of responses indicated by the lower standard deviation. Biomimicry Architecture has the lowest familiarity level, closer to the lower end of the Likert scale and a relatively higher standard deviation.

4.3 S.T.E.A.M. AND ITS CULTURAL SIGNIFICANCE IN GHANA

The **Objective 1** of the research delved into the progression of STEAM education and its cultural significance in Ghana, particularly in the town of Kyebi. It seeks to gauge stakeholders' perceptions of the benefits of STEAM education and understand the reason for the neglect of STEAM in the Ghanaian context. By collecting data through questionnaires and interviews from various stakeholders, including residents of Kyebi, tertiary students, STEAM educators/advocates, and built environment professionals, this study seeks to provide insights into the status quo of STEAM education in Ghana and to propose recommendations for its advancement.

4.3.1 Benefits of STEAM Education

The research presented the recognized advantages of STEAM education, as outlined in existing literature (Andrienko 2021; Rao et al., 2021; Mejias et al., 2021), to the participants. The goal was to determine whether their views corresponded with the findings in the literature. The data collected were then compared across different

stakeholder groups to uncover any differences in opinions. The findings regarding the benefits of STEAM education, providing insights into the perspectives of each stakeholder category are presented as follows.

According to the data from the questionnaires, stakeholders generally agree on the benefits of STEAM education. Integrating the expression of culture into teaching garnered significant agreement, with 30% agreeing and 40% strongly agreeing, while only 10% disagreed. Regarding STEAM encouraging interdisciplinary learning received overwhelming agreement, with 15% agreeing and 80% strongly agreeing. Similarly, promoting visual and verbal expression was widely supported, with 20% agreeing and 75% strongly agreeing. STEAM enhancing student engagement was also well-received, as 10% agreed and 80% strongly agreed. Furthermore, STEAM preparing students for diverse career paths was also agreed with generally, with 15% agreeing and 85% strongly agreeing. STEAM bridging the gap between STEM and arts was positively acknowledged as well, with 13% agreeing and 85% strongly agreeing. Finally, STEAM fostering creativity and innovation received significant agreement, with 20% agreeing and 70% strongly agreeing. A summary of the data is illustrated in Figure 4.10.

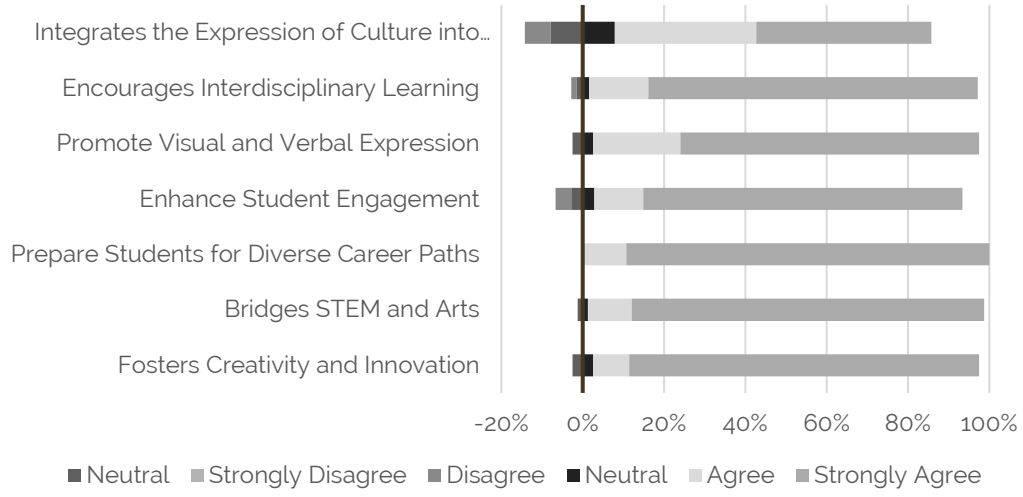


Figure 4.10 Stakeholders' Opinions on Benefits of STEAM Education

(Source: Author's Construct,2024)

These findings highlight the general recognition of the benefits of STEAM education among stakeholders, emphasizing the importance of integrating diverse perspectives and approaches into educational practices to nurture well-rounded individuals

prepared for future challenges. A summary of the benefits of STEAM Education showing the Mean, Standard Deviation and RII ranking is presented in the Table 4.13.

Table 4.13 Ranking of Respondents Opinions on Benefits of STEAM Education.

Benefits of S.T.E.A.M.	(N)	Min.	Max.	Mean	Standard Deviation	RII
1. Prepare Students for Diverse Career Paths	158	4	5	4.89	0.311	0.978481
2. Bridges STEM and Arts	158	3	5	4.84	0.430	0.968354
3. Fosters Creativity and Innovation	158	3	5	4.81	0.507	0.962025
4. Encourages Interdisciplinary Learning	158	2	5	4.75	0.572	0.950633
5. Promote Visual and Verbal Expression	158	3	5	4.68	0.565	0.936709
6. Enhance Student Engagement	158	2	5	4.65	0.757	0.93038
7. Integrates the Expression of Culture into Teaching	158	2	5	4.15	0.909	0.829114
Valid N (listwise)	**158**					

(Source: Author's Construct,2024)

The RII ranking for STEAM Education benefits highlights key priorities. Leading the list is preparing students for diverse careers, followed by bridging STEM and arts. Also crucial are STEAM fostering creativity, encouraging interdisciplinary learning,

and promoting visual and verbal expression. Enhancing student engagement and integrating cultural expression into teaching are vital too. Overall, the ranking emphasizes the multifaceted advantages of STEAM education, from career readiness to interdisciplinary collaboration and cultural inclusivity.

The ensuing sections provide a summary presentation of the collected data from the various stakeholders regarding the benefits of LLCs for STEAM education.

4.3.1.1 Fostering of Creativity and Innovation

As illustrated in figure 4.11, stakeholders overwhelmingly agree on the notion that STEAM fosters creativity and innovation. The data reveals strong support across all groups, with a vast majority of Kyebi locals (95%) and STEAM educators and advocates (100%) strongly agreeing with this statement. Among tertiary students, while a portion (15%) remain neutral, a significant majority (85%) either agree or strongly agree. Even among Built Environment Professionals, where a slightly higher percentage (10%) express neutrality, the majority (90%) acknowledge the role of STEAM in promoting creativity and innovation. This unanimous consensus underscores the widespread recognition of STEAM's potential to cultivate innovative thinking and creative problem-solving skills among learners.

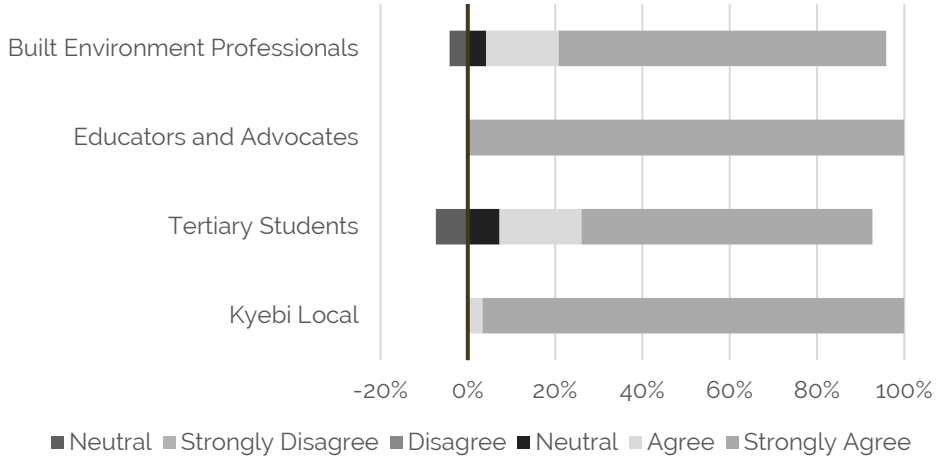


Figure 4.11 Stakeholders' Opinions on STEAM Fostering of Creativity and Innovation (Source: Author's Construct,2024)

The implications suggest a clear mandate for further investment and emphasis on integrating STEAM education into curricula, highlighting its role in preparing individuals for the evolving demands of the modern workforce and fostering a culture of innovation and creativity.

4.3.1.2 Bridging STEM and the Arts

From the illustration Figure 4.12, stakeholders overwhelmingly agree on the significance of STEAM in bridging STEM and the arts. The data indicates robust support across all groups, with the vast majority of Kyebi locals (94%) and STEAM educators and advocates (100%) strongly agreeing with this notion. Among tertiary students, while a small portion (5%) remain neutral, a significant majority (95%) either agree or strongly agree. Even among Built Environment Professionals, where a slightly higher percentage (18%) express agreement, the overwhelming majority (82%) strongly agree with the idea.

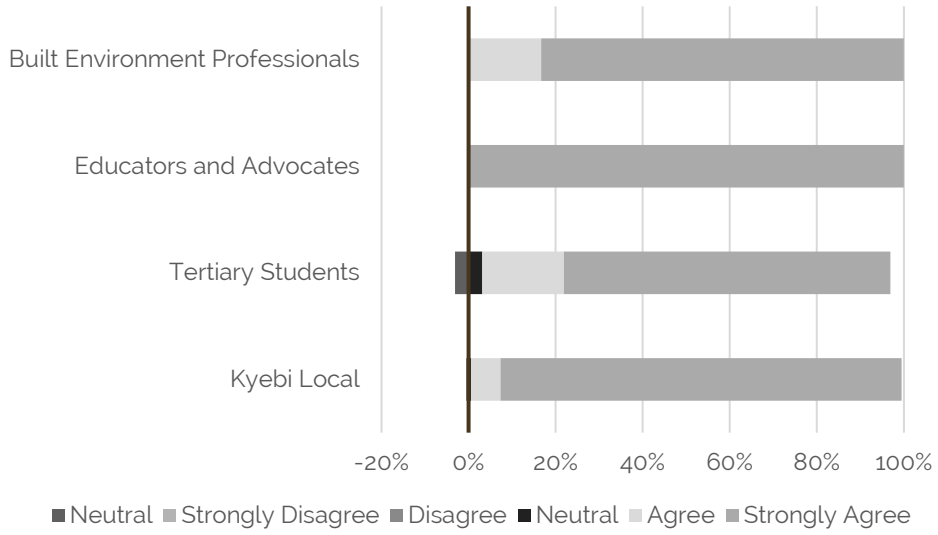


Figure 4.12 Stakeholders' Opinions on STEAM Bridging STEM and the Arts

(Source: Author's Construct,2024)

This widespread consensus underscores the recognition of STEAM's role in integrating diverse disciplines and fostering interdisciplinary approaches to learning and problem-solving. The implications suggest a clear mandate for further promoting interdisciplinary education initiatives that bridge the gap between STEM and the arts, fostering holistic and innovative approaches to addressing complex challenges in various fields.

4.3.1.3 Preparing Students for Diverse Career Paths

The various stakeholders as illustrated in Figure 4.13 resoundingly agree on the importance of STEAM in preparing students for diverse career paths. The data indicates overwhelming support across all groups, with the vast majority of Kyebi locals (95%) and STEAM educators and advocates (100%) strongly agreeing with this

notion. Among tertiary students, while a quarter (25%) express agreement, an even higher percentage (75%) strongly agree. Even among Built Environment Professionals, where a smaller portion (18%) express agreement, the majority (82%) strongly agree with the idea.

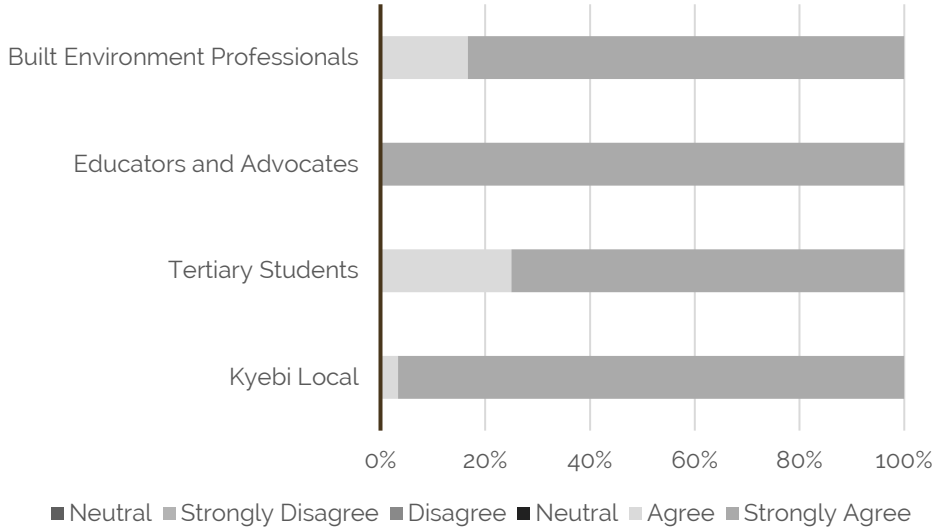


Figure 4.13 Stakeholders' Opinions on STEAM Preparing Students for Diverse Career Paths (Source: Author's Construct,2024)

This unanimous consensus underscores the recognition of STEAM's role in equipping students with the diverse skills and knowledge needed for success in various career fields.

4.3.1.4 Enhancing of Student Engagement

As seen in figure 4.14, stakeholders widely recognize the role of STEAM in enhancing student engagement. The data reflects overwhelming agreement across most groups, with 95% of Kyebi locals and all STEAM educators and advocates strongly supporting this perspective. Despite some dissent among tertiary students, with 10% expressing disagreement, a majority (75%) either agreed or strongly agreed.

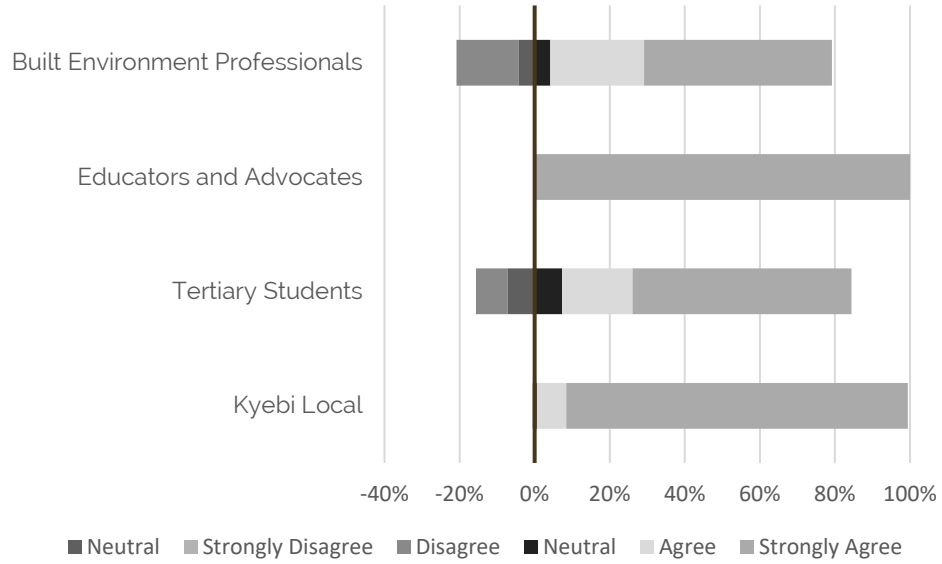


Figure 4.14 Stakeholders' Opinions on STEAM Enhancing of Student Engagement (Source: Author's Construct,2024)

Among Built Environment Professionals, while a minority (20%) disagreed, a significant majority (75%) agreed or strongly agreed with the notion. This consensus suggests a widespread acknowledgment of STEAM's ability to captivate and involve students in learning activities. The implications highlight the importance of leveraging STEAM methodologies and approaches to foster active participation and enthusiasm among learners, ultimately leading to more impactful educational experiences and outcomes.

4.3.1.5 Encouraging Interdisciplinary Learning

Figure 4.15 depicts stakeholders' perspectives on STEAM's role in encouraging interdisciplinary learning. The data reveals strong agreement across most groups, with 85% of Kyebi locals and the majority of tertiary students (90%) either agreeing or strongly agreeing. STEAM educators and advocates also show overwhelming support, with 78% strongly agreeing and 22% agreeing. Among Built Environment Professionals, while a minority (10%) remained neutral, 90% either agreed or strongly agreed with the notion.

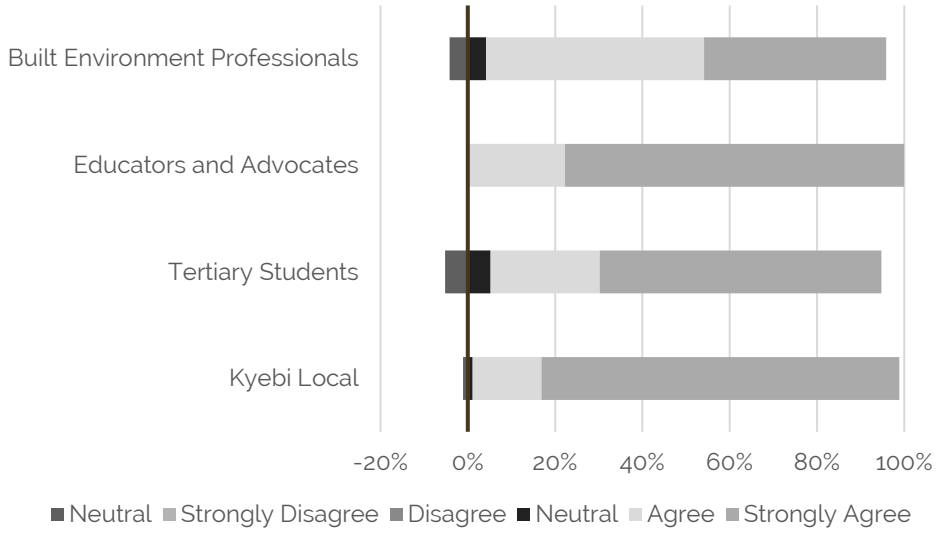


Figure 4.15 Stakeholders' Opinions on STEAM Encouraging Interdisciplinary Learning (Source: Author's Construct,2024)

This widespread consensus underscores the recognition of interdisciplinary learning as a crucial aspect of STEAM education. The implications emphasize the importance of promoting interdisciplinary approaches within educational contexts, fostering collaboration across diverse disciplines, and preparing students for real-world challenges that require multifaceted problem-solving skills.

4.3.1.6 Promotion of Visual and Verbal Expression

Figure 4.22 presents stakeholders' viewpoints on STEAM's promotion of visual and verbal expression. The data indicates a high level of agreement among all stakeholder groups. Specifically, 85% of Kyebi locals and a majority of tertiary students (80%) either agreed or strongly agreed with the statement. Notably, STEAM educators and advocates unanimously supported this notion, with 100% strongly agreeing. Among Built Environment Professionals, while a minority (10%) remained neutral, the majority (90%) either agreed or strongly agreed.

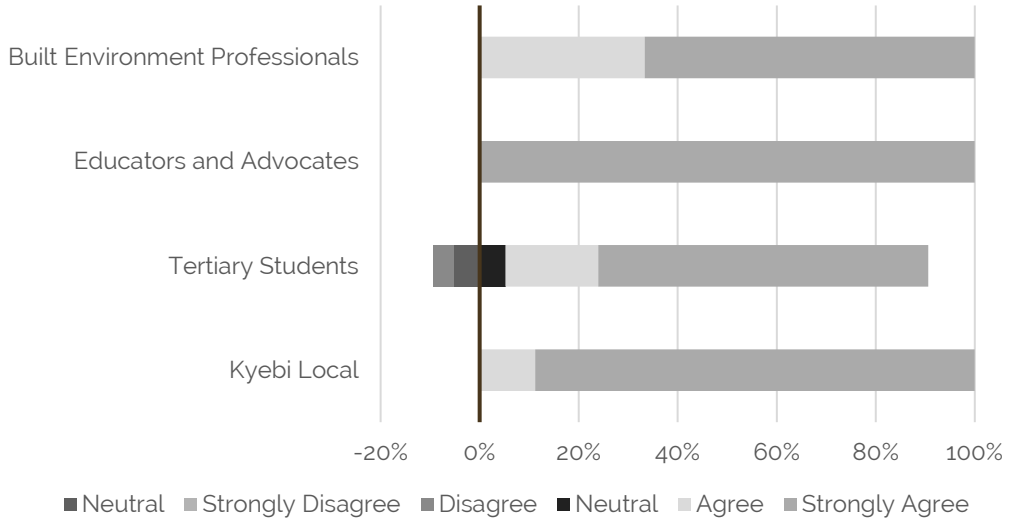


Figure 4.16 Stakeholders' Opinions on STEAM Promotion of Visual and Verbal Expression (Source: Author's Construct,2024)

This consensus highlights the widespread acknowledgment of the importance of visual and verbal expression within the STEAM framework. The implications suggest the need to prioritize activities and initiatives that enhance students' abilities to communicate and express ideas effectively, leveraging various forms of artistic and linguistic expression to enrich STEAM education and foster creativity and innovation.

4.3.1.7 Integration of Cultural Expression

In Figure 4.23, stakeholders' opinions on the STEAM integration of cultural expression are depicted. The data reveals a strong inclination towards agreement across all stakeholder groups. Specifically, 85% of Kyebi locals and a majority of tertiary students (60%) either agreed or strongly agreed with the statement, despite some neutral responses from the latter group. STEAM educators and advocates overwhelmingly supported this integration, with 90% strongly agreeing. Among Built Environment Professionals, while a small portion (15%) disagreed, the majority (70%) either agreed or strongly agreed.

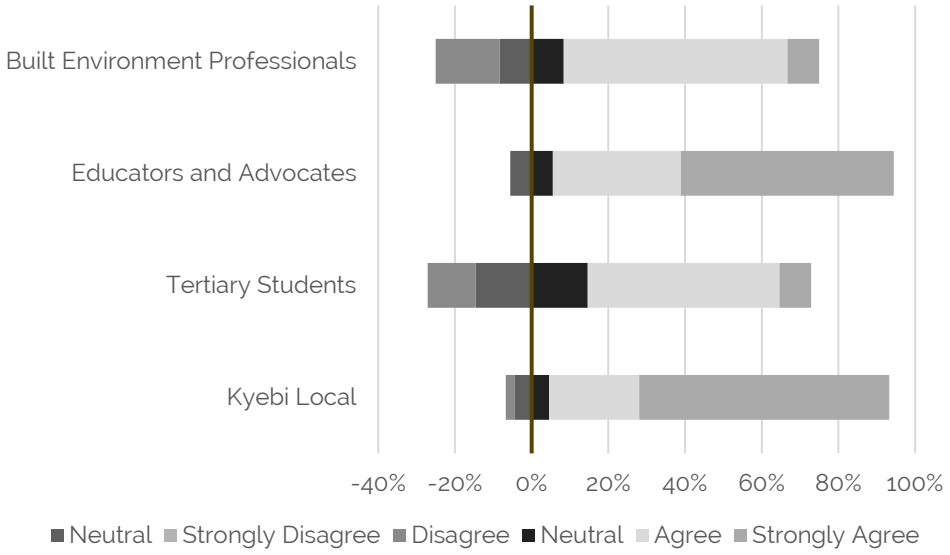


Figure 4.17 Stakeholders' Opinions on STEAM Integration of Cultural Expression (Source: Author's Construct,2024)

This consensus underscores the recognition of the importance of cultural integration within the STEAM framework (Akintoye et al., 2023: Bayode, 2023). The implications suggest a need to incorporate diverse cultural perspectives and practices into STEAM education to foster inclusivity, creativity, and a deeper understanding of global issues among students. Additionally, it highlights the potential for collaborative initiatives that bridge cultural divides and promote cultural appreciation and exchange within educational settings.

4.3.2 Neglect for S.T.E.A.M. Education in Ghana

The study investigated why STEAM education is overlooked in Ghana, using insights from existing literature to guide the inquiry (Caton,2021; Kommers2022; Leavy et al.,2023; Pugalee, 2022; Sánchez et al., 2019).

These literature-based findings were then presented to the participants to gauge if their views mirrored those in the literature. The data collected were further analyzed across various stakeholder groups to uncover any disparities in opinions. As illustrated in Figure 4.18 illustrated, stakeholders' opinions on neglect for S.T.E.A.M. education in Ghana. The data reveals significant concerns across various aspects. Regarding the lack of parental awareness, a vast majority (88%) strongly agreed, indicating widespread acknowledgment of this issue. Similarly, for the lack of professional training for educators, 80% of respondents strongly agreed, suggesting a recognized

need for improved training initiatives. Concerning limited resources, the overwhelming majority (88%) strongly agreed, highlighting the challenges posed by resource constraints. Additionally, the data indicates a strong consensus on the ignorance of the social benefits of STEAM, with 75% of respondents strongly agreeing. This emphasizes the importance of raising awareness about the societal advantages of STEAM education. In terms of ineffective integration strategies of STEAM programs, 80% of respondents strongly agreed, emphasizing the need for more effective approaches to integrating STEAM into educational curricula. Lastly, regarding the lack of awareness by educational institutions, 90% of respondents strongly agreed, indicating a critical need for educational institutions to prioritize and promote STEAM initiatives.

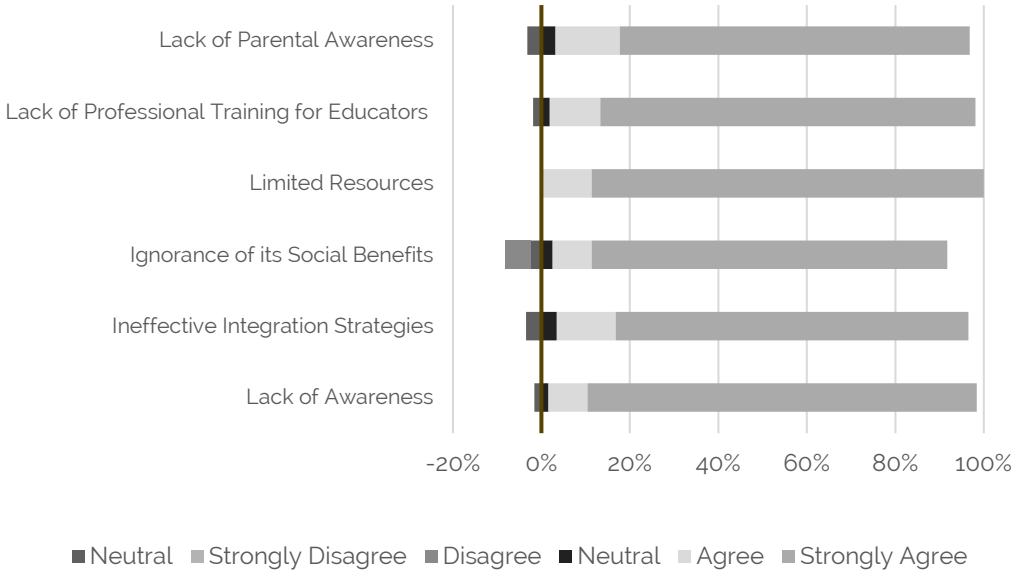


Figure 4.18 Stakeholders' Opinions on Neglect for S.T.E.A.M. Education in Ghana (Source: Author's Construct,2024)

Overall, the data highlights the need for concerted efforts to address these challenges and enhance the support and implementation of S.T.E.A.M. education in Ghana.

A summary of the Neglect for S.T.E.A.M. Education in Ghana showing the Mean, Standard Deviation and RII ranking is presented in the Table 4.14.

Table 4.14 Ranking of Respondents Opinions on Neglect for S.T.E.A.M. in Ghana

Neglect for STEAM Due to…	(N)	Min.	Max.	Mean	Standard Deviation	RII
1. Limited Resources	158	4	5	4.89	0.318729	0.977215
2. Lack of Awareness	158	3	5	4.85	0.439705	0.96962
3. Lack of Professional Training for Educators	158	3	5	4.81	0.480868	0.962025
4. Ineffective Integration Strategies	158	3	5	4.73	0.571608	0.94557
5. Lack of Parental Awareness	158	3	5	4.73	0.582644	0.94557
6. Ignorance of its Social/Cultural Benefits	158	2	5	4.64	0.823372	0.927848
Valid N (listwise)	158					

(Source: Author's Construct,2024)

The RII ranking from Table 4.8 indicates that stakeholders perceive limited resources as the primary reason for neglecting S.T.E.A.M. education, followed by lack of awareness and professional training for educators. Ineffective integration strategies, lack of parental awareness, and ignorance of its social benefits are also significant concerns but rank lower in priority. This aligns with past analyses of similar data, which have consistently highlighted resource constraints and awareness gaps as major barriers to effective S.T.E.A.M. education initiatives.

The subsequent sections outline the gathered data regarding the benefits of STEAM education.

4.3.2.1 Lack of Awareness by Educational Institutions

As depicted in figure 4.25, stakeholders, including tertiary students, STEAM educators and advocates, and built environment professionals, overwhelmingly agree on the lack of awareness by educational institutions as a significant reason for neglecting S.T.E.A.M. education in Ghana.

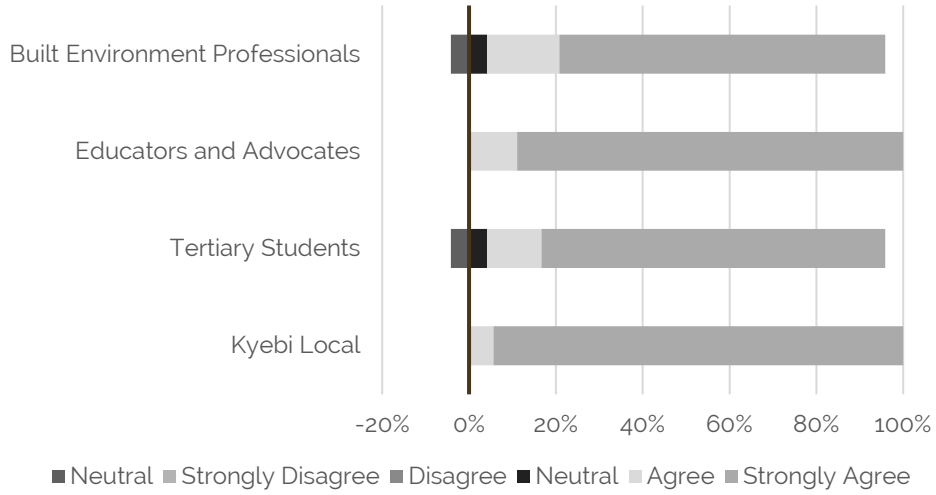


Figure 4.19 Stakeholders' Opinions on Lack of Awareness by Educational Institutions (Source: Author's Construct,2024)

This consensus underscores the pressing need for educational institutions to enhance their awareness and understanding of the importance of S.T.E.A.M. education. Failure to address this issue may result in continued neglect of S.T.E.A.M. initiatives, hindering the development of a robust and innovative educational landscape.

4.3.2.2 STEAM Ineffective Integration Strategies

The representation in Figure 4.20, stakeholders unanimously agree on the ineffectiveness of integration strategies as a significant reason for neglecting S.T.E.A.M. education in Ghana. About 5% of Kyebi Locals agreed, while 95% strongly agreed with this sentiment. Among tertiary students, 20% remained neutral, while 20% agreed and 60% strongly agreed. Similarly, among STEAM educators and advocates, 10% agreed, and 90% strongly agreed.

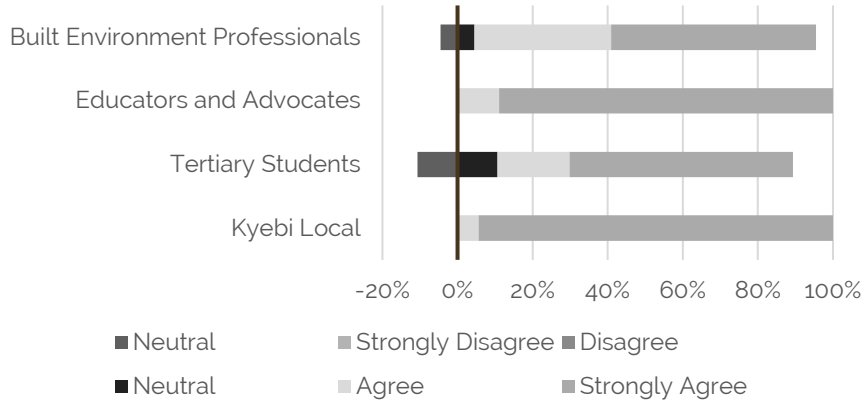


Figure 4.20 Stakeholders' Opinions on STEAM Ineffective Integration Strategies (Source: Author's Construct,2024)

As illustrated the Figure 4.20, among built environment professionals, 10% remained neutral, while 40% agreed, and 50% strongly agreed. These percentages underscore the critical need for more effective integration strategies to promote S.T.E.A.M. education and ensure its successful implementation.

4.3.2.3 Ignorance About Social/Cultural Benefits

From the data as shown in Figure 4.21, stakeholders overwhelmingly acknowledge ignorance about the social and cultural benefits as a significant reason for neglecting S.T.E.A.M. education in Ghana. Among Kyebi locals, 5% agreed, while 95% strongly agreed with this sentiment. For tertiary students, 20% remained neutral, while 20% agreed, and 60% strongly agreed. Similarly, among STEAM educators and advocates, 10% agreed, and 90% strongly agreed. Among built environment professionals, 10% remained neutral, while 35% agreed, and 55% strongly agreed.

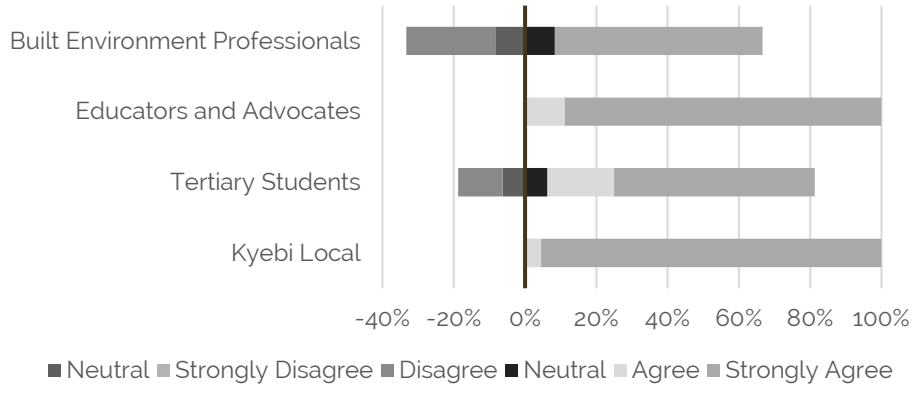


Figure 4.21 Stakeholders' Opinions on Ignorance About Social Benefits (Source: Author's Construct,2024)

These findings also underscore the critical need for raising awareness about the societal and cultural advantages of S.T.E.A.M. education to garner greater support and commitment from stakeholders towards its advancement and implementation.

4.3.2.4 Limited Resource Allocation

In figure 4.22, stakeholders expressed overwhelming agreement regarding ignorance about the social and cultural benefits as a key reason for neglecting S.T.E.A.M. education in Ghana. Among Kyebi locals, 5% agreed, while 95% strongly agreed with this sentiment. For tertiary students, 18% agreed, and 82% strongly agreed. Similarly, among STEAM educators and advocates, 12% agreed, and 88% strongly agreed. Among built environment professionals, 25% agreed, while 75% strongly agreed.

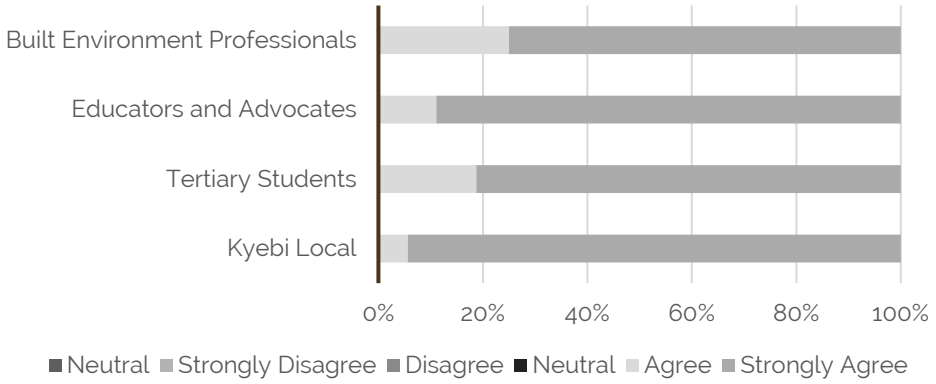


Figure 4.22 Stakeholders' Opinions on Limited Resource Allocation (Source: Author's Construct,2024)

These findings emphasize the critical importance of addressing awareness gaps regarding the societal and cultural advantages of S.T.E.A.M. education. Effective strategies to educate stakeholders about these benefits can lead to greater support and commitment toward advancing S.T.E.A.M. education initiatives in Ghana.

4.3.2.5 Lack of Training for Educators

As illustrated in figure 4.23, stakeholders overwhelmingly agreed that the lack of training for educators contributes significantly to the neglect of S.T.E.A.M. education in Ghana. Among Kyebi locals, 8% agreed, while 92% strongly agreed with this sentiment. For tertiary students, 10% remained neutral, while 18% agreed, and 72% strongly agreed. Similarly, among STEAM educators and advocates, 12% agreed, and 88% strongly agreed. Among built environment professionals, 20% remained neutral, while 10% agreed, and 70% strongly agreed.

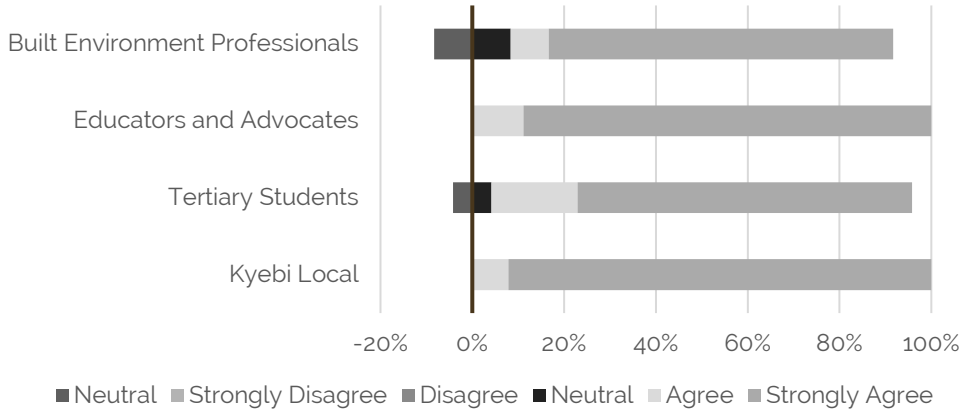


Figure 4.23 Stakeholders' Opinions on Lack of Training for Educators

(Source: Author's Construct,2024)

These finding as validate by the STEAM educators and Advocates emphasize the need for comprehensive training programs tailored to educators to equip them with the necessary skills and knowledge to effectively integrate S.T.E.A.M. education into the curriculum. Addressing this training gap can enhance educators' capacity to deliver quality S.T.E.A.M. education and thereby contribute to its advancement in Ghana.

4.3.2.6 Lack of Parental Awareness

As illustrated in Figure 4.24, stakeholders' opinions indicate a consensus on the significant impact of lack of parental awareness on the neglect of S.T.E.A.M. education in Ghana. Among Kyebi locals, 10% agreed, while 90% strongly agreed with this notion. For tertiary students, 16% remained neutral, while 20% agreed, and 64% strongly agreed.

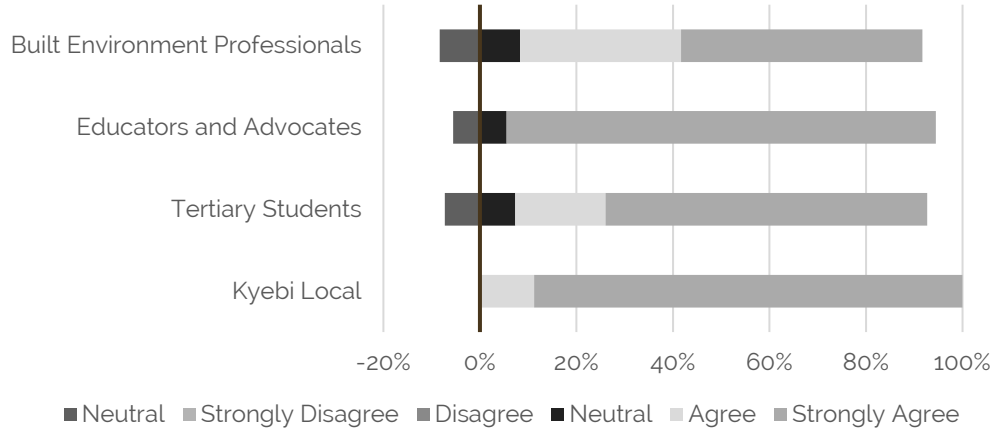


Figure 4.24 Stakeholders' Opinions on Lack of Parental Awareness

(Source: Author's Construct,2024)

Similarly, among STEAM educators and advocates, about 10% had a neutral opinion, while 90% strongly agreed. Among built environment professionals, 20% remained neutral, while 30% agreed, and 50% strongly agreed.

These findings underline the crucial role of parental involvement and awareness in supporting S.T.E.A.M. education initiatives.

4.4 LIVING-LEARNING COMMUNITIES FOR S.T.E.A.M.

The **Objective 2** of this study explores Living-Learning Communities' (LLCs) potential for integrating STEAM education and the challenges they pose in Ghana. It aims to assess stakeholders' views on LLCs' benefits for STEAM education and investigate the challenges hindering their integration. Specifically, the Objective 2 seeks to assess stakeholders' perceptions of the benefits that LLCs offer for STEAM education and to investigate the challenges posed by LLCs for the implementation of STEAM education initiatives in Ghana. Through the administration of questionnaires and interviews to residents of Kyebi, as well as stakeholders such as tertiary students, STEAM educators/advocates, and built environment professionals, this study aims to provide insights into the opportunities and barriers associated with LLCs in facilitating STEAM education in Ghana.

4.4.1 Benefits of Living-Learning Communities

The study investigated the benefits of Living-Learning Communities (LLCs) for STEAM education, drawing from existing literature. These benefits were then presented to the participants to ascertain if their views aligned with the literature. Subsequently, the collected data were analyzed across different stakeholder categories to identify any variations in opinions.

The data from the questionnaires, as illustrated in figure 4.25, reveals notable percentages regarding Living-Learning Communities (LLCs) and their role in various aspects of STEAM education. For enabling Culture Integration with the Arts, 30% of respondents agreed and 45% strongly agreed, while only 5% disagreed and approximately 20% remained neutral. This indicates substantial support for LLCs in fostering cultural integration within educational settings. In terms of cultivating a sense of belonging, 25% agreed and 65% strongly agreed, with 10% remaining neutral.

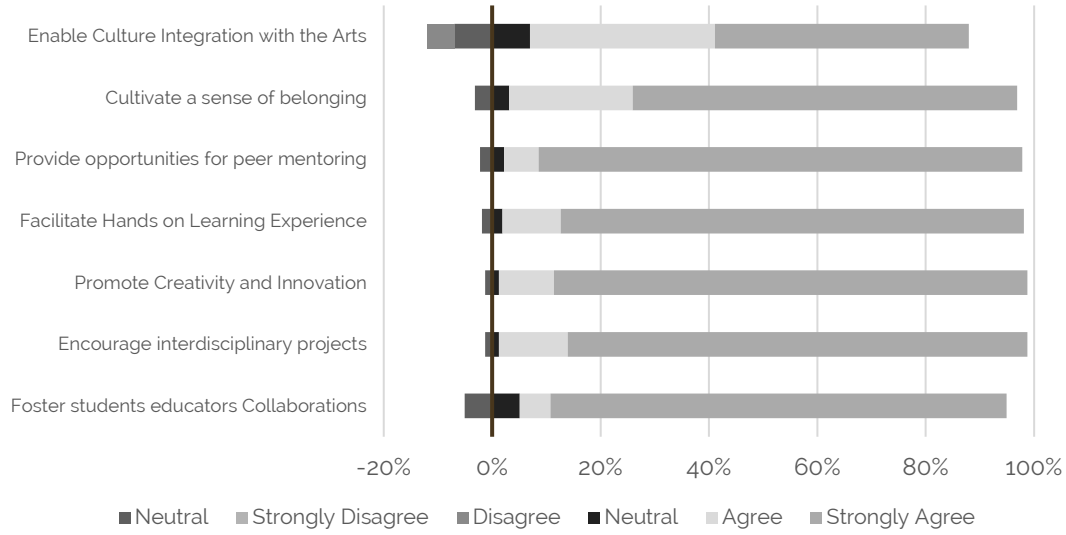


Figure 4.25 Stakeholders' Opinions on Benefits of Living-Learning Communities (Source: Author's Construct,2024)

This suggests that a majority of respondents recognize the importance of LLCs in creating inclusive and supportive learning environments. Regarding LLCs providing the opportunity for peer mentoring, 10% agreed and 84% strongly agreed, with only 6% remaining neutral. This emphasizes the significance of LLCs in facilitating peer learning and support networks among students. For LLCs facilitating hands-on learning experiences, 15% agreed and 80% strongly agreed, with 5% remaining neutral. This highlights the role of LLCs in promoting experiential learning and practical skill development. In terms of promoting creativity and innovation, 10% agreed and 86% strongly agreed, with 4% remaining neutral. This suggests widespread acknowledgment of LLCs as platforms for fostering creativity and innovation among students. Lastly, for encouraging interdisciplinary project collaborations, 16% agreed and 80% strongly agreed, with 4% remaining neutral. This emphasizes the importance of LLCs in facilitating collaboration and cross-disciplinary learning opportunities. Overall, the data indicates strong endorsement for LLCs across various educational aspects. These findings imply that incorporating LLCs into educational frameworks can significantly enhance cultural integration, foster a sense of belonging, facilitate peer mentoring and hands-on learning experiences, promote creativity and innovation, and encourage interdisciplinary collaboration among students.

A summary of the potential benefits of Living-Learning Communities showing the Mean, Standard Deviation and RII ranking is presented in the Table 4.15

Table 4.15 Ranking of Respondents Opinions on Benefits of LLCs to STEAM.

LLCs in S.T.E.A.M. will…	N	Min.	Max.	Mean	Std. Deviation	RII
1. Promote Creativity and Innovation	158	3	5	4.85	0.425	0.96962
2. Provide opportunities for peer mentoring	158	3	5	4.85	0.468	0.96962
3. Encourage interdisciplinary projects	158	3	5	4.82	0.445	0.964557
4. Facilitate Hands on Learning Experience	158	3	5	4.82	0.477	0.963291
5. Foster students' educators Collaborations	158	3	5	4.74	0.630	0.948101
6. Cultivate a sense of belonging	158	3	5	4.65	0.598	0.929114
7. Enable Culture Integration with the Arts	158	2	5	4.23	0.874	0.84557
Valid N (listwise)	**158**					

(Source: Author's Construct,2024)

From the Table 4.15, Promoting creativity and innovation emerges as the most significant advantage, followed by providing opportunities for peer mentoring and encouraging interdisciplinary projects. These findings suggest a strong emphasis on fostering creativity, collaboration, and hands-on learning experiences within LLCs. While LLCs cultivating a sense of belonging and enabling cultural integration with the arts are also valued, they rank lower in comparison. Overall, the implications accent

the importance of prioritizing activities and initiatives that enhance creativity, collaboration, and practical learning experiences within LLCs to enrich STEAM education.

The ensuing sections provide a summary presentation of the collected data from the various stakeholders regarding the benefits of LLCs for STEAM education.

4.4.1.1 Fostering Students' Educators Collaborations

The data from Figure 4.26 indicates strong agreement among stakeholders regarding the role of Living-Learning Communities (LLCs) in fostering collaboration between students and educators.

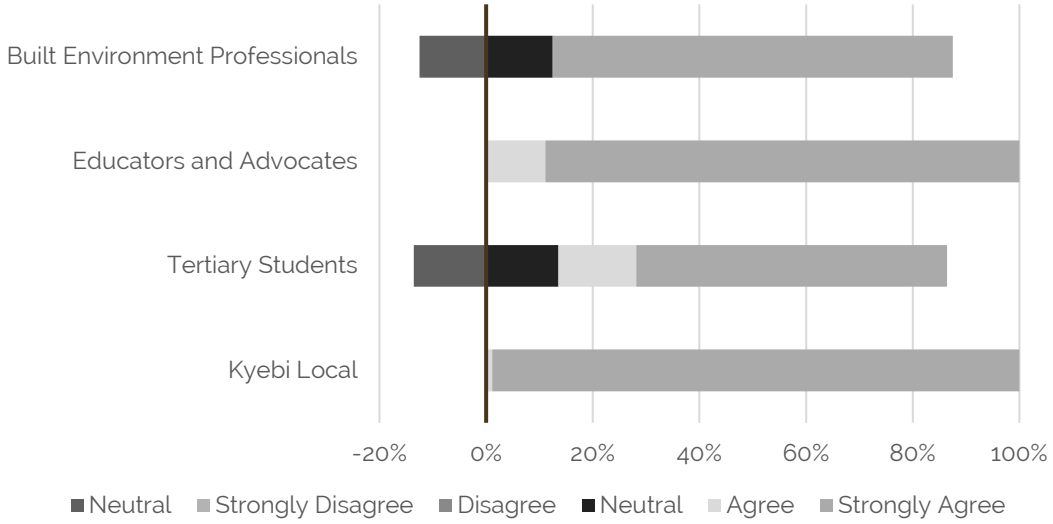


Figure 4.26 Stakeholders' Opinions on LLCs Fostering Students' Educators Collaborations (Source: Author's Construct,2024)

Specifically, an overwhelming majority of Kyebi locals (96%) and STEAM educators and advocates (90%) strongly agreed with the statement. Tertiary students also largely concurred, with 65% strongly agreeing and 15% agreeing. While Built Environment Professionals showed strong support (70%), a notable portion (30%) remained neutral. These findings highlight the perceived importance of LLCs in promoting collaborative learning environments, suggesting potential benefits for student engagement and educational outcomes.

4.4.1.2 Encouraging Interdisciplinary Projects

As depicted in Figure 4.27, the data indicates overwhelming agreement among stakeholders regarding the role of Living-Learning Communities (LLCs) in

encouraging interdisciplinary projects. Among Kyebi locals, 95% strongly agreed and 5% agreed with the statement. Tertiary students also largely supported this notion, with 60% strongly agreeing and 30% agreeing, while only 10% remained neutral. Similarly, STEAM Educators and Advocates unanimously (100%) strongly agreed with the concept. Built Environment Professionals also showed strong support, with 85% strongly agreeing and 15% agreeing as illustrated in Figure 4.27.

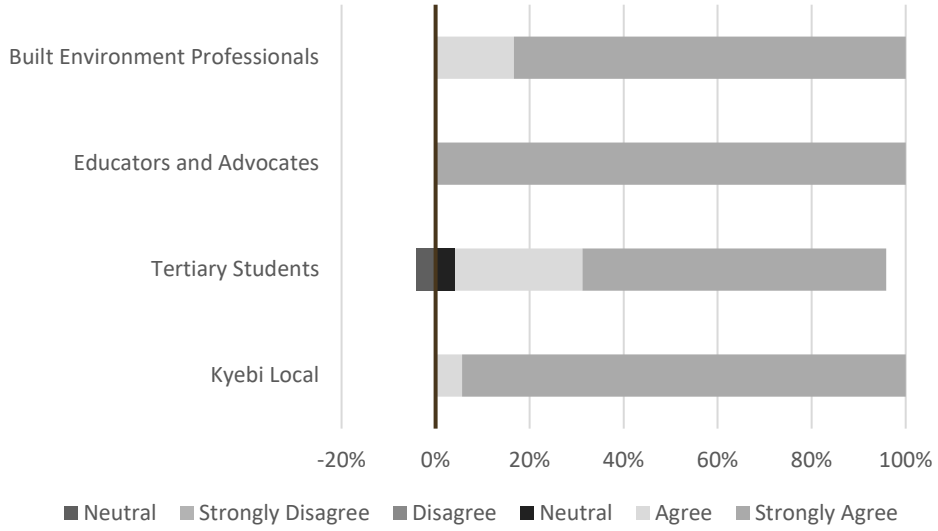


Figure 4.27 Stakeholders' Opinions on LLCs Encouraging Interdisciplinary Projects (Source: Author's Construct,2024)

These findings underscore the perceived value of LLCs in facilitating interdisciplinary collaboration, suggesting potential benefits for innovation, knowledge exchange, and holistic learning experiences within the community.

4.4.1.3 Promoting Creativity and Innovation

As depicted in Figure 4.28, the data reveals overwhelming agreement among stakeholders regarding the role of Living-Learning Communities (LLCs) in promoting creativity and innovation. Among Kyebi locals, 95% strongly agreed and 5% agreed with the statement. Tertiary students also largely supported this notion, with 75% strongly agreeing and 20% agreeing, while only 5% remained neutral. Similarly, STEAM Educators and Advocates unanimously (100%) strongly agreed with the concept. Built Environment Professionals also showed strong support, with 90% strongly agreeing and 10% remaining neutral.

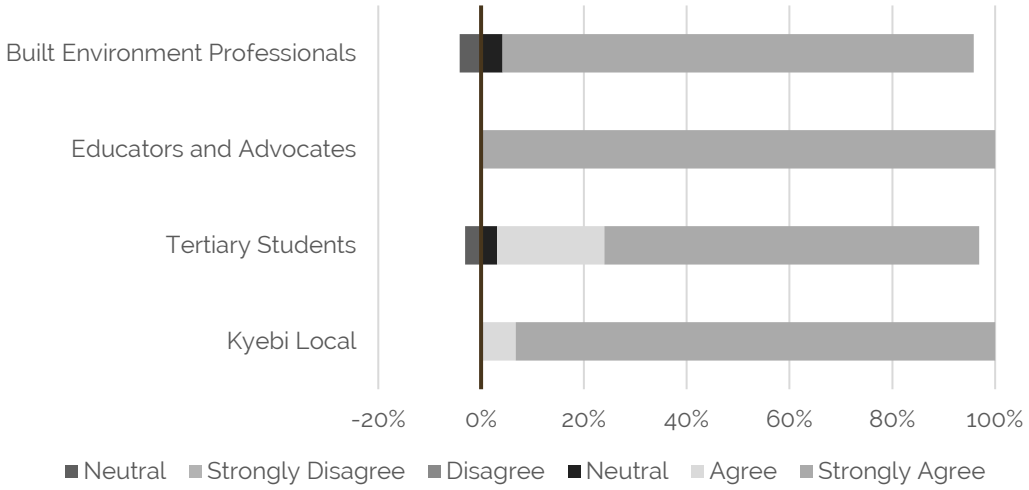


Figure 4.28 Stakeholders' Opinions on LLCs Promoting Creativity and Innovation (Source: Author's Construct,2024)

These findings emphasize the perceived value of LLCs in fostering a culture of creativity and innovation within the community, suggesting potential benefits for problem-solving, critical thinking, and the development of innovative solutions to real-world challenges.

4.4.1.4 Facilitating Hands on Learning Experience

As shown in figure 4.29, stakeholders widely agree on the importance of Living-Learning Communities (LLCs) in facilitating hands-on learning experiences.

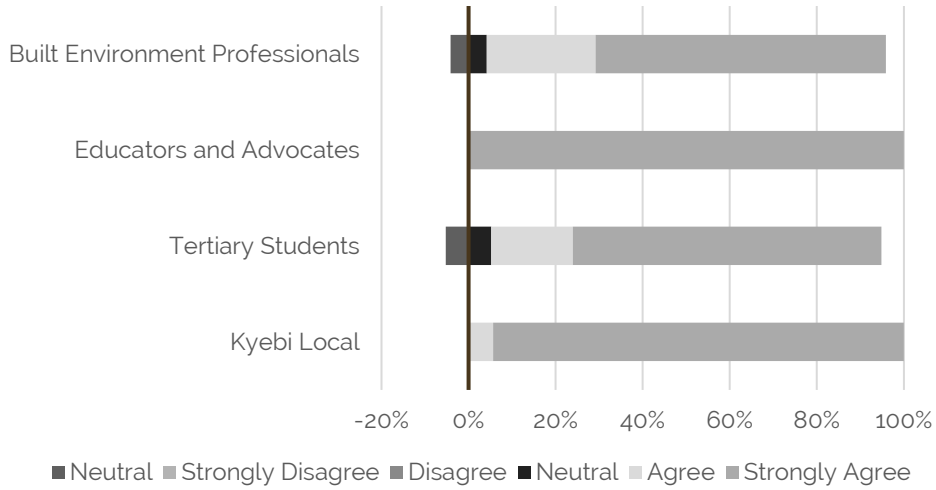


Figure 4.29 Stakeholders' Opinions on LLCs Facilitating Hands on Learning Experience (Source: Author's Construct,2024)

Among Kyebi locals, 95% strongly agreed, with only 5% agreeing. Among tertiary students, 70% strongly agreed, 20% agreed, and 10% were neutral. STEAM Educators and Advocates unanimously (100%) supported this concept. Built Environment Professionals also showed strong support, with 65% strongly agreeing and 25% agreeing, while 10% were neutral. These findings underscore the perceived significance of LLCs in providing practical learning opportunities, suggesting potential benefits for student engagement and skill development.

4.4.1.5 Providing Opportunities for Peer Mentoring

As depicted in Figure 4.30, stakeholders overwhelmingly agree on the importance of providing opportunities for peer mentoring within Living-Learning Communities (LLCs). Among Kyebi locals, 70% strongly agreed, while 26% agreed, with only 4% expressing a neutral opinion. Among tertiary students, 70% strongly agreed, 20% agreed, and 10% were neutral. STEAM Educators and Advocates showed significant support, with 100% strongly agreeing. Built Environment Professionals also expressed strong agreement, with 60% strongly agreeing and 20% agreeing, while 20% had a neutral opinion.

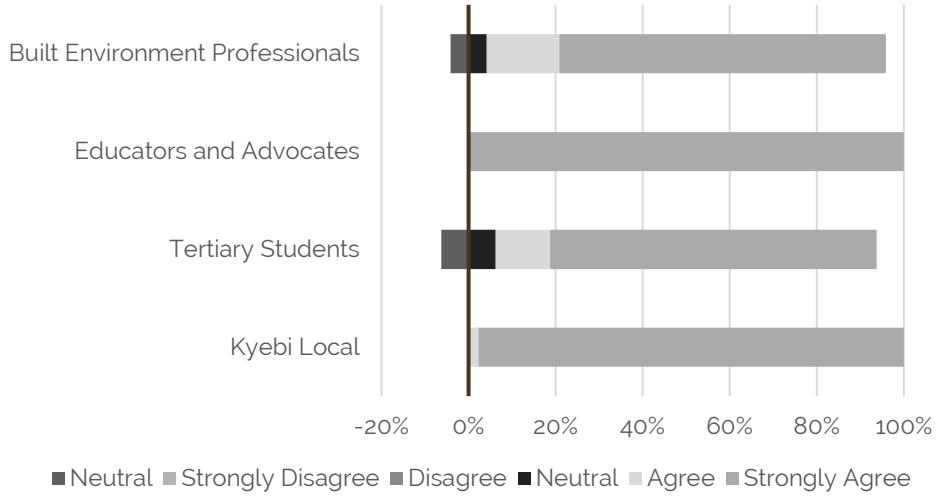


Figure 4.30 Stakeholders' Opinions on Providing Opportunities for Peer Mentoring (Source: Author's Construct,2024)

These findings highlight the perceived value of peer mentoring in LLCs, suggesting its potential to enhance learning outcomes, foster collaboration, and build supportive networks within educational communities.

4.4.1.6 Cultivating a sense of belonging

In figure 4.31, stakeholders overwhelmingly support the notion of cultivating a sense of belonging within Living-Learning Communities (LLCs). Among Kyebi locals, 75% strongly agreed and 23% agreed, with only 2% expressing a neutral opinion. Among tertiary students, 70% strongly agreed, 20% agreed, and 10% were neutral. STEAM Educators and Advocates showed significant support, with 65% strongly agreeing and 35% agreeing. Built Environment Professionals also expressed strong agreement, with 60% strongly agreeing and 20% agreeing, while 20% had a neutral opinion.

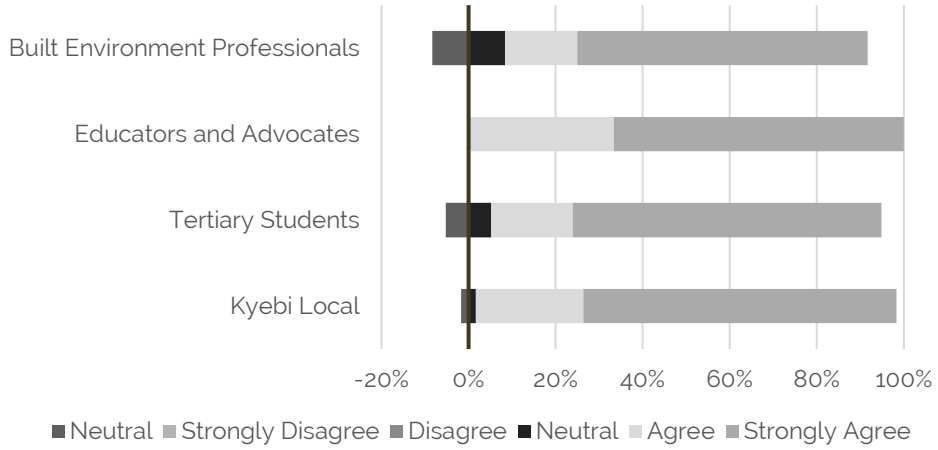


Figure 4.31 Stakeholders' Opinions on Cultivating a sense of belonging

(Source: Author's Construct,2024)

These findings show the respondents appreciation of LLCs fostering a sense of belonging in LLCs, indicating its potential to enhance student engagement, satisfaction, and overall well-being within educational communities.

4.4.1.7 Enabling Culture Integration with the Arts

In figure 4.32, stakeholders overwhelmingly support the idea of enabling culture integration with the arts within Living-Learning Communities (LLCs). Among Kyebi locals, 70% strongly agreed and 20% agreed, with only 10% expressing a neutral opinion. Among tertiary students, 15% strongly agreed, 55% agreed, 20% had a neutral opinion, and 10% disagreed. STEAM Educators and Advocates predominantly supported the concept, with 80% strongly agreeing, while 10% had a neutral opinion and 10% agreed.

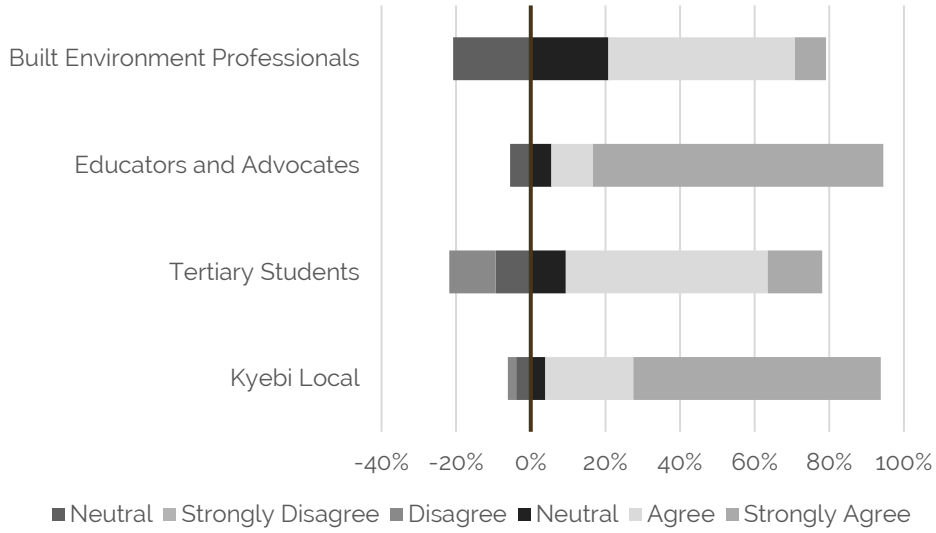


Figure 4.32 Stakeholders' Opinions on Enabling Culture Integration with the Arts (Source: Author's Construct,2024)

Built Environment Professionals showed mixed responses, with 50% agreeing, 10% strongly agreeing, and 40% having a neutral opinion. These findings suggest the significant potential of integrating arts and culture within LLCs to enhance student experiences, promote creativity, and foster a vibrant and inclusive learning environment.

4.4.2 Challenges of Living-Learning Communities

The research delved into the anticipated challenges associated with Living-Learning Communities (LLCs), drawing insights from existing literature. These identified challenges were then presented to the diverse array of participants involved in the study to assess the alignment of their perspectives with the documented literature. Subsequently, the collected data were systematically analyzed across different stakeholder categories to uncover potential discrepancies in opinions regarding the challenges faced by LLCs. The ensuing sections provide a comprehensive presentation of the data pertaining to these challenges, shedding light on the nuanced perspectives observed within each stakeholder group.

The data from the questionnaires as represented in Figure 4.33 reveals insights into various challenges faced by Living-Learning Communities (LLCs) and stakeholders' perceptions regarding these challenges. Regarding LLCs improving with limited resources, 70% of respondents strongly agreed, while 10% agreed and 20% remained neutral. For effective conflict resolution, 50% strongly agreed, 30% agreed, 10%

remained neutral, and 10% disagreed. Addressing issues of low participation saw 25% strongly agreeing, 20% agreeing, 40% remaining neutral, and 15% disagreeing. Balancing academic and social needs received strong support, with 65% strongly agreeing, 25% agreeing, 5% remaining neutral, and 5% disagreeing. Challenges with faculty and staff turnover were acknowledged, with 25% strongly agreeing, 35% agreeing, 30% remaining neutral, and 10% disagreeing. Adapting to student interests was perceived as challenging by 60% who strongly agreed, 15% who agreed, 15% who remained neutral, and 10% who disagreed. Lastly, integrating academic and residential life posed challenges for students, with 70% strongly agreeing, 20% agreeing, and 10% remaining neutral.

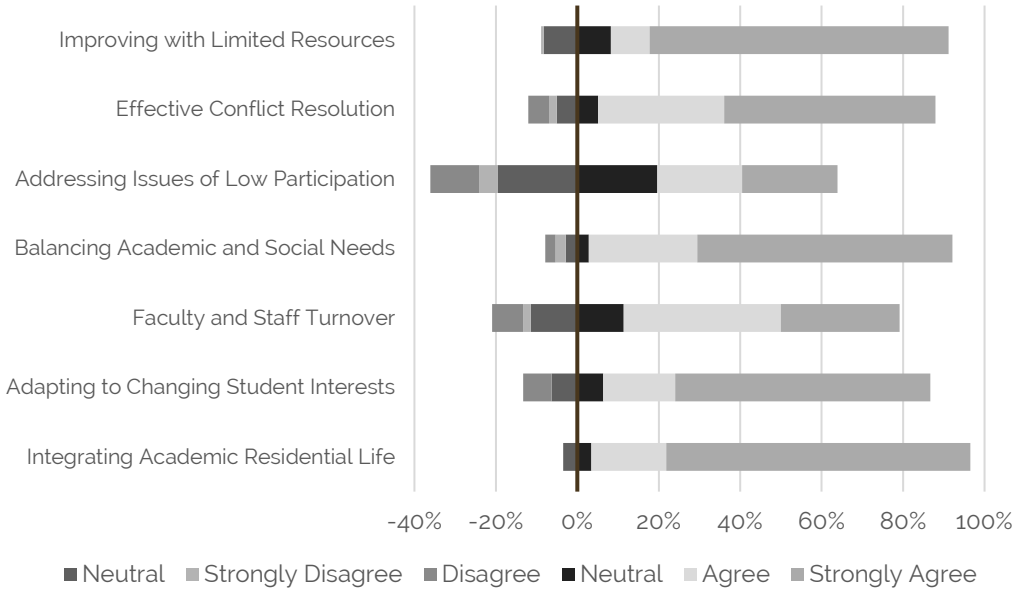


Figure 4.33 Stakeholders' Opinions on Challenges of Living-Learning Communities (Source: Author's Construct,2024)

These findings spotlight the multifaceted nature of challenges within LLCs and highlight the importance of addressing these challenges to ensure the effectiveness and sustainability of LLCs in promoting holistic student development and learning experiences.

A summary of the Challenges of LLCs for STEAM, showing the Mean, Standard Deviation and RII ranking, is presented in the Table 4.16.

Table 4.16 Ranking of Respondents Opinions on Challenges of LLCs to STEAM.

LLCs in S.T.E.A.M. will Difficulty with…	N	Min.	Max.	Mean	Standard Deviation	RII
1. Integrating Academic Residential Life	158	3	5	4.68	0.600	0.935443
2. Improving with Limited Resources	158	1	5	4.55	0.810	0.910127
3. Balancing Academic and Social Needs	158	1	5	4.44	0.906	0.888608
4. Adapting to Changing Student Interests	158	2	5	4.36	0.952	0.872152
5. Effective Conflict Resolution	158	1	5	4.26	0.966	0.851899
6. Faculty and Staff Turnover	158	1	5	3.85	0.989	0.770886
7. Addressing Issues of Low Participation	158	1	5	3.47	1.110	0.693671
Valid N (listwise)	158					

(Source: Author's Construct,2024)

The ensuing sections provide a summary presentation of the collected data from the various stakeholders regarding the challenges of LLCs for STEAM education.

4.4.2.1 Integrating Academic Residential Life

As depicted in figure 4.34, concerning Stakeholders' Opinions on Integrating Academic/Residential Life as a challenge, approximately 10% of the Kyebi Locals held a neutral stance, while 15% agreed and 75% strongly agreed. Among tertiary students, 10% expressed neutrality, with 20% agreeing and 70% strongly agreeing. STEAM Educators and Advocates saw 35% agreement, and 65% strongly agreed. Built Environment Professionals exhibited 25% agreement and 75% strong agreement.

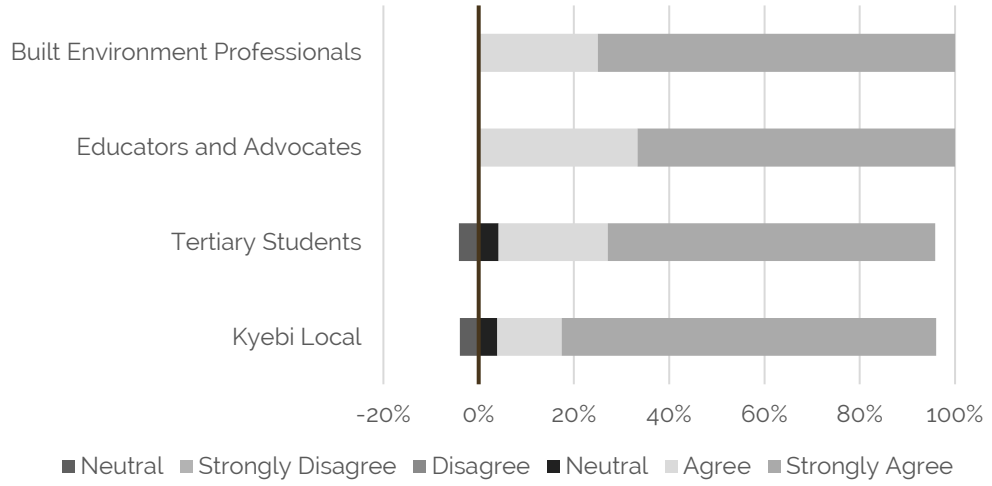


Figure 4.34 Stakeholders' Opinions on Integrating Academic/Residential Life as a challenge (Source: Author's Construct,2024)

Analyzing the data suggests a widespread acknowledgment of the challenges associated with integrating academic and residential life within LLCs, indicating a need for tailored strategies to address these concerns effectively.

4.4.2.2 Adapting to Changing Student Interests

As depicted in Figure 4.36, concerning Stakeholders' Opinions on Adapting to Changing Student Interests as a challenge, approximately 10% of the Kyebi Locals expressed neutrality, while 20% agreed and 70% strongly agreed. Among tertiary students, 15% disagreed, with 20% expressing neutrality, 20% agreeing, and 45% strongly agreeing. STEAM Educators and Advocates exhibited 10% neutrality, 10% agreement, and 80% strong agreement. Built Environment Professionals saw 20% disagreement, 10% neutrality, 20% agreement, and 50% strong agreement.

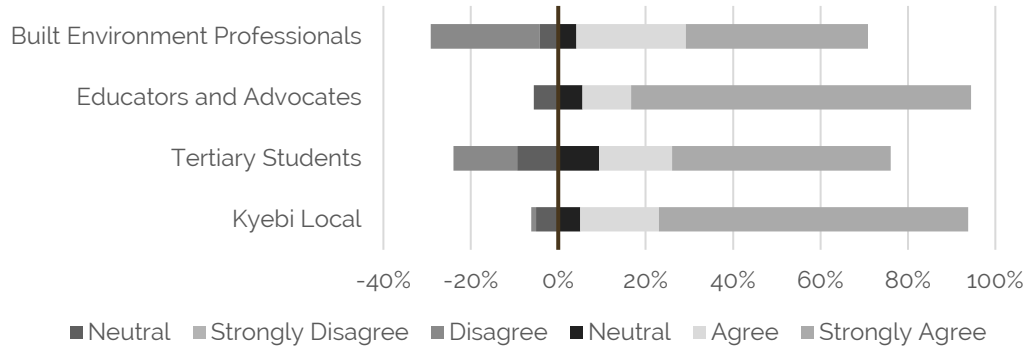


Figure 4.35 Stakeholders' Opinions on Adapting to Changing Student Interests as a challenge (Source: Author's Construct,2024)

Analyzing the data highlights a widespread recognition of the challenge associated with adapting to changing student interests within LLCs. It highlights the importance of proactive measures to stay abreast of evolving student needs and preferences to ensure the continued relevance and effectiveness of LLC programs.

4.4.2.3 Faculty and Staff Turnover

As depicted in Figure 4.36, stakeholders' opinions on faculty and staff turnover as a challenge vary across different groups. Among Kyebi Locals, there is a significant percentage that strongly agrees with this challenge, indicating its perceived importance. Tertiary students also show a notable agreement, with a considerable portion expressing neutrality. Similarly, STEAM Educators and Advocates and Built Environment Professionals acknowledge this challenge, with a majority either agreeing or strongly agreeing.

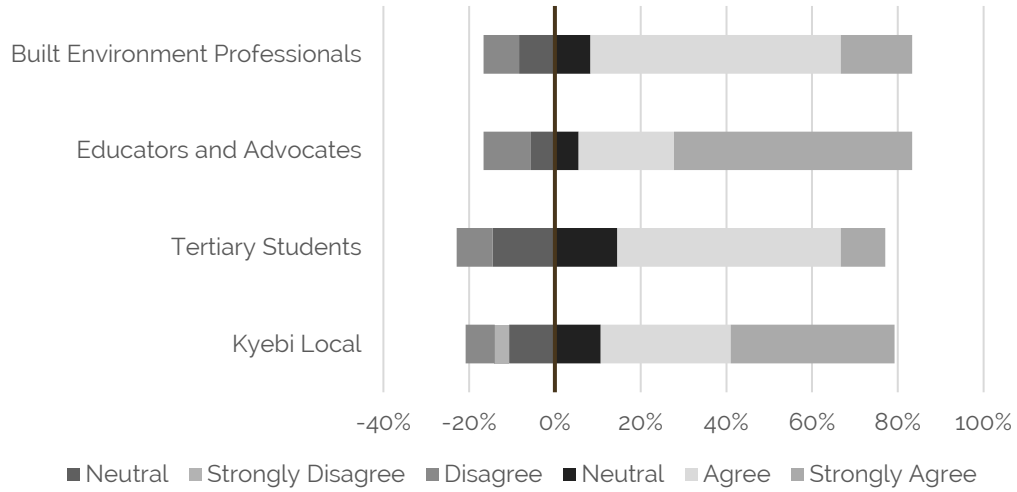


Figure 4.36 Stakeholders' Opinions on Faculty and Staff Turnover as a challenge (Source: Author's Construct,2024)

These findings suggest that addressing faculty and staff turnover is crucial for the sustained effectiveness and stability of Living-Learning Communities (LLCs) in the context of STEAM education.

4.4.2.4 Balancing Academic and Social Needs

As shown in Figure 4.37, stakeholders agree on the challenge of balancing academic and social needs within Living-Learning Communities (LLCs). Among Kyebi Locals, 10% disagreed, 5% remained neutral, and 25% agreed, with a significant majority (60%) strongly agreeing. Tertiary students also expressed substantial agreement, with

5% disagreeing, 10% remaining neutral, and 30% agreeing, while 55% strongly agreed. Similarly, STEAM Educators and Advocates, as well as Built Environment Professionals, recognized this challenge, with 10% disagreeing and 10% remaining neutral.

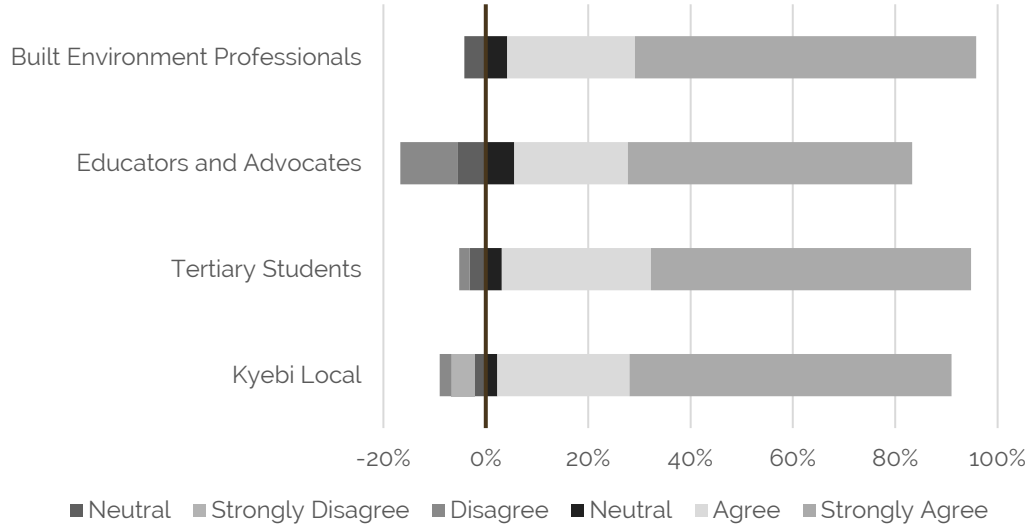


Figure 4.37 Stakeholders' Opinions on Balancing Academic and Social Needs as a challenge (Source: Author's Construct,2024)

However, a considerable majority in both groups (STEAM Educators and Advocates: 20% agree, 60% strongly agree; Built Environment Professionals: 20% agree, 70% strongly agree) implied the importance of addressing this balance for effective LLCs in STEAM education.

4.4.2.5 Addressing Issues of Low Participation

As depicted in Figure 4.38, stakeholders perceive addressing issues of low participation as a challenge within Living-Learning Communities (LLCs). Among Kyebi Locals, 10% disagreed, 40% remained neutral, and 15% agreed, with 35% strongly agreeing. Tertiary students showed higher disagreement, with 20% disagreeing, 40% remaining neutral, and 35% agreeing, while only 5% strongly agreed. Similarly, STEAM Educators and Advocates expressed concerns, with 20% disagreeing, 20% remaining neutral, 40% agreeing, and 20% strongly agreeing.

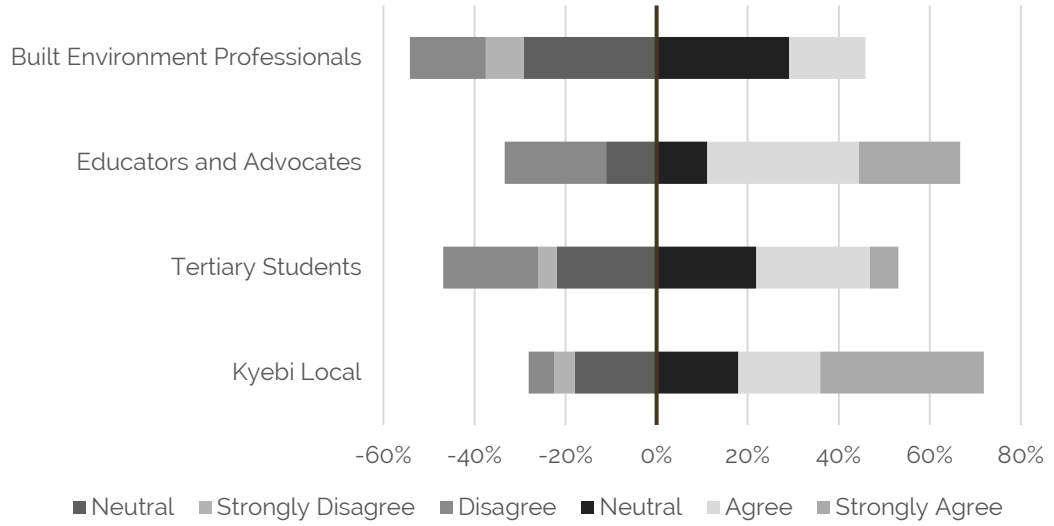


Figure 4.38 Stakeholders' Opinion on Addressing Issues of Low Participation as a challenge (Source: Author's Construct,2024)

From the Figure 4.44, the Built Environment Professionals also recognized the challenge, with 20% disagreeing, 60% remaining neutral, and 20% agreeing. The data suggests a need for strategies to enhance participation rates within LLCs to ensure their effectiveness in STEAM education.

4.4.2.6 Effective Conflict Resolution

In figure 4.39, stakeholders' perspectives on effective conflict resolution as a challenge within Living-Learning Communities (LLCs) are highlighted. Among Kyebi Locals, 5% disagreed, 5% remained neutral, and 30% agreed, with 60% strongly agreeing. Tertiary students expressed similar sentiments, with 10% disagreeing, 20% remaining neutral, and 25% agreeing, while 45% strongly agreed. STEAM Educators and Advocates demonstrated a high level of concern, with 45% agreeing and 55% strongly agreeing. Built Environment Professionals also acknowledged the challenge, with 20% remaining neutral, 40% agreeing, and 40% strongly agreeing. The data underscores the importance of implementing effective conflict resolution strategies within LLCs to foster a harmonious learning environment conducive to STEAM education.

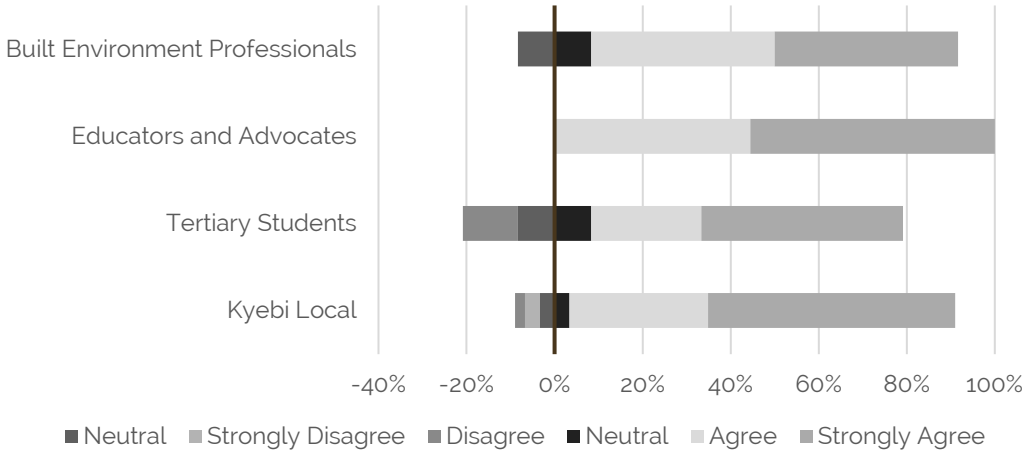


Figure 4.39 Stakeholders' Opinion on Effective Conflict Resolution as a challenge (Source: Author's Construct,2024)

The data emphasizes the importance of implementing effective conflict resolution strategies within LLCs to foster a harmonious learning environment conducive to STEAM education.

4.4.2.7 Improving with Limited Resources

In figure 4.40, stakeholders' perspectives on the challenge of improving Living-Learning Communities (LLCs) with limited resources are depicted. Among Kyebi Locals, 20% had a neutral opinion, while 2% agreed and 78% strongly agreed with the challenge. Similarly, among tertiary students, 15% had a neutral opinion, while 15% agreed and 70% strongly agreed. STEAM Educators and Advocates showed alignment, with 10% neutral, 20% agreeing, and 70% strongly agreeing.

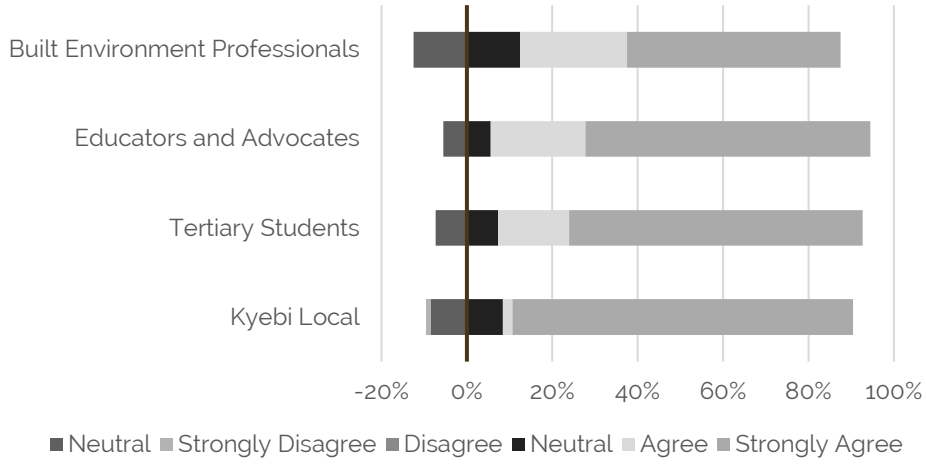


Figure 4.40 Stakeholders' Opinion on Improving with Limited Resources as a challenge (Source: Author's Construct,2024)

From the Figure 4.40, Built Environment Professionals also acknowledged the challenge, with 30% neutral, 20% agreeing, and 50% strongly agreeing. These findings underscore the need for innovative strategies and resource management techniques to enhance LLCs despite resource constraints.

4.5 BIOMIMICRY'S POTENTIAL AND CHALLENGES FOR S.T.E.A.M.

Objective 3 of this study focuses on exploring the potential of Biomimicry Architecture in designing a Living-Learning Community STEAM Hub and addressing the challenges associated with its implementation. The aim is to evaluate stakeholders' perspectives on the benefits of Biomimicry for STEAM education and to examine the obstacles encountered in its integration. Specifically, Objective 3 aims to understand stakeholders' perceptions of the advantages offered by Biomimicry architecture for STEAM education and to investigate the challenges arising from its application in the design life cycle of buildings within the context of STEAM/educational facilities in Ghana. Through the distribution of questionnaires to residents of Kyebi and stakeholders such as tertiary students, STEAM educators/advocates, and built environment professionals, this study aims to provide insights into various aspects, including Biomimetic Principles, Cultural considerations, potentials of Biomimicry for STEAM, and the barriers associated with its implementation. Additionally, interviews were conducted with built environment professionals, specifically Architects, to further explore these topics.

4.5.1 Biomimicry in Design

In the pursuit of understanding Biomimicry's application in design, two comprehensive interviews were conducted alongside questionnaire surveys. These interviews featured two seasoned architects, designated as **Arc. A** and **Arc. B**, both equipped with master's degrees in Architecture. **Arc. A** brings to the table nearly a decade of professional experience, while **Arc. B** boasts over two decades of immersive practice. Despite their divergent backgrounds, both individuals exhibit a moderate level of familiarity with STEAM education. However, **Arc. A** hold a more substantial familiarity with Living-Learning Communities, contrasting with **Arc. B's** comparatively slight acquaintance with the concept. Notably, both **Arc. A and Arc. B** demonstrate a high level of familiarity with Biomimicry Architecture. These interviews serve as invaluable resources, providing nuanced perspectives on the integration of Biomimicry in

architectural design, while also shedding light on varying levels of familiarity with associated concepts among architectural practitioners.

4.5.1.1 Biomimetic Principles for Educational Facilities

From their responses, both **Arc. A** and **Arc. B** highlighted the potential for integrating biomimicry principles into the design of a Living-Learning Community S.T.E.A.M. Hub across multiple levels. **Arc. A** leaned towards the Ecosystem Level, emphasizing the importance of replicating the working principles of natural ecosystems within the design. They argued that by mimicking the resilience, adaptability, and efficiency found in natural ecosystems, the S.T.E.A.M. Hub could better facilitate interdisciplinary learning and innovation. Conversely, **Arc. B** favored the Organism Level, advocating for direct imitation of nature's forms and structures in the architectural design. They emphasized the aesthetic and functional benefits of incorporating biomimetic designs inspired by specific organisms, such as trees or animals, to create a more harmonious and sustainable living environment. Overall, both interviews underscored the versatility of biomimicry principles and the potential for their integration at various levels to enhance the functionality, sustainability, and overall appeal of the Living-Learning Community S.T.E.A.M. Hub.

4.5.1.2 Cultural Considerations

Both **Arc. A** and **Arc. B** provided insights into how biomimicry could contribute to creating culturally sensitive and inclusive designs for the Living-Learning Community S.T.E.A.M. Hub. **Arc. A** emphasized the importance of observing and incorporating cultural elements from the local context into the design process. They suggested that biomimicry principles could help in understanding and respecting the natural and cultural heritage of the community, allowing for the creation of spaces that resonate with the local culture and identity. **Arc. B**, on the other hand, focused on the behavioral level of biomimicry, suggesting that by studying natural processes and systems, designers could gain insights into inclusive and collaborative behaviors found in ecosystems. They proposed that biomimicry could inspire design strategies that promote diversity, equity, and inclusivity within the S.T.E.A.M. Hub, fostering a sense of belonging and cultural appreciation among its users. Overall, both interviews highlighted the potential for biomimicry to inform culturally sensitive and inclusive design approaches for the Living-Learning Community S.T.E.A.M. Hub, emphasizing

the importance of integrating local cultural elements and promoting inclusive behaviors inspired by nature.

4.5.2 Potentials of Biomimicry for S.T.E.A.M. Education

Questionnaires were utilized to elicit stakeholders' viewpoints regarding the benefits of biomimicry architecture in STEAM education, as outlined in existing literature. In addition, interviews were conducted with two professional architects, Interviewee **Arc. A** and **Arc. B**, to enrich the research and bolster its credibility. This mixed-method approach aimed to triangulate insights from various sources, enabling a comprehensive examination of the potential of biomimicry architecture within the realm of STEAM education. By integrating responses from both questionnaires and expert interviews, the study aims to offer a nuanced understanding of the implications and practical applications of incorporating biomimicry principles in educational environments.

The data from the questionnaires, depicted in Figure 4.41, indicates varying degrees of agreement among respondents regarding the benefits of biomimicry in educational facilities. For improving sustainability, a majority of respondents (65%) either agreed or strongly agreed, suggesting a positive perception of biomimicry's potential in this aspect. Similarly, a significant portion of respondents (77%) agreed or strongly agreed with biomimicry's contribution to the community's cultural identity, indicating its perceived value in fostering cultural connections. Regarding collaborative opportunities across fields, the majority (60%) agreed or strongly agreed, highlighting biomimicry's role in interdisciplinary engagement.

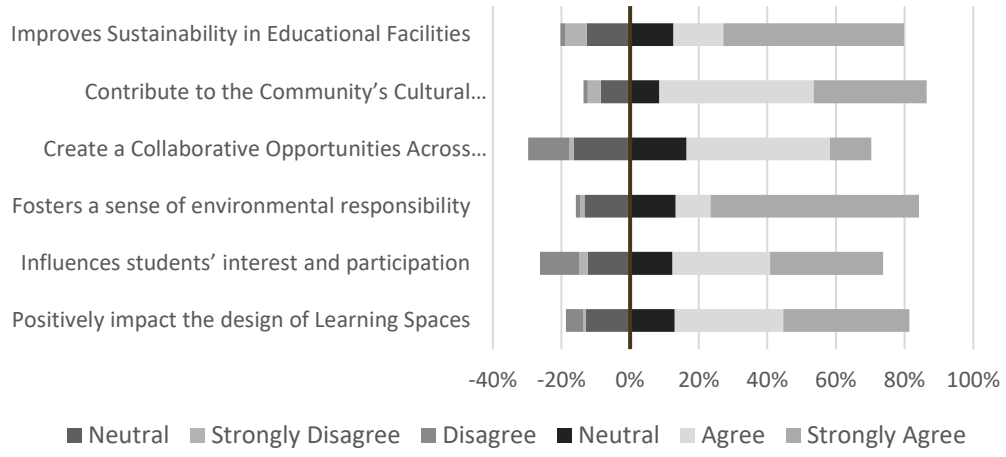


Figure 4.41 Stakeholder Perceptions on Potentials of Biomimicry for S.T.E.A.M. Education (Source: Author's Construct,2024)

Furthermore, from the Figure 4.41, for fostering a sense of environmental responsibility, a substantial percentage (68%) agreed or strongly agreed, underscoring the perceived impact of biomimicry in cultivating environmental consciousness. Regarding its influence on students' interest and participation, the majority (60%) agreed or strongly agreed, suggesting its potential to enhance student engagement. Additionally, for its positive impact on the design of learning spaces, a considerable proportion (60%) agreed or strongly agreed, indicating its perceived effectiveness in creating conducive learning environments.

Interviewees **Arc. A** and **Arc. B** provided valuable insights into these findings. Both expressed agreement with the potential of biomimicry in improving sustainability, fostering cultural identity, and creating collaborative opportunities. They emphasized its role in promoting environmental responsibility and enhancing student engagement. Moreover, they highlighted the importance of integrating biomimicry principles into the design process to optimize learning spaces. Their perspectives align with the questionnaire data, affirming the potential benefits of biomimicry in educational contexts.

Overall, the data suggests a positive perception of biomimicry's potential benefits among stakeholders, corroborated by the insights provided by **Arc. A** and **Arc. B.** These findings emphasize the importance of incorporating biomimicry principles in educational design to promote sustainability, cultural inclusivity, interdisciplinary collaboration, environmental stewardship, student engagement, and optimal learning environments.

The data from Table 4.17 ranks the perceived benefits of biomimicry in educational settings using the Relative Importance Index (RII). "Fosters a sense of environmental responsibility" was ranked highest, indicating strong agreement among respondents, followed by "Improves Sustainability in Educational Facilities" and "Contributes to the Community’s Cultural Identity." These findings highlight the recognition of biomimicry's potential to instill ecological awareness, promote sustainable practices, and preserve cultural heritage. "Positively impacts the design of Learning Spaces" was also significant, while "Influences students’ interest and participation" and "Creates Collaborative Opportunities Across Fields" ranked slightly lower.

Table 4.17 Ranking of Opinions on Benefits of Biomimicry for STEAM.

Benefits of Biomimicry	N	Min.	Max.	Mean	Standard Deviation	RII
1. Fosters a sense of environmental responsibility	158	1	5	4.28	0.983	0.855696
2. Improves Sustainability in Educational Facilities	158	1	5	4.06	1.185	0.811392
3. Contribute to the Community's Cultural Identity	158	1	5	4.02	0.947	0.803797
4. Positively impact the design of Learning Spaces	158	1	5	3.99	0.944	0.797468
5. Influences students' interest and participation	158	1	5	3.78	1.104	0.755696
6. Create a Collaborative Opportunities Across Fields	158	1	5	3.51	0.901	0.702532
Valid N (listwise)	158					

(Source: Author's Construct,2024)

Overall, the data underscores the positive perception of biomimicry's benefits in education, emphasizing the importance of integrating its principles into curricula and facility design to enhance student engagement and interdisciplinary collaboration while promoting environmental stewardship. The subsequent sections show summaries of the opinions of the various stakeholders

4.5.2.1 Positive Impact the Design of Learning Spaces

The data depicted in Figure 4.42 highlights stakeholders' agreement regarding the positive impact of biomimicry on the design of learning spaces. Among Kyebi Locals, a significant majority, constituting 63%, either agree or strongly agree, indicating widespread acknowledgment of the value of integrating biomimicry principles into

educational environments. Tertiary students also express strong agreement, with 67% either agreeing or strongly agreeing, suggesting their recognition of the benefits that biomimicry can offer in enhancing learning spaces. Similarly, STEAM Educators and Advocates exhibit overwhelming agreement, with 80% either agreeing or strongly agreeing, underscoring their endorsement of the potential advantages associated with biomimicry.

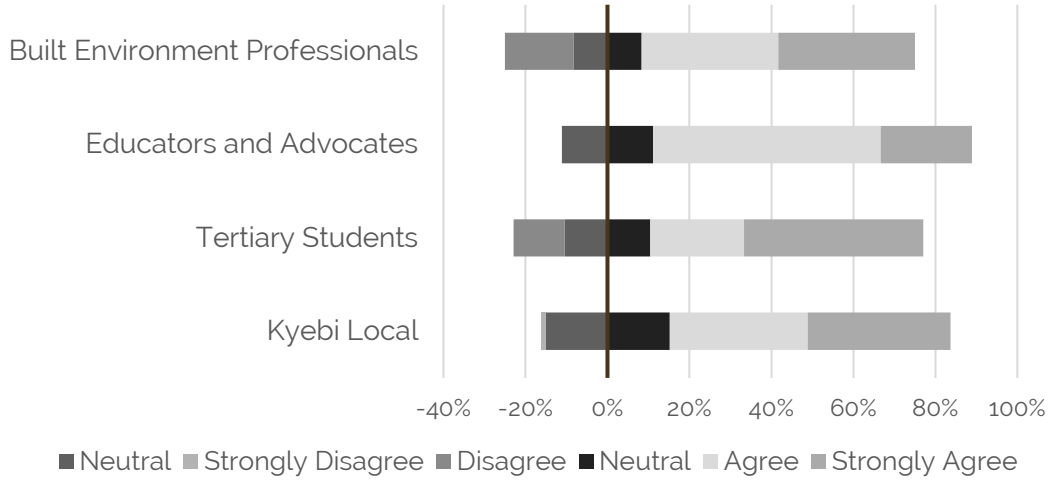


Figure 4.42 Stakeholders' Opinions on Biomimicry Positively impacting the design of Learning Spaces (Source: Author's Construct,2024)

Built Environment Professionals also demonstrate considerable agreement, although with slightly higher levels of disagreement compared to other groups. Overall, the data underscores stakeholders' consensus regarding the positive role of biomimicry in enhancing the design of learning spaces, indicating ample opportunities for its integration to foster innovative and sustainable educational environments.

4.5.2.2 Influence on students' interest and participation

In Figure 4.43, stakeholders' perspectives on the influence of biomimicry on students' interest and participation in STEAM are delineated. Among Kyebi Locals, 50% either agree or strongly agree, indicating a significant portion acknowledging the potential of biomimicry to enhance students' engagement in STEAM disciplines. Tertiary students demonstrate a higher level of agreement, with 78% either agreeing or strongly agreeing, underscoring their recognition of the positive impact biomimicry can have on student interest and involvement in STEAM fields. Similarly, STEAM Educators and Advocates express overwhelming agreement, with 90% either agreeing or strongly

agreeing, suggesting their confidence in the efficacy of biomimicry in stimulating students' enthusiasm for STEAM subjects.

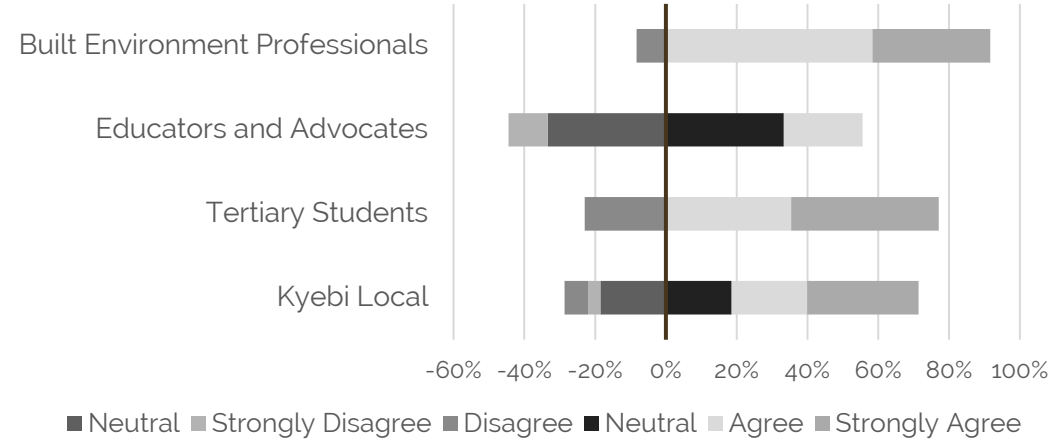


Figure 4.43 Stakeholders' Opinions on Biomimicry Influencing students' interest and participation in STEAM (Source: Author's Construct,2024)

Built Environment Professionals also show substantial agreement, with 90% agreeing with the notion of biomimicry positively influencing students' interest and participation in STEAM. Overall, the data indicates a consensus among stakeholders regarding the potential of biomimicry to inspire and engage students in STEAM education, highlighting its significance in fostering interest and participation in these disciplines.

4.5.2.3 Fostering of a sense of environmental responsibility

The data from Figure 4.44 reveals stakeholders' perceptions regarding biomimicry's role in fostering environmental responsibility.

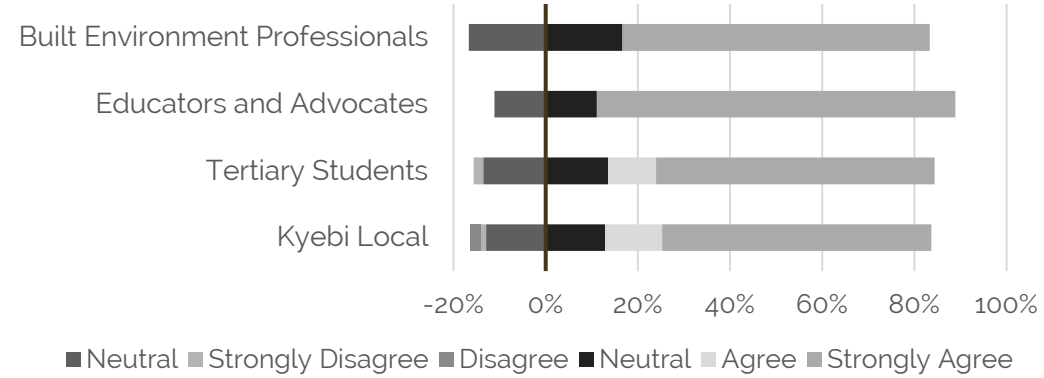


Figure 4.44 Stakeholders' Opinions on Biomimicry Fosters a sense of Environmental Responsibility (Source: Author's Construct,2024)

Among Kyebi Locals, 66% express agreement, while 68% of tertiary students, 70% of STEAM Educators and Advocates, and 64% of Built Environment Professionals similarly concur. This broad consensus highlights the recognition of biomimicry's potential to promote environmental stewardship.

4.5.2.4 Creation of Collaborative Opportunities Across Fields

As depicted in Figure 4.45, stakeholders' views on Biomimicry Creating Collaborative Opportunities Across Fields vary. Among Kyebi Locals, 50% agree with this notion, while 35% of tertiary students, 80% of STEAM Educators and Advocates, and 65% of Built Environment Professionals express agreement.

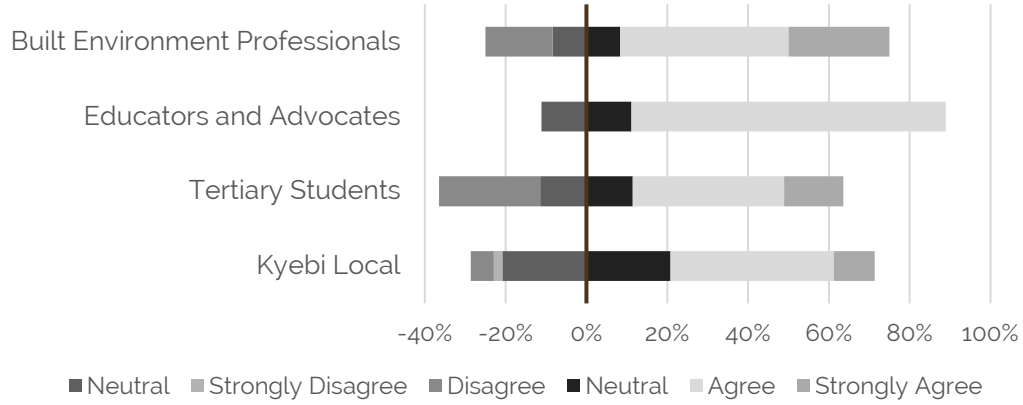


Figure 4.45 Stakeholders' Opinions on Biomimicry Creating a Collaborative Opportunities Across Fields (Source: Author's Construct,2024)

This diversity in perspectives underscores the potential for biomimicry to foster interdisciplinary collaboration.

4.5.2.5 Contribution to the Community's Cultural Identity

As illustrated in Figure 4.46, stakeholders' opinions on the contribution of Biomimicry to the community's cultural identity vary. Among Kyebi locals, approximately 10% disagreed with this notion, while 10% held a neutral stance, and 50% agreed, with 30% strongly agreeing. Tertiary students showed a higher degree of neutrality, with 35%, while 40% agreed and 25% strongly agreed. STEAM Educators and Advocates had a minor disagreement rate of 10%, with 80% in agreement and 10% strongly agreeing.

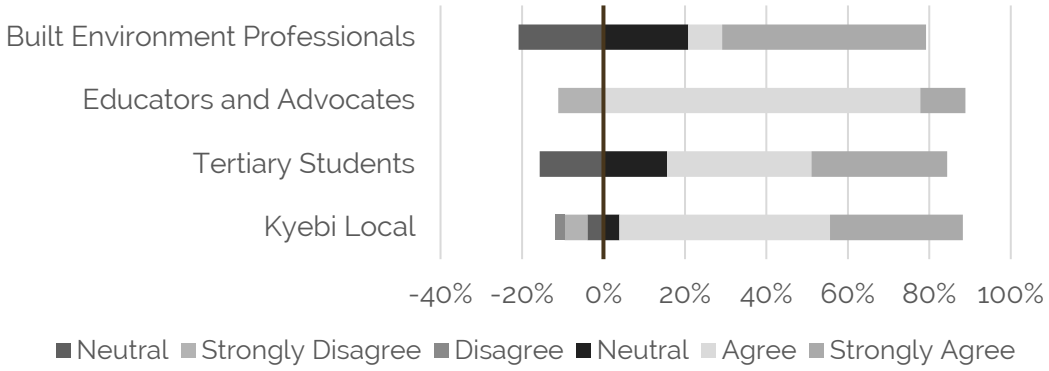


Figure 4.46 Stakeholders' Opinions on Biomimicry Contributing to the Community's Cultural Identity (Source: Author's Construct,2024)

Among Built Environment Professionals, 40% held a neutral stance, 10% agreed, and 50% strongly agreed. This diversity in opinions highlights the complexity of incorporating Biomimicry into cultural contexts and underscores the importance of considering various perspectives in its implementation.

4.5.2.6 Improvement in Sustainability in Educational Facilities

As illustrated in Figure 4.47, stakeholders' opinions on the role of Biomimicry in improving sustainability in educational facilities vary. Among Kyebi locals, approximately 15% disagreed with this proposition, while 40% remained neutral, and 45% strongly agreed.

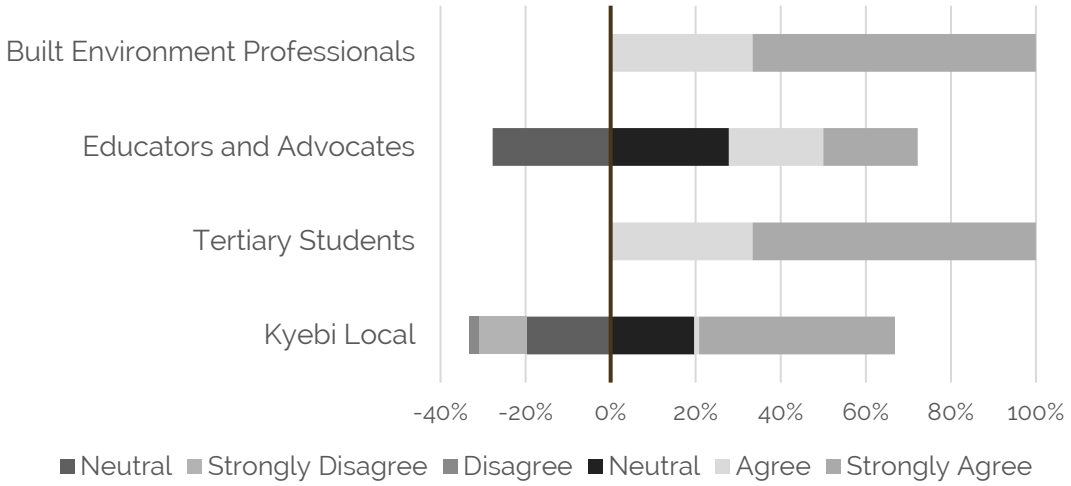


Figure 4.47 Stakeholders' Opinions on Biomimicry Improving Sustainability in Educational Facilities (Source: Author's Construct,2024)

Among tertiary students, 35% agreed, and 65% strongly agreed. STEAM Educators and Advocates exhibited a higher level of neutrality, with 60%, while 20% agreed, and 20% strongly agreed. Built Environment Professionals showed a higher degree of agreement, with 30% in agreement and 70% strongly agreeing.

This divergence in opinions emphasizes the need for a nuanced approach to integrating Biomimicry into educational infrastructure to ensure its effectiveness and relevance.

4.5.3 Challenges of Biomimicry for STEAM Education

The interviews with **Arc. A** and **Arc. B** provided valuable insights into the challenges of implementing Biomimicry architecture, aligning with existing literature. These challenges include stakeholders' lack of awareness, financial constraints, expertise shortages, limited access to resources, cultural considerations, and maintaining biomimicry features. Gathering data on these challenges enriches the research by offering a deeper understanding of practical obstacles, guiding strategies for overcoming them, and enhancing the credibility of the study's findings.

4.5.3.1 Stakeholders lack awareness

The interviews conducted with **Arc. A** and **Arc. B** underscored stakeholders' lack of awareness as a notable hurdle in implementing Biomimicry architecture. **Arc. B** mentioned that this suggests a potential resistance or reluctance among decision-makers and community members to adopt Biomimicry principles due to a limited understanding of its benefits. The implications of this challenge are significant, as it may impede the successful integration of Biomimicry features into architectural designs and result in missed opportunities for sustainable solutions. **Arc A** suggested addressing this issue requires awareness-building initiatives such as educational workshops and public outreach campaigns to foster understanding and support for Biomimicry principles among stakeholders.

4.5.3.2 Financial limitations

The interviews with **Arc. A** and **Arc. B** highlighted financial limitations as a significant challenge in implementing Biomimicry for STEAM in Kyebi. Both **Arc. A and Arc B** mentioned that this constraint suggests that the costs associated with integrating Biomimicry principles into architectural designs may exceed available budgets, hindering the realization of sustainable and innovative solutions. **Arc. B** added that the implications of financial limitations are profound, as they may restrict

access to necessary resources, materials, and expertise needed for successful Biomimicry integration. Both interviewees **Arc. A** and **Arc. B** mentioned that consequently, projects may face delays, compromises in design quality, or even abandonment due to insufficient funding. Addressing this challenge, **Arc. A** suggested that there be the need to explore alternative funding sources, advocating for budget allocations dedicated to sustainable initiatives, and prioritizing cost-effective Biomimicry solutions that align with project budgets.

4.5.3.3 Expertise Shortage Hampering Successful Integrating

The interviews with Arc. A and Arc. B emphasized expertise shortage as a significant challenge in successfully integrating Biomimicry for STEAM in Kyebi. Both **Arc. A** and **Arc. B** highlighted that the scarcity of professionals with expertise in Biomimicry principles and practices hampers the seamless integration of these innovative concepts into architectural designs. **Arc. A** mentioned that this shortage may lead to suboptimal implementation of Biomimicry solutions, compromising the effectiveness and sustainability of projects. Additionally, **Arc. B** emphasized that the lack of expertise could impede the identification of suitable biomimetic strategies tailored to specific project requirements and environmental contexts. Consequently, projects may encounter setbacks, design errors, or operational inefficiencies due to the absence of specialized knowledge in Biomimicry. To address this challenge, both interviewees **Arc. A** and **Arc. B** emphasized the importance of investing in capacity building, training programs, and collaborative initiatives to nurture a pool of professionals proficient in Biomimicry principles and applications. **Arc A** stressed the need for interdisciplinary collaboration and knowledge-sharing platforms to bridge the gap in expertise and facilitate successful integration of Biomimicry into architectural practices.

4.5.3.4 Limited access to biomimicry resources and materials

The interviews with **Arc. A** and **Arc. B** highlighted the challenge of limited access to biomimicry resources and materials in implementing Biomimicry for STEAM in Kyebi. **Arc. A.** expressed concerns about the scarcity of biomimicry resources, emphasizing its impact on architects' creativity and the realization of sustainable design outcomes. In contrast, **Arc. B** adopted a more optimistic view, acknowledging the challenge but emphasizing the importance of resourcefulness and adaptation in overcoming limitations. Both **Arc. A** and **Arc. B** recognized the need for collaborative

efforts to improve access to biomimicry resources and materials and emphasized the importance of investing in research and development initiatives.

4.5.3.5 Balancing biomimicry innovations with cultural considerations

The interviews with **Arc. A** and **Arc. B** both emphasized the challenge of balancing biomimicry innovations with cultural considerations in implementing Biomimicry for STEAM in Kyebi. **Arc. A** emphasized the necessity of aligning biomimetic designs with cultural sensitivities to ensure community acceptance and relevance. However, **Arc. B** expressed concerns about the potential conflict between biomimicry innovations and cultural preservation, suggesting that overly rigid adherence to cultural norms could stifle design creativity and innovation. Both **Arc. A** and **Arc. B** highlighted the importance of striking a balance between biomimetic principles and cultural values, advocating for a nuanced approach that respects cultural heritage while embracing innovation. **Arc. B** emphasized the need for interdisciplinary collaboration and community engagement to navigate this complex challenge effectively.

4.5.3.6 The complexity of maintaining biomimicry features

Arc. B revealed the complexity of maintaining biomimicry features as a significant challenge in implementing Biomimicry for STEAM in Kyebi. **Arc. A** underscored the importance of ongoing maintenance to ensure the longevity and functionality of biomimetic elements in architectural designs. However, **Arc. B** expressed skepticism about the feasibility of long-term maintenance, citing concerns about the durability and practicality of biomimetic features in real-world settings. Both **Arc. A** and **Arc. B** acknowledged the need for comprehensive planning and monitoring strategies to address maintenance challenges effectively. **Arc A** emphasized the importance of incorporating resilient and adaptable biomimetic solutions that can withstand environmental stressors and require minimal upkeep. Additionally, he highlighted the importance of education and training programs to equip stakeholders with the skills and knowledge necessary for effective maintenance practices.

4.5.4 Community Engagement for Design

In the interviews conducted with Arc. A and Arc. B regarding the relevance of community engagement for design, both **Arc. A** and **Arc. B** emphasized its critical importance based on their experiences. **Arc. A** highlighted that community engagement fosters a deeper understanding of local needs, preferences, and cultural

values, which are essential for creating meaningful and sustainable designs. **Arc. B** echoed this sentiment, emphasizing that involving community stakeholders in the design process promotes transparency, inclusivity, and ownership, ultimately leading to more successful outcomes.

Arc. B mentioned that community engagement fosters knowledge-sharing and capacity-building, empowering community members to contribute to the hub's development and maintenance. This collaborative approach enhances the design's relevance, sustainability, and fosters community ownership and pride. Overall, the insights provided by Arc. A and Arc. B accentuates the importance of community engagement as a fundamental aspect of the design process, particularly in projects aimed at serving and benefiting local communities like the Living-Learning Community S.T.E.A.M. Hub in Kyebi.

4.6 APPLYING BIOMIMICRY TO DESIGN A S.T.E.A.M. HUB IN KYEBI

The **Objective 4** of this study focuses on applying the concept of biomimicry to design a sustainable Living-Learning Community S.T.E.A.M. Hub in Kyebi. To effectively achieve this objective, it is crucial to investigate the participants' interest in the project, their willingness to recommend others to participate, their opinion regarding the incorporation of Living-Learning Communities for STEAM, and their appreciation of incorporating Biomimicry Architecture into the design. These data serve as foundational elements for informing the design process, ensuring that the proposed S.T.E.A.M. Hub aligns with the preferences, needs, and aspirations of the community and stakeholders involved. By systematically gathering and analyzing this information, the study aims to establish a strong rationale for the development of a Living-Learning Community S.T.E.A.M. Hub in Kyebi that not only integrates biomimetic principles but also garners support and enthusiasm from key stakeholders.

4.6.1 Interest in Participating in a STEAM Program

The data collected from participants in Kyebi encompassing students from various educational levels such as Junior High School (J.H.S), Senior High School (S.H.S), Vocational/Technical institutes, Teacher Training institutions, Tertiary education, and some Educators from these institutions, indicates a high level of interest in participating in STEAM programs, with 85.4% of respondents expressing agreement. Specifically, among tertiary students, 60.4% agreed to participate, highlighting substantial interest within this demographic. However, a notable proportion of

participants, including 14.6% of Kyebi locals and 31.3% of tertiary students, expressed uncertainty about their participation as illustrated in Figure 4.48.

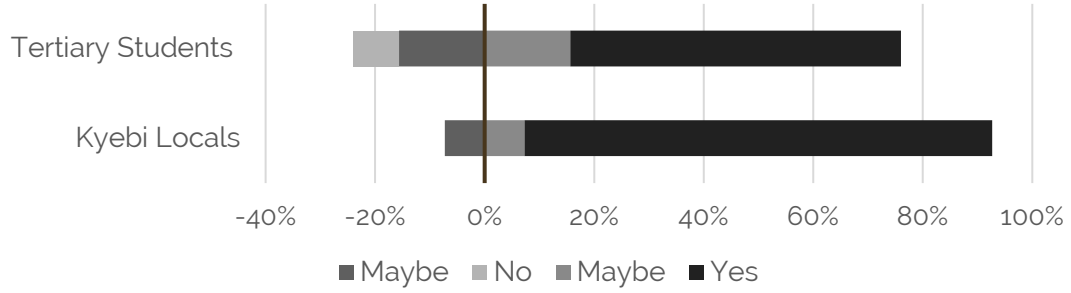


Figure 4.48 Stakeholder Interest in Participating in a STEAM Program

(Source: Author's Construct,2024)

These findings suggest both enthusiasm and hesitancy among participants, emphasizing the importance of addressing concerns and uncertainties to ensure broad engagement in STEAM initiatives. Overall, the data underscores the potential for successful implementation of STEAM programs in Kyebi while highlighting the need for targeted efforts to enhance participation and address any reservations among participants.

The histogram in Figure 4.49 provides a visual representation of stakeholder interest in participating in STEAM programs, with the normal curve skewing towards the left which represented Yes. Among the 137 participants, the average mean of 1.44 indicates a generally positive attitude towards STEAM programs.

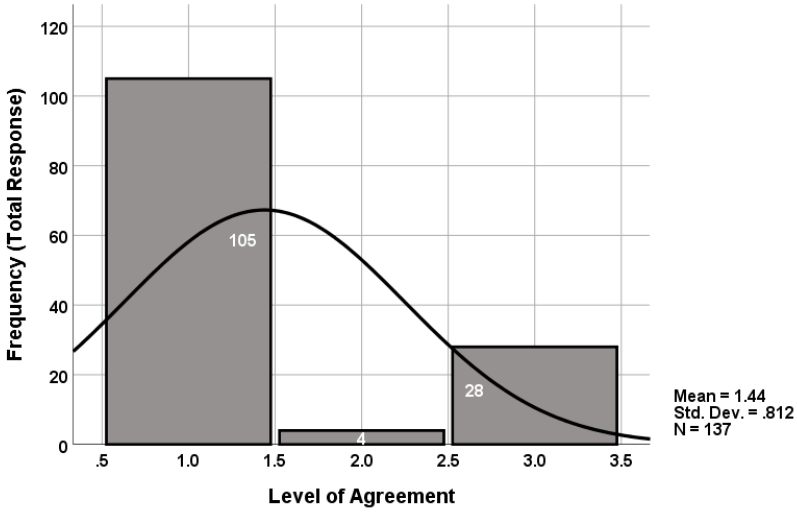


Figure 4.49 Stakeholders Interest in Participating in a STEAM Program

(Source: Author's Construct,2024)

The relatively low standard deviation of 0.812 suggests a moderate level of consistency in stakeholders' levels of interest.

This data implies a widespread enthusiasm for STEAM initiatives among the surveyed stakeholders. The clustering of responses towards the agreement end of the Likert scale suggests a prevailing consensus regarding the value and importance of STEAM programs. This indicates a strong foundation for the development and implementation of STEAM initiatives within the community. Overall, the data suggests a favorable environment for the promotion and advancement of STEAM education and underscores the potential for successful engagement and participation in related programs and activities.

4.6.2 Willingness in Recommending STEAM Programs

The histogram illustrated in Figure 4.50 provides an overview of stakeholder willingness to recommend STEAM programs in Kyebi, with the normal curve skewing towards the left (Yes). Among the 158 participants, the average mean of 1.14 suggests a strong inclination towards recommending STEAM programs. The relatively low standard deviation of 0.511 indicates a moderate level of consistency in stakeholders' willingness to recommend such programs.

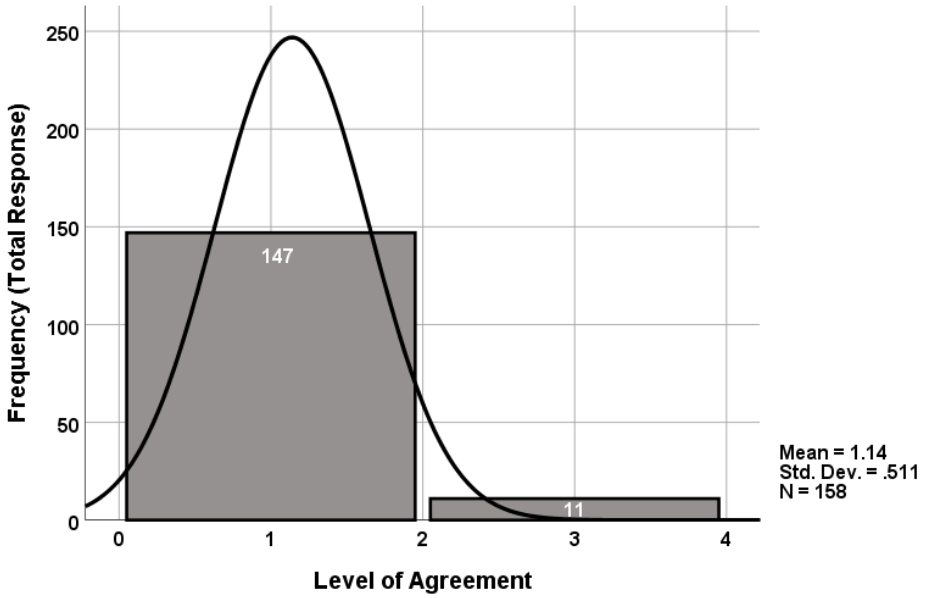


Figure 4.50 Stakeholders Willingness in Recommending STEAM Programs

(Source: Author's Construct,2024)

This data implies a widespread endorsement of STEAM initiatives among the surveyed stakeholders. The clustering of responses towards the agreement end of the

Likert scale indicates a prevailing consensus regarding the value and importance of recommending STEAM programs to others. This suggests a high level of confidence in the benefits and effectiveness of STEAM education within the community. The data underscores the potential for successful advocacy and promotion of STEAM programs, as well as the likelihood of positive word-of-mouth referrals within the community. Overall, the findings suggest a favorable environment for the promotion and advancement of STEAM education initiatives in Kyebi, with significant support from stakeholders.

4.6.3 Suggestion on Incorporating LLCs into STEAM

The histogram in Figure 4.51 presents a general overview of stakeholder opinions regarding the incorporation of Living-Learning Communities (LLCs) into STEAM in Kyebi, with the normal curve skewed towards the left, indicating a predominant inclination towards incorporating LLCs into STEAM initiatives. Among the 158 participants, the average mean of 1.36 suggests a strong endorsement for integrating LLCs into STEAM education. The relatively moderate standard deviation of 0.733 indicates some variability in stakeholders' opinions but still reflects a considerable consensus favoring the incorporation of LLCs.

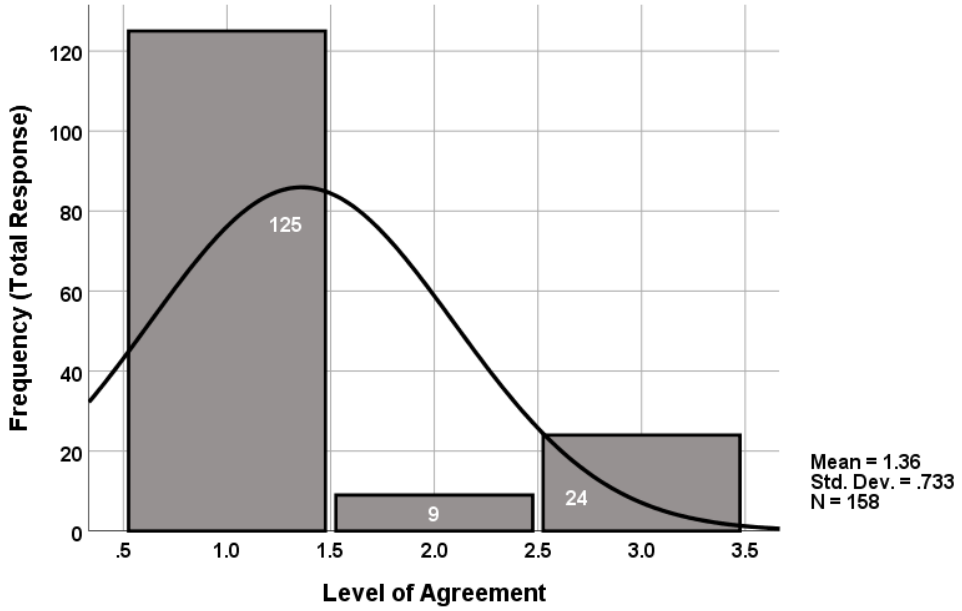


Figure 4.51 Stakeholders Suggestion on Incorporating LLCs into STEAM

(Source: Author's Construct,2024)

This data implies a widespread recognition among stakeholders of the potential benefits that LLCs can bring to STEAM education in Kyebi. The clustering of

responses towards the "Yes" end of the spectrum indicates a prevailing sentiment in favor of leveraging LLCs to enhance STEAM learning experiences. The findings suggest that stakeholders perceive LLCs as valuable assets for promoting interdisciplinary learning, fostering innovation, and creating collaborative environments conducive to STEAM education. Overall, the data highlights a positive attitude towards the integration of LLCs into STEAM initiatives in Kyebi, indicating a potential pathway for enriching educational experiences and fostering holistic development within the community.

4.6.4 Appreciation of Incorporating Biomimicry Architecture into the Design

The data analysis from Figure 4.52 reveals a strong inclination among stakeholders towards incorporating Biomimicry Architecture into the design of the STEAM Hub in Kyebi. With the majority of respondents expressing appreciation for this approach, indicated by the left-skewed distribution of responses, there is a notable consensus on the potential benefits it offers. The average mean of 1.23 suggests widespread support for Biomimicry integration, emphasizing its importance in promoting sustainability and innovation within the STEAM Hub.

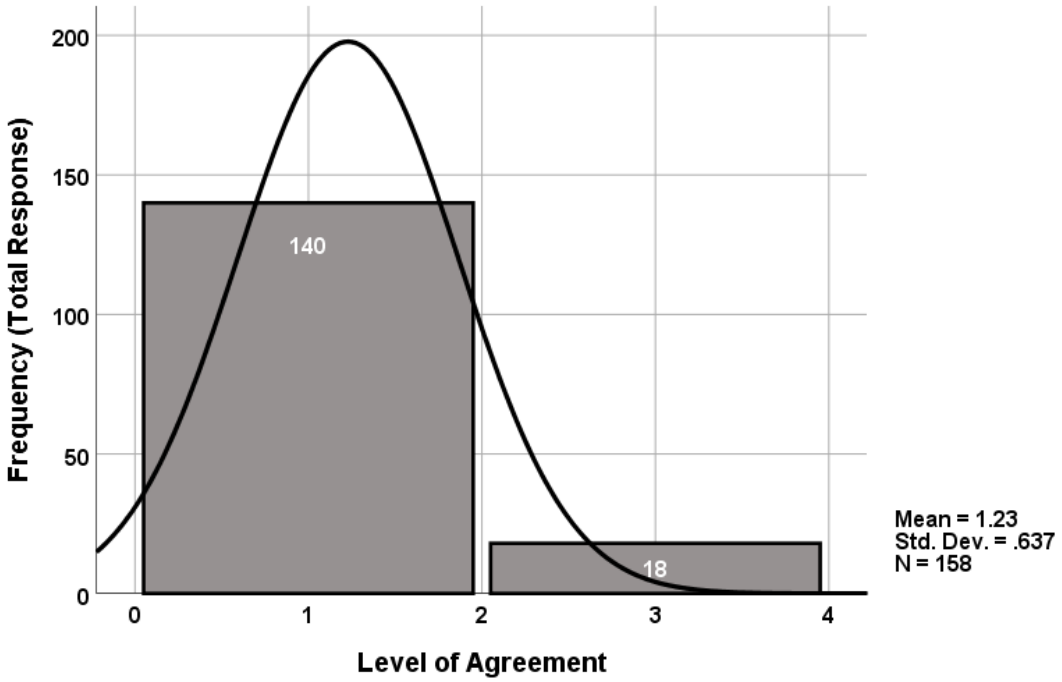


Figure 4.52 Stakeholders Appreciation of Incorporating Biomimicry Architecture into the Design (Source: Author's Construct,2024)

This data emphasizes the significance of embracing nature-inspired design principles to address contemporary challenges and foster interdisciplinary learning. Overall,

stakeholders' positive attitudes towards Biomimicry Architecture highlight a promising direction for the development of a sustainable and innovative STEAM Hub in Kyebi.

4.6.5 Programs and Activities to Considered for the Design

To ensure the optimal design of a Living-Learning Community STEAM Hub that caters to the diverse needs of its stakeholders, participants in the research were invited to evaluate their agreement with the inclusion of various activities and programs. These encompassed Technical and Vocational training, S.T.E.A.M. Teacher Development Programs, S.T.E.A.M. Summer Camps, Cultural Training Programs, Art and Science Workshops, Community Arts Projects, STEM Inspired Art Exhibitions, and Coding and Robotics Club. The results were analyzed and ranked to discern the activities most favored by the participants, thereby informing the prioritization of activities and programs for the hub's design.

The data summary from the questionnaire exercise, encompassing responses from 158 participants, is succinctly illustrated in Figure 4.53, offering a comprehensive portrayal of the findings gleaned from the study. From Figure 4.53, it is evident that the participants overwhelmingly supported the various programs and activities presented. Specifically, for Technical and Vocational training, the majority (92.4%) either agreed or strongly agreed, indicating a high level of endorsement. Similarly, STEAM teacher training programs received strong support, with 76.6% of participants strongly agreeing. The enthusiasm for STEAM Summer Camps was also notable, with 85.4% strongly agreeing. Cultural training programs garnered mixed responses, with a significant portion (61.4%) either agreeing or strongly agreeing, despite some participants expressing neutrality or disagreement. Art and Science Workshops were well-received, with 78.5% strongly agreeing. Community art projects and STEM inspired Art Exhibitions both received substantial support, though a notable proportion of participants expressed neutrality towards community art projects. Finally, Coding and Robotics Clubs were highly favored, with 76.6% strongly agreeing.

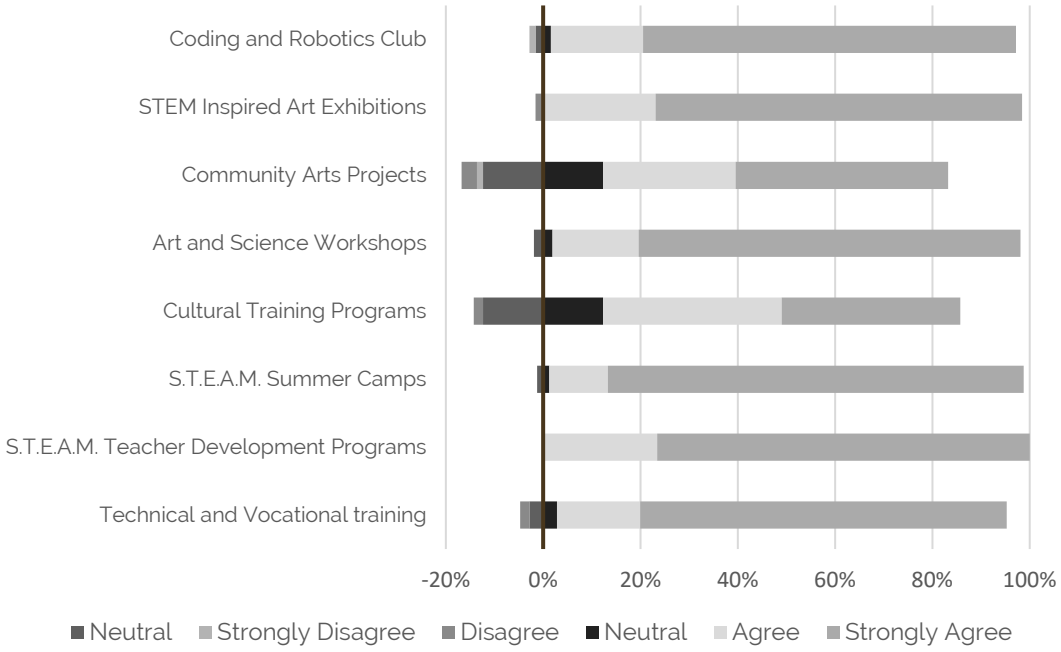


Figure 4.53 Stakeholders' Interest in Programs and Activities to be Considered for the LLC STEAM Hub (Source: Author's Construct,2024)

The data suggests a clear enthusiasm and endorsement for a diverse range of programs and activities within the context of a Living-Learning Community STEAM Hub. This high level of support underscores the potential effectiveness and appeal of such initiatives in fostering STEAM education and community engagement. The implications of these findings indicate a strong foundation for the development and implementation of the proposed programs, with potential benefits for enhancing educational experiences, promoting cultural exchange, and nurturing creativity and innovation within the community. Additionally, the varied responses highlight the importance of considering individual preferences and needs when designing and prioritizing activities within the hub to ensure inclusivity and maximize impact.

The Relative Important Index (RII) was utilised to rank the various programs and activities in a descending order of interest by the stakeholders that participated in the research. A summary of the Minimum and Maximum point selected on the Likert-scale, the mean, standard deviations and the RII are presented in the Table 4.18.

Table 4.18 Ranking of Respondents interest in proposed programs

Programs/Activities to be Considered for the design	N	Min.	Max.	Mean	Standard Deviation	RII
1. S.T.E.A.M. Summer Camps	158	3	5	4.83	0.440	0.9658
2. S.T.E.A.M. Teacher Development Programs	158	4	5	4.77	0.425	0.9532
3. Art and Science Workshops	158	3	5	4.75	0.516	0.9494
4. STEM Inspired Art Exhibitions	158	2	5	4.72	0.540	0.9443
5. Coding and Robotics Club	158	1	5	4.70	0.655	0.9392
6. Technical and Vocational training	158	2	5	4.66	0.675	0.9316
7. Community Arts Projects	158	1	5	4.09	0.960	0.8177
8. Cultural Training Programs	158	2	5	4.08	0.829	0.8165
Valid N (listwise)	**158**					

(Source: Author's Construct,2024)

From the data provided in Table 4.18, STEAM Summer Camps ranked highest with a mean of 4.83, Standard Deviation of 0.440, and an RII of 0.966, indicating the highest level of interest among participants. Following closely, STEAM Teacher Training Programs obtained the second position with a mean of 4.77, Standard Deviation of 0.425, and an RII of 0.953. Art and Science Workshops ranked third with a mean of 4.75, Standard Deviation of 0.516, and an RII of 0.949. STEM Inspired Art Exhibitions and Coding and Robotics Clubs also received high rankings with respective RIIs of 0.944 and 0.939. Conversely, Community Arts Projects and Cultural Training Programs were rated lower in stakeholders' preferences, as evidenced by their lower RII scores of 0.817 and 0.816, respectively. These findings suggest a strong interest in hands-on learning experiences and professional development opportunities within the STEAM field. On the other hand, Community Arts Projects and Cultural Training Programs ranked lower in stakeholders' preferences. While these activities may still hold value, their lower ranking suggests that they may not be perceived by some

stakeholders as essential components of the Living-Learning Community STEAM Hub in Kyebi. The findings from the major stakeholders (Kyebi Locals, Tertiary Students and Educators and Advocates outside the community) of the research are presented in as follows.

4.6.5.1 Technical and Vocational Training

The data from Figure 4.54 reveals a strong overall interest in Technical and Vocational Training among stakeholders, with varying degrees of approval. Kyebi locals and tertiary students showed favorable interest, with approximately 95% and 90% approval rates, respectively, despite some minor disapproval.

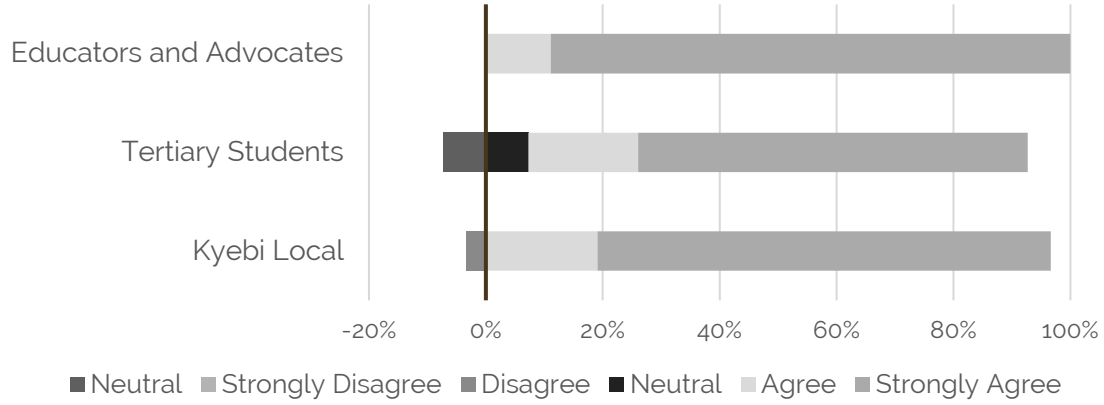


Figure 4.54 Stakeholders' Interest in Technical and Vocational training

(Source: Author's Construct,2024)

Notably, STEAM Educators and Advocates unanimously supported the initiative. These findings suggest widespread recognition of the importance of such programs in skills development. Addressing any concerns raised by dissenting voices will be crucial for ensuring broader community support and effective program implementation.

4.6.5.2 STEAM Teacher Development Programs

The data as illustrated in Figure 4.55 indicates significant interest in STEAM Teacher Training Programs across all stakeholder groups, with varying levels of enthusiasm. Kyebi locals and tertiary students showed favorable interest, with approximately 75% and 77% expressing strong enthusiasm, respectively, and around 25% and 23% showing moderate interest. Notably, STEAM Educators and Advocates exhibited the

highest level of interest, with 78% expressing keen enthusiasm and 22% showing moderate interest.

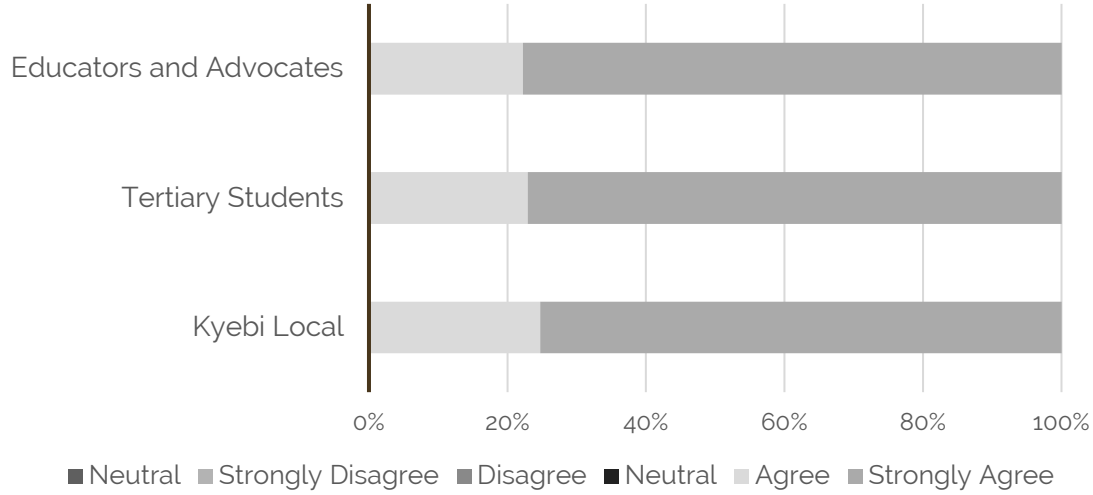


Figure 4.55 Stakeholders' Interest in S.T.E.A.M. Teacher Development Programs (Source: Author's Construct,2024)

These findings highlight widespread recognition of the importance of such programs in enhancing teaching effectiveness and promoting STEAM education within the community. Collaborative efforts will be essential to tailor training programs effectively and meet the diverse needs of educators, ultimately enhancing the quality of STEAM education in the community.

4.6.5.3 STEAM Summer Camps

The data from Figure 4.56 indicates significant interest in STEAM Summer Camp Programs across all stakeholder groups as well, with varying levels of enthusiasm. Kyebi locals and tertiary students showed favorable interest, with approximately 87% and 80% expressing strong enthusiasm, respectively, and around 13% and 15% showing moderate interest. Notably, STEAM Educators and Advocates exhibited the highest level of interest, with 88% expressing keen enthusiasm and 12% showing moderate interest.

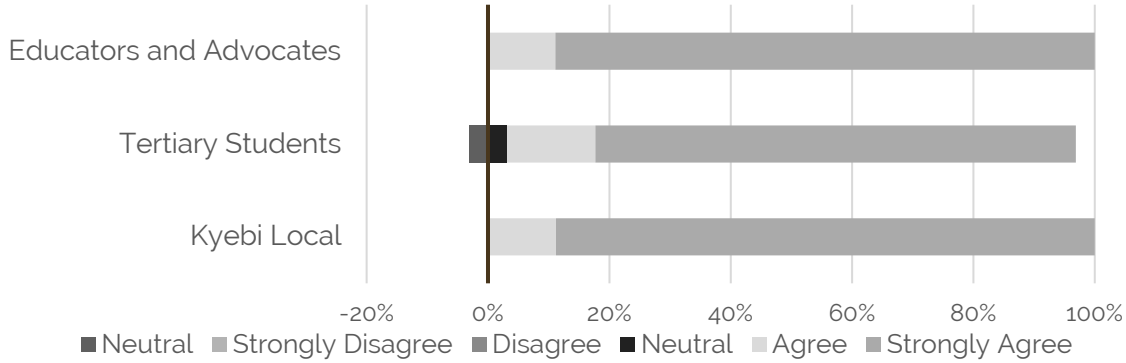


Figure 4.56 Stakeholders' Interest in S.T.E.A.M. Summer Camps

(Source: Author's Construct,2024)

These findings highlight widespread recognition of the importance of such programs in fostering interest and engagement in STEAM fields among students. Collaborative efforts will be essential to tailor summer camp programs effectively and ensure their success in promoting STEAM education within the community.

4.6.5.4 Cultural Training Programs

The data as presented in Figure 4.57 indicates mixed sentiments regarding Cultural Training Programs among surveyed stakeholders. While a majority of Kyebi locals (67%) and tertiary students (70%) expressed strong favorable interest, a notable minority showed disinterest or only moderate interest. Among STEAM Educators and Advocates, a significant majority (90%) demonstrated moderate to keen interest.

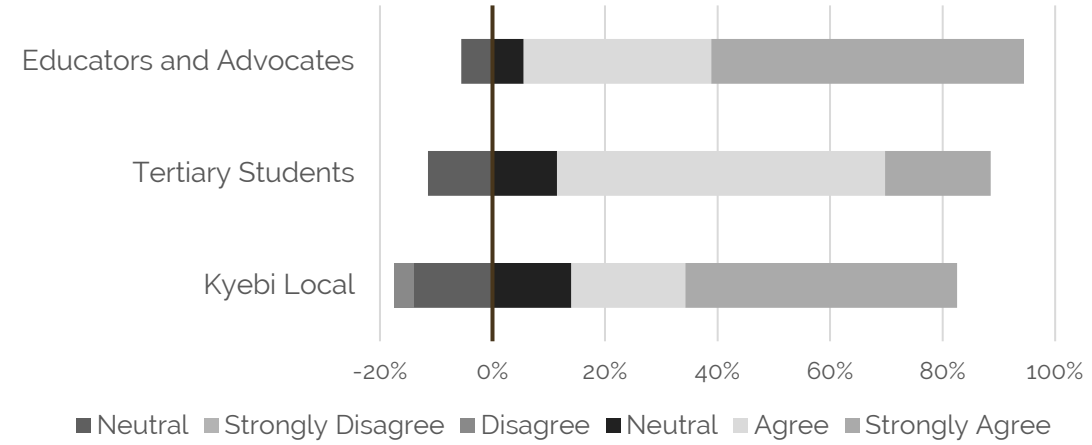


Figure 4.57 Stakeholders' Interest in Cultural Training Programs

(Source: Author's Construct,2024)

These findings underscore the importance of tailoring Cultural Training Programs to address varying levels of interest and concerns within the community. Collaboration among program developers, educators, and cultural experts will be essential to create engaging and impactful initiatives that promote cultural understanding and appreciation effectively.

4.6.5.5 Art and Science Workshops

The data from Figure 4.58 indicates strong interest in Art and Science Workshops among surveyed stakeholders. The majority of Kyebi locals (78%), tertiary students (75%), and STEAM Educators/Advocates (78%) expressed keen enthusiasm for these workshops, with additional percentages showing some level of interest. These findings underscore the potential of Art and Science Workshops to engage participants and contribute to STEAM education.

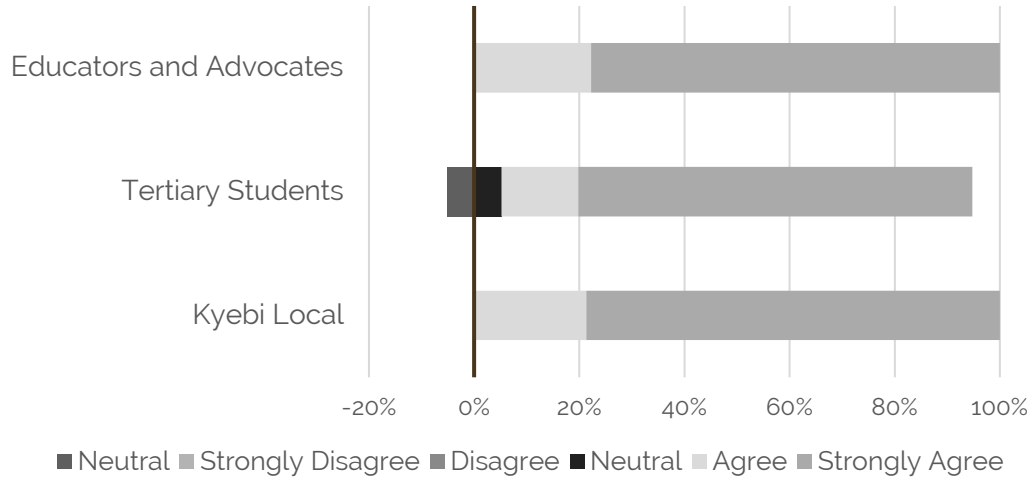


Figure 4.58 Stakeholders' Interest in Art and Science Workshops

(Source: Author's Construct,2024)

The implications suggest the importance of integrating such workshops into educational programs and community initiatives to support interdisciplinary learning and foster creativity and innovation. Collaboration among stakeholders will be essential for designing and implementing effective workshops that cater to participants' interests and needs.

4.6.5.6 Community Art Projects

The data from Figure 4.59 illustrates stakeholders' interest in Community Art Projects. While the majority of Kyebi locals (58%) and STEAM Educators/Advocates (80%)

expressed strong favorable interest, a notable portion of locals (20%) showed negative interest. Tertiary students displayed moderate interest (55%), with smaller percentages showing some interest (15%) or the most interest (15%).

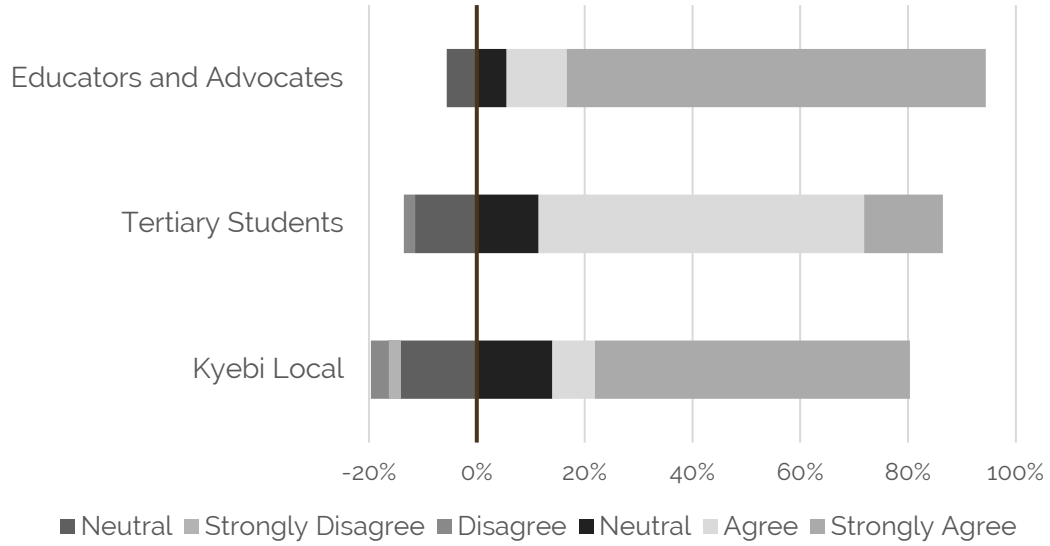


Figure 4.59 Stakeholders' Interest in Community Arts Projects

(Source: Author's Construct,2024)

These findings highlight the potential for Community Art Projects to engage stakeholders, particularly educators and advocates, but also indicate a need for community outreach to address concerns among locals and encourage broader participation. Collaboration among stakeholders could enhance project success and community involvement, fostering cultural enrichment through STEAM education.

4.6.5.7 STEM Inspired Art Exhibitions

The data from Figure 4.60 reveals stakeholders' interest in STEM Inspired Art Exhibitions. A significant majority of Kyebi locals (80%) and tertiary students (70%) showed strong favorable interest, suggesting potential enthusiasm for such exhibitions. However, a small percentage of locals (3%) and students (2%) expressed negative interest. STEAM Educators and Advocates demonstrated keen interest (78%), indicating professional endorsement and potential collaboration.

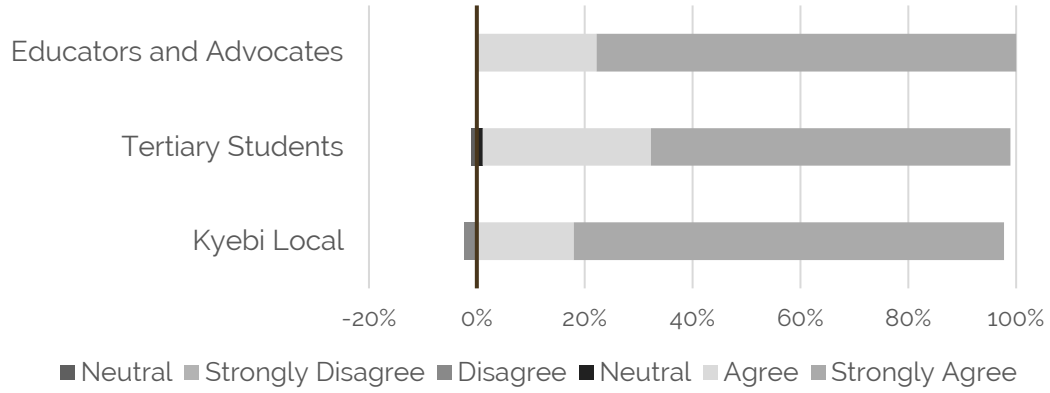


Figure 4.60 Stakeholders' Interest in STEM Inspired Art Exhibitions

(Source: Author's Construct,2024)

These findings suggest a promising opportunity for STEM-inspired art exhibitions to engage and inspire stakeholders, with potential benefits for education and community enrichment. Efforts to address concerns of disinterested stakeholders may enhance overall engagement and participation, contributing to the success of such initiatives.

4.6.5.8 Coding and Robotics Clubs

The data from Figure 4.61 illustrates stakeholders' interest in Coding and Robotics Clubs. A significant majority of Kyebi locals (76%) and tertiary students (70%) showed strong favorable interest, indicating a high level of enthusiasm for such clubs. However, a small percentage of locals (3%) and students (5%) expressed negative interest, suggesting potential barriers to participation that warrant further exploration. STEAM Educators and Advocates demonstrated keen interest (77%), highlighting professional endorsement and potential support for club initiatives.

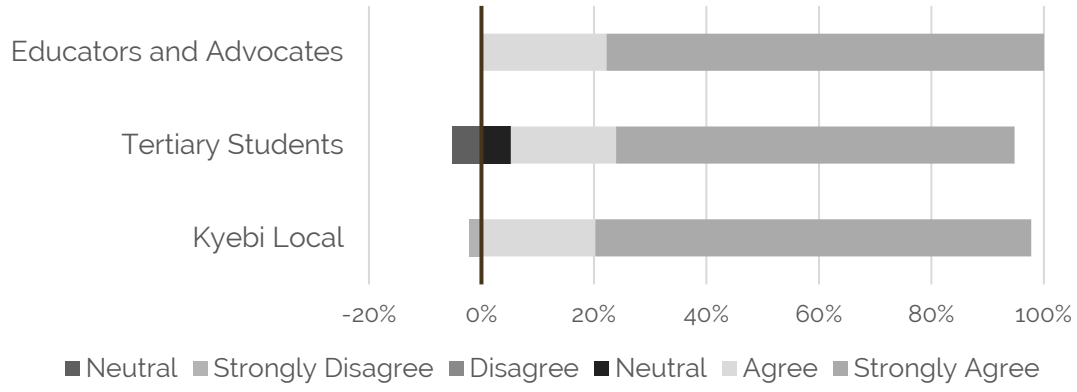


Figure 4.61 Stakeholders' Interest in Coding and Robotics Club

(Source: Author's Construct,2024)

These findings suggest a promising opportunity to establish more Coding and Robotics Clubs, with potential benefits for enhancing technological literacy and fostering innovation. Addressing the concerns of disinterested stakeholders through awareness creation may be essential for promoting broader participation and ensuring the success of these clubs and their role in promoting STEAM education in Kyebi.

4.7 STATE OF THE COMMUNITY REPORT

This section delineates information pertinent to Kyebi, encompassing its geographical location, spatial extent, demographic profile, land use, vegetative characteristics and biodiversity, transportation systems, provisioning of public utilities and amenities, and the state of education of the community since it is essential that the study's conclusions are established within the context of the research location.

Kyebi is located in the central portion of the Eastern region, Ghana (Figure 4.62). It is located 55km away from Koforidua, 105km from Accra and 179km from Kumasi. It is located in the central portion of Eastern Region situated just a brief ten-minute drive from the main Kumasi Accra Road at Bunso Junction with a total land area of approximately 725km^2.

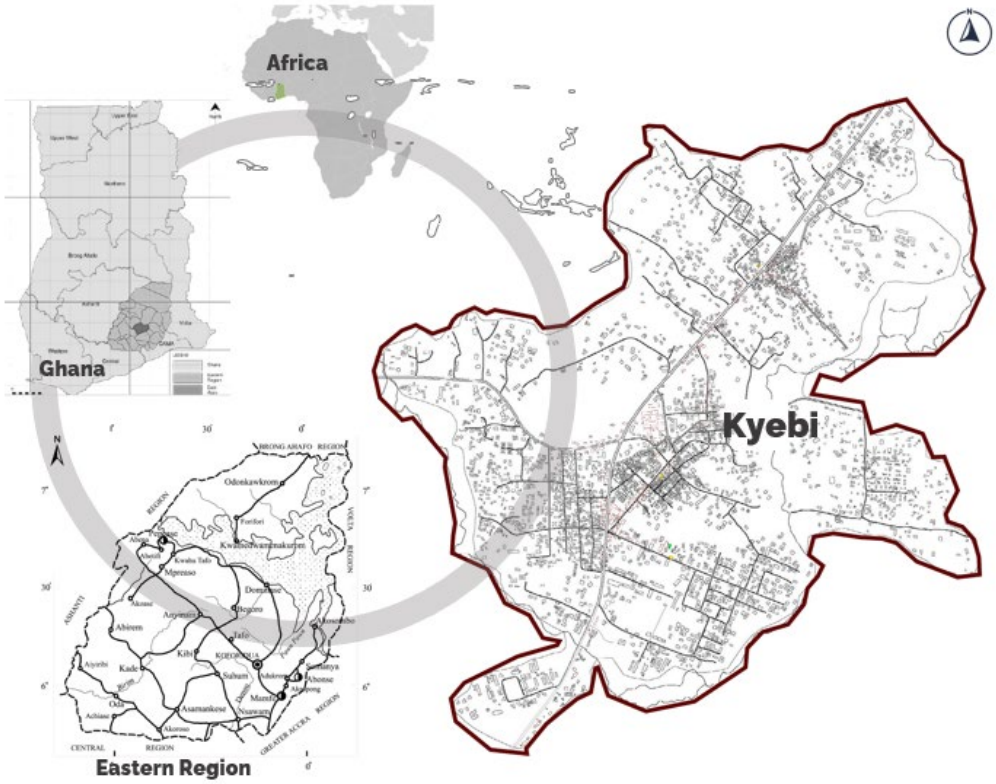


Figure 4.62 Map showing location of Kyebi, Eastern Region

(Source: Author's Construct,2024)

In 2008, Kyebi was granted municipal status through a legislative instrument. Serving as the administrative hub of the municipality, Kyebi, along with three neighboring communities, constitutes approximately 20% of the municipality's overall population of 117,000. The Abuakwa South Municipality has a population of approximately 168,000 people (Ghana Statistical Service, 2012). Kyebi was of a population of approximately 12,000 people in 2013 (Marful et al, 2019, Population and Housing Census, 2010). The projected population of Kyebi in the year 2024 is approximately 14,519 people (Author's Construct, 2024). A summary of the socio-economic statistics of Kyebi and its surrounding is presented in the Table 4.19

Table 4.19 Basic Socio-Economic Statistics of Kyebi and Surrounding Towns

Characteristic Features	Kyebi and surrounding towns	Municipal	Regional	National
Population	26,200	117,000	2,427,570	29,970,000
Pop. Growth Rate	2.1	2.1	2.1	2.2
Sex Ratio	96.0	96.0	96.1	95.2
Urban Population	52.0	59.9	43.4	50.9
Household Size	4.0	4.0	4.1	4.4
Disability ratio	3.9	3.7	3.6	3.0
Literacy Rate	76.2	75.6	56.6	71.5
Employment Rate	66.5	65.9	64.0	98
Poverty Rate	18.3	20.2	21.7	24%

Source: world population review, 2019, GSS report 2017, GSS population and housing census 2010, Marful et al. 2019

4.7.1 History of Kyebi

Kyebi serves as both the administrative capital of Akyem Abuakwa state and the headquarters of the Abuakwa South Municipal Assembly, catering to the eastern region of Ghana. Nestled within the mineral-rich expanse of the Atiwa mountain range, The origins of Kyebi's populace trace back to a migration from Adansi in the Ashanti Region, driven by the pursuit of arable land, potable water sources, and security. This migration necessitated conflicts with indigenous Kyidoms and Akwamus, with the former reputedly originating from the Birim River, their primary water source. Under the leadership of Nana Ofori Panin, Akyem Abuakwa's capital was ultimately

relocated to "Kyebirie," derived from the black hat emblematic of a hunter who frequented the area for hunting endeavors. Subsequently, the town came to be known as Kyebi, a transformation influenced by the Europeans' linguistic adaptation, eventually resulting in the current appellation of Kibi. Kyebi's early settlement, motivated by spiritual beliefs, was deliberately situated away from the revered River Birim, engendering the town's diverse array of cultural and historical landmarks that serve as enduring testaments to its captivating past. Renowned for its deep-rooted cultural and historical significance, Kyebi holds a prominent place in Ghana's historical narrative as it stands as a testament to Ghana's historical evolution (Marful et al., 2019).



Figure 4.63 Entrance to the King's Palace with the Bretuo (leopard), the Totem of Kyebi (Source: Author's Field Survey, 2024)

4.7.2 Culture of Kyebi

Kyebi's rich culture shines through its vibrant festivals like Ohum-kan, Ohum-Kyire, and Odwira, marking key agricultural and ancestral milestones. During these festivities, traditional attire proudly showcases Kyebi's heritage, with the king receiving blessings and homage. Beyond festivals, Kyebi maintains cultural traditions, including wearing specific attire for court proceedings and welcoming visitors with white garments symbolizing hospitality.

In addition to festivals, Kyebi observes traditional rites like marriage and funeral ceremonies. However, some practices like puberty rites have been discontinued, while

certain activities are prohibited, such as farming on Tuesdays or women being near the river during menstruation. Despite these restrictions, Kyebi experiences low rates of social issues like drug abuse and theft, underscoring the effectiveness of cultural preservation efforts. Authorities remain dedicated to safeguarding and promoting Kyebi's cultural identity.

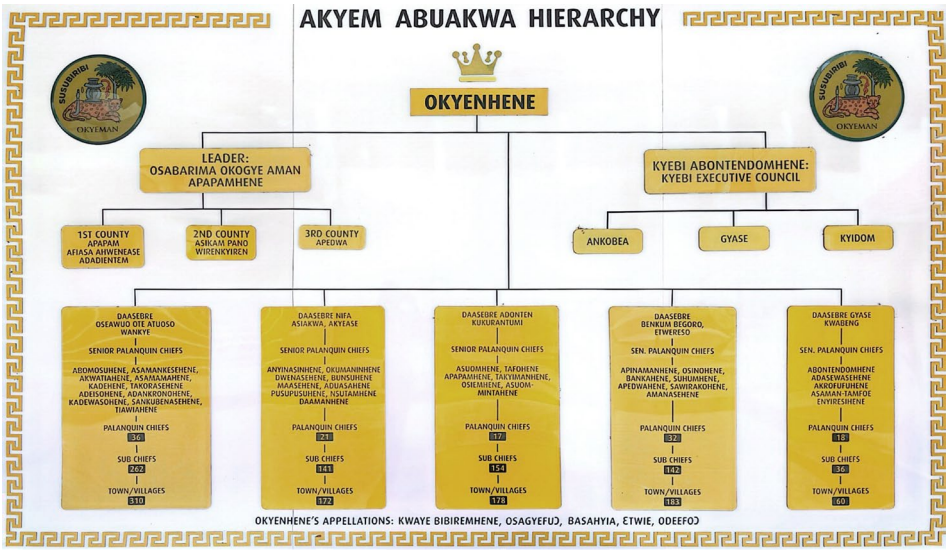


Figure 4.64 Hierarchy of the Traditional Council of Akyem Abuakwa

(Source: Author's Field Survey, 2024)

Kyebi boasts a rich cultural tapestry, comprising residents from diverse ethnic backgrounds such as Akan, Ga, Ewes, and others. Akan's represent the predominant ethnic group, comprising 71.8% of the population. Additionally, Christianity is the dominant religion, with 86.2% of residents adhering to it, while Muslims constitute 6.4% of the population. The town's cultural and religious diversity reflects its dynamic character and underscores the harmonious coexistence among people of varied backgrounds. This favorable environment fosters opportunities for investment and development.

4.7.3 The Traditional Authority and The Municipal Assembly

In recent years, the traditional leadership has forged a fruitful partnership with the municipal assembly to ensure effective governance in Kyebi. This collaboration has led to the initiation of numerous development initiatives aimed at enhancing the town's progress. These projects encompass the establishment of essential infrastructure like the J.B Danquah Library, healthcare facilities, and educational institutions, alongside

the refurbishment of the old courthouse. Furthermore, efforts have been directed towards creating an industrial site for artisans and improving transportation through the construction of feeder roads. Additionally, collaborative endeavors have included the coordination of various clean-up campaigns and awareness programs, addressing issues such as the impact of illegal mining activities and promoting effective waste management practices.



Figure 4.65 Ofori Panin Fie Akyem Abuakwa with a Statue of Nana Ofori-Atta I (Source: Author's Field Survey, 2024)

4.7.4 Education in Kyebi

The literacy rate in the municipality stands at a commendable 77.7%, indicating a predominantly skilled labor force. Although literacy is slightly more prevalent among males, with 50.4% compared to 49.6% among females, there is evidence of progress in narrowing the gender gap, as illustrated in Figure 4.66.

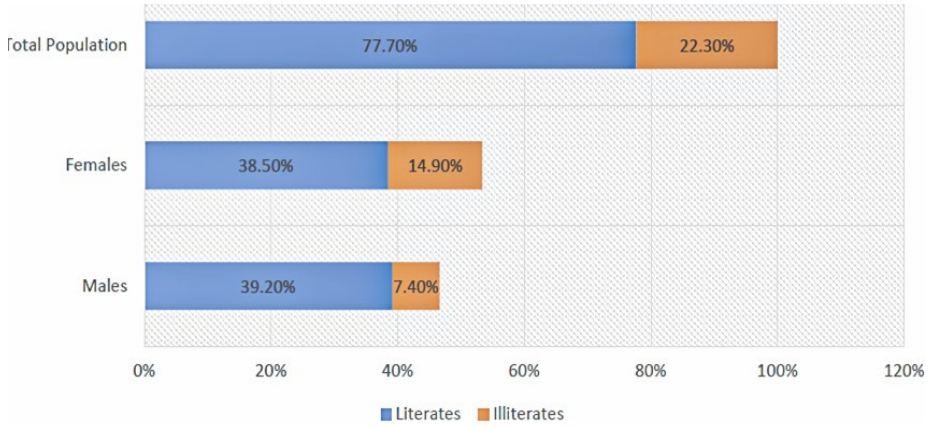


Figure 4.66 Literacy Rate in Abuakwa South Municipality

(Source: Department of Architecture KNUST, Field Survey, 2018)

To further promote gender equality in education, initiatives like Science, Technology, Mathematics, and English clinics should prioritize encouraging girls' education, thereby continuing the trend of closing the literacy disparity between males and females.

4.7.4.1 Educational Institutions in Kyebi

Educational institutions in Kyebi encompass a range of establishments catering to various levels of learning. These include primary schools, junior high schools, senior high schools, and tertiary institutions. Among the notable educational institutions in Kyebi are: Abuakwa State College, St. Dominic's R/C Junior High School, Kibi Senior High School, Kibi Anglican School, Kyebi Technical Institute, Pentecost Preparatory School, and Kibi Presbyterian College of Education as illustrated in Figure 4.67



1. **Abuakwa State College**
2. **St. Dominic's R/C Junior High School**
3. **Kibi Senior High School**
4. **Kibi Anglican School**
5. **Kyebi Technical Institute**
6. **Pentecost Preparatory School**
7. **Kibi Presbyterian College of Education**

Figure 4.67 Google Maps location of some educational Institutions in Kyebi

(Source: Author's Field Survey, 2024)

4.7.4.2 STEAM Education in Kyebi

STEAM education in Kyebi encompasses a multifaceted approach to learning that integrates science and the arts in teaching students at the basic school level by creating an educational framework that emphasizes hands-on, interdisciplinary experiences aimed at fostering creativity, critical thinking, and problem-solving skills among basic school students. In Kyebi, STEAM education initiatives are designed to introduce students to the challenges of the modern industry while also nurturing their appreciation for the arts and sciences at a very young age. Through a combination of innovative teaching methods, practical activities, and community engagement, STEAM education in Kyebi seeks to empower learners with the knowledge and skills needed to thrive in an increasingly complex and interconnected world.

In Kyebi, STEM education at the high school level is bolstered by the establishment of school clubs and initiatives, often in collaboration with the Education Directorate, traditional council, and international institutions. These partnerships aim to provide students with enhanced STEM learning opportunities beyond the regular curriculum. School clubs offer platforms for hands-on activities, competitions, and projects, while initiatives led by the Education Directorate focus on integrating STEM principles into the broader educational framework.



Figure 4.68 Abuakwa State College A. Entrance gate, B. school compound

(Source: Author’s Field Survey, 2024)

Collaboration with the traditional council underscores the community's commitment to STEM education, while partnerships with international institutions bring global perspectives and resources to enrich teaching and learning experiences. Through these collective efforts, Kyebi's high schools cultivate a culture of innovation and scientific inquiry, preparing students for future success in STEM fields.

Kibi Presbyterian College of Education is a key institution in Kyebi, providing teacher training and promoting STEM education initiatives. It prepares future teachers to effectively teach STEM subjects through active learning strategies and critical thinking skills. Collaborating with local schools and educational authorities, the college conducts workshops and seminars to enhance STEM instruction proficiency among educators. By fostering excellence in teaching and learning, the college contributes significantly to advancing STEM education in Kyebi and inspiring the next generation of innovators.



Figure 4.69 Kibi Presbyterian College of Education A. Entrance, B. Administration (Source: Author's Field Survey, 2024)

Kyebi Technical Institute plays a pivotal role in promoting STEM education by offering practical training in engineering, construction, woodwork, fashion, and other technical fields. This hands-on approach not only equips students with valuable skills but also fosters innovation and problem-solving abilities crucial in STEM disciplines.



Figure 4.70 (a) Kyebi Technical Institute Entrance (b) Vocational Training Block (Source: Author's Field Survey, 2024)

By integrating STEM principles into its curriculum, the institute prepares students for diverse career pathways while meeting the demands of modern industries. Through partnerships with local industries and educational authorities, Kyebi Technical Institute ensures that its programs align with STEM initiatives, contributing to regional development and empowering students for success in STEM-related fields.

The J.B. Danquah Library in Kyebi serves as a key educational and cultural institution, providing resources and services to support learning, research, and community engagement. Named after Joseph Boakye Danquah, it offers a diverse collection of materials, including books and digital resources, and hosts educational events and programs. The library plays a vital role in promoting literacy, lifelong learning, and intellectual discourse within the community, making it an invaluable asset for residents and students in Kyebi and neighboring areas. The library also houses the Coding and Robotics Club activities in the Abuakwa South Municipality.



Figure 4.71 The J.B. Danquah Library of the Abuakwa South Municipality.

(Source: Author's Field Survey, 2024)

These educational institutions, among others in Kyebi, contribute significantly to the intellectual growth and development of the community, empowering individuals with knowledge and skills essential for their personal and professional advancement.

4.7.5 Transportation and Traffic Considerations

In Kyebi, there exist three main categories of roads classified by their functions. These categories include arterials, collectors, and local roads (Figure 4.72). The Kyebi-Bunso road, also referred to as Oman Road, functions as an arterial road traversing the town center, where it collects and distributes traffic from lower-tier roads to other regions. Key collector roads in Kyebi include Apapam road and Nana Dokua Crescent, which gather traffic directed towards Oman road. Examples of minor collector roads are

Kuntunkunuku Street and Opayin Frimpong Avenue. Conversely, local roads are narrower in width and typically serve residential areas, accommodating minimal traffic.

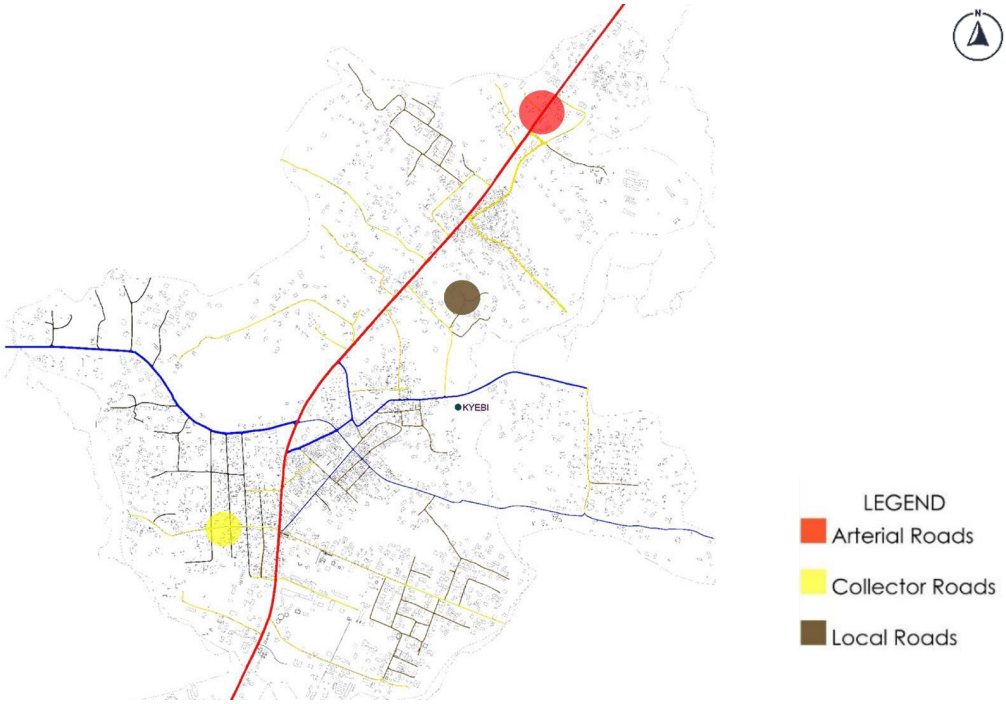


Figure 4.72 The Main Arterial and Some Collector Roads in Kyebi
(Source: Field Survey, 2018; Marful et al, 2019)

Major landmarks in Kyebi are often situated along the primary arterial and collector roads. For instance, the chiefs' palace is situated along Nana Doakua Crescent Road, a significant collector road. Furthermore, arterial and collector roads are typically paved and equipped with drainage systems, resulting in favorable surface conditions and smoother traffic flow.



Figure 4.73 An Aerial Drone Image of New Landmarks Springing Along the Main Kyebi Bunsu Road (Source: Field Survey, 2018; Marful et al, 2019)

The streets serve as the primary hub for commercial activities within the community, with more than 90 percent of businesses located along the main Kyebi-Bunsu Road (Figure 4.74). These roads are categorized as either arterial routes or collectors. However, the lack of signage, crosswalks, seating areas, pedestrian pathways, accessible routes, and proper street names contributes to the limited effectiveness of the roads.



Figure 4.74 Main Kyebi Bunsu Road showing the prevalent commercial activities along it (Source: Author's Field Survey, 2024)

While many of the roads are surfaced with pavement, the absence of clear markings poses a safety hazard for both pedestrians and vehicles sharing the roads. Additionally, the drainage channels alongside the streets are uncovered and frequently clogged with solid waste.



Figure 4.75 Some roads with clear markings for safety A. Mangoase Link B. Nana Dokua CR (Source: Author's Field Survey, 2024)

A road construction project (Figure 4.76)is currently underway in the community, connecting the old site to the new site where new residential settlements are being developed. This road development initiative aims to improve connectivity and accessibility within the community, facilitating transportation between the two areas. It signifies a proactive approach to infrastructure development, catering to the needs of the growing population and fostering urban growth in the community.



Figure 4.76 New Road Construction Underway Link the Old community to the New Site (Source: Author's Field Survey, 2024)

4.7.6 Ecology and Biodiversity of Kyebi

Kyebi and its nearby regions are endowed with a diverse natural environment. The presence of a protected forest reserve along its borders creates a peaceful microclimate amidst the rainforest and provides habitat for various species. The ecological map of Kyebi, displayed in Figure 4.77, showcases the abundant flora found within the municipality, predominantly in open spaces and newer settlements, though less so in the older areas. The landscape is characterized by rolling hills and mountain ranges, ranging from 240 to 300 meters above sea level, with soil primarily composed of silt and clay loam. Vegetation covers more than half of the land area, and rainfall, which occurs for much of the year, sustains the Birim River as the municipality's primary water source, as shown in Figure 4.84.

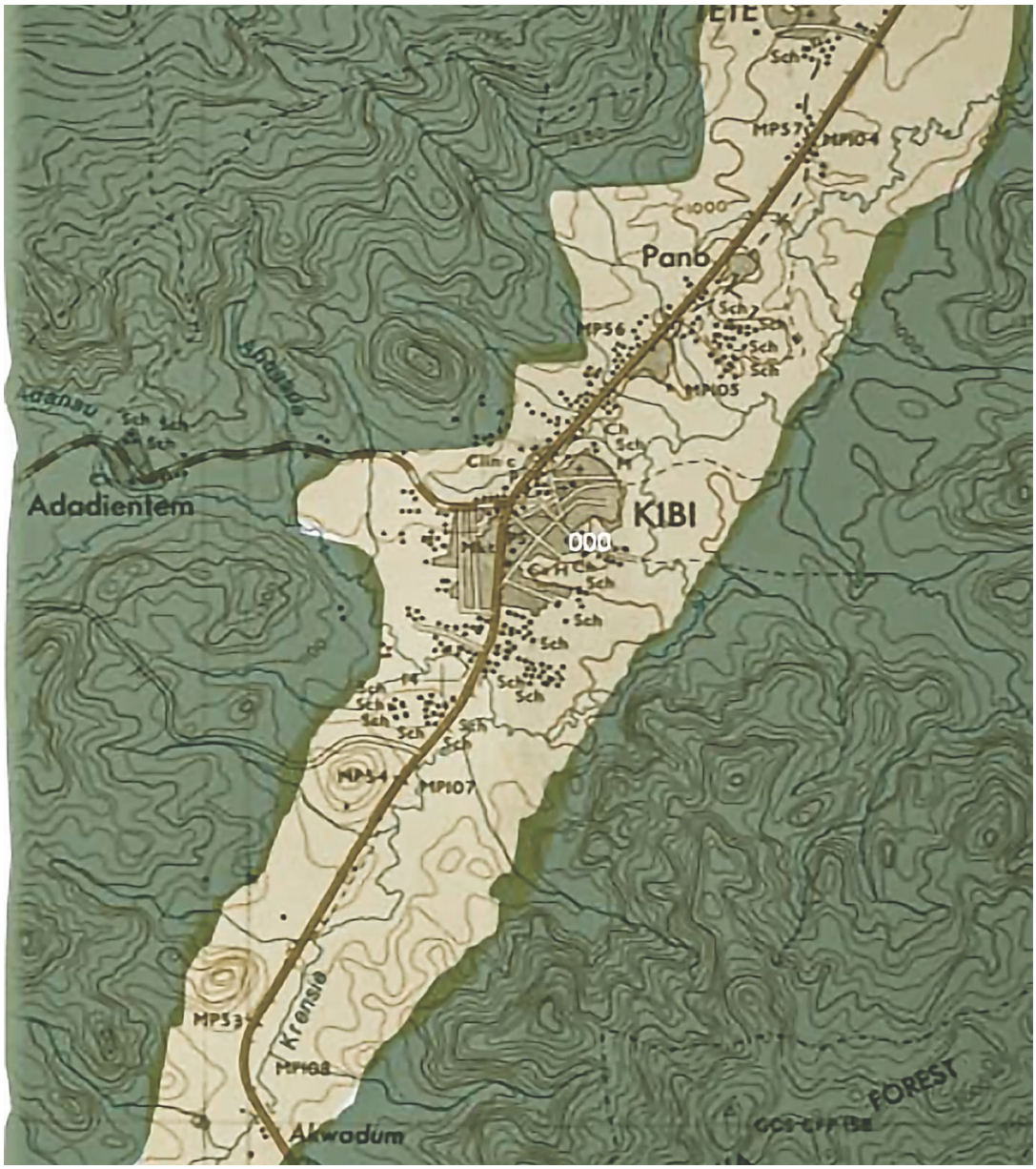


Figure 4.77 Topography Map showing the Land Form of Kyebi

(Source: Department of Architecture KNUST, Field Survey, 2018))

Within a 2-mile radius of Kibi, the landscape features considerable changes in elevation, with the highest point rising 1,135 feet above sea level, and an average elevation of 1,182 feet. Within a 10-mile radius, there are substantial variations in elevation, reaching up to 2,201 feet, and within 50 miles, elevation differences are even more pronounced, with heights changing up to 2,792 feet. The land cover within 2 miles of Kibi comprises cropland (39%), trees (32%), grassland (17%), and shrubs (11%). In the 10-mile radius, trees (39%) and cropland (38%) dominate, while within 50 miles, cropland (39%) prevails, with trees covering 23% of the area.



Figure 4.78 Typical landscape of Kyebi showing the land form and Vegetation

(Source: Author's Field Survey, 2024)

4.7.6.1 Biodiversity of Kyebi

Different areas have different types of vegetation and wildlife, known as ecological zones. These zones are defined by the plants and animals that live there. Figure 4.79 shows the ecological zones in Kyebi. Tick trees are mostly found in the western part of the town, while plantain trees dominate the northern zone. As you move away from the town, the southern section is mainly covered by cocoa trees. Several types of plants grow in the ecological zones of Kyebi, including Odum, Kyenkyen, Wawa, Coconut Palm, Maize, and Cocoa. These plants have various uses, such as construction. Trees like Wawa, Odum, and Kyenkyen are commonly used for paneling, joinery, and sometimes veneer. Coconut palms and maize are grown as sources of food, and coconut palms are also used for beautification purposes. Cocoa is primarily cultivated for exportation.

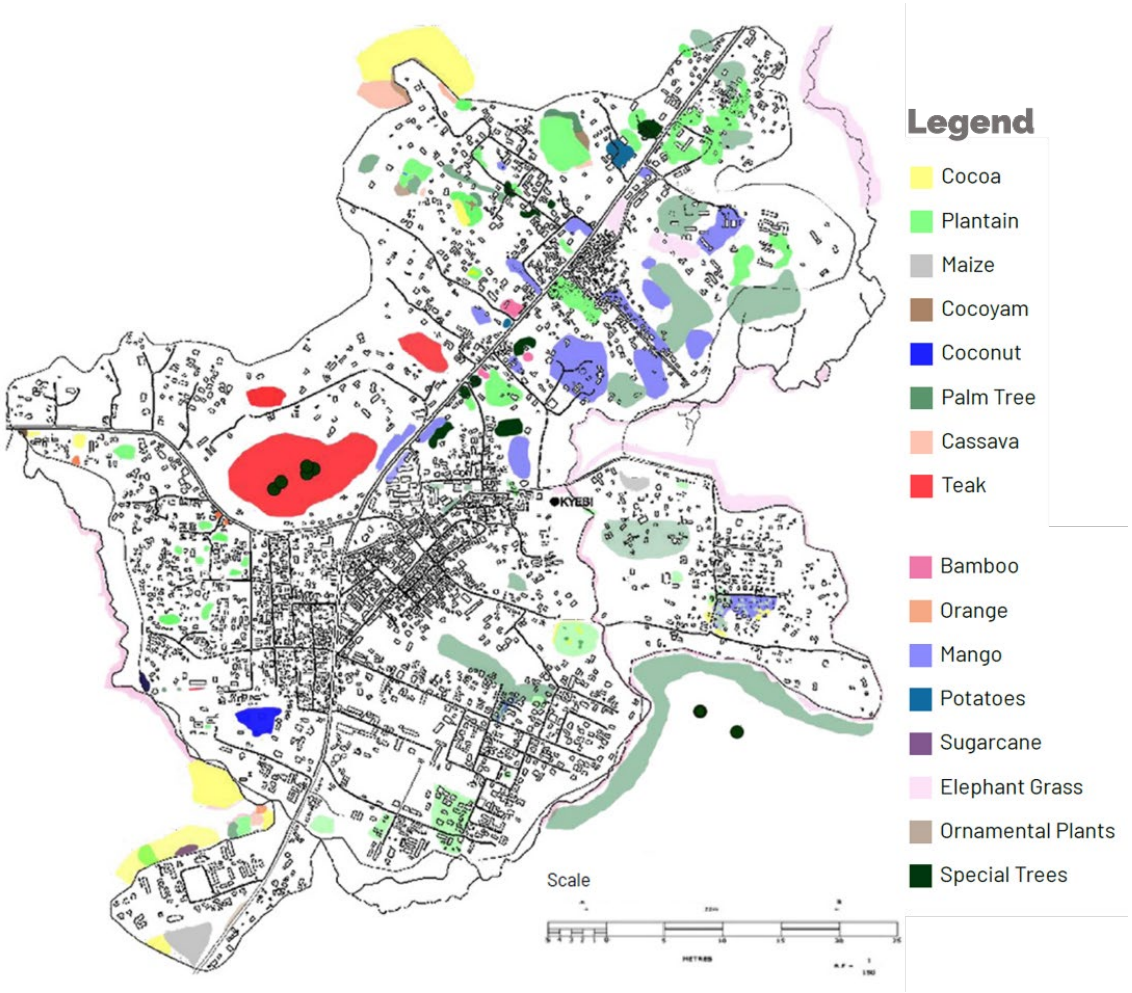


Figure 4.79 Showing Vegetation / Ecological Zones in Kyebi

(Source: Department of Architecture KNUST, Field Survey, 2018)

Plantain plantations in Kyebi as shown in Figure 4.80, are typically small in size and can often be found in the backyard of homes. These plantations serve primarily for food purposes, particularly for the production of fufu and Ampesi, traditional Ghanaian dishes.



Figure 4.80 Images of Plantain Plantations found all over Kyebi

(Source: Author's Field Survey, 2024)

The cultivation of plantains in home gardens allows residents to have easy access to this staple food item, contributing to the self-sustainability of households. Additionally, backyard plantations offer a convenient and readily available source of fresh plantains, ensuring that families have access to nutritious and locally grown produce.

In Kyebi, palm tree families are not only cultivated for their aesthetic appeal but also serve as a vital food source. These trees, including coconut palms, are valued for their nutritious fruit, which provides water and versatile meat. Additionally, palm oil extracted from the fruit is a staple in local cuisine. Overall, palm trees enhance the landscape while fulfilling important dietary needs in the community.



Figure 4.81 Images showing the biodiversity of Kyebi

(Source: Author's Field Survey, 2024)

In Kyebi, various trees and shrubs serve diverse purposes beyond their aesthetic value. Some species are specifically cultivated for shading, providing relief from the tropical sun, while others are used for ground cover to prevent soil erosion and maintain soil moisture. Additionally, certain trees and shrubs offer medicinal properties, serving as natural remedies for various ailments. Moreover, they contribute to biodiversity, supporting local ecosystems and wildlife habitats. Overall, these plants play essential roles in enhancing environmental sustainability and community well-being in Kyebi.as seen in Figure 4.88

4.7.7 Climate and Weather Patterns of Kyebi

In Kyebi, the wet season is characterized by cloudy skies, while the dry season experiences partial cloud cover, with consistently hot and humid conditions throughout the year (Figure 4.82).

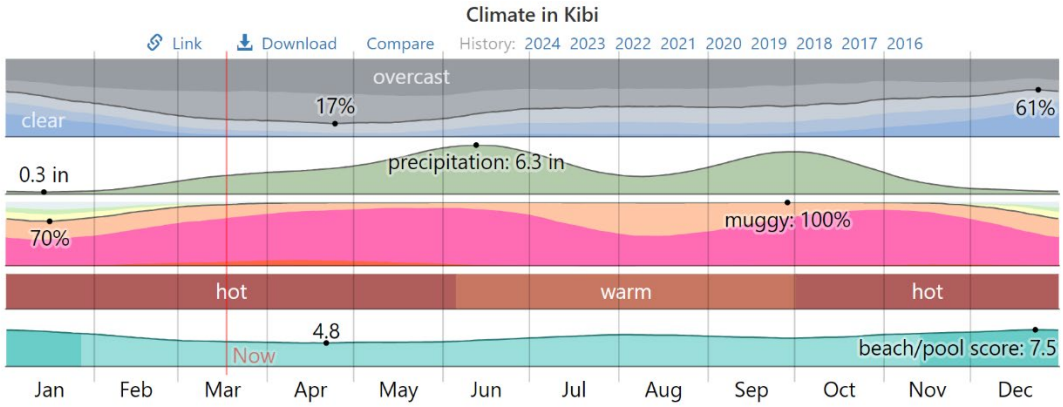


Figure 4.82 Kibi weather by month showing the various parameters that influence the weather pattern (weatherspark.com)

The temperature typically ranges from 69°F to 93°F over the course of the year, seldom dropping below 65°F or exceeding 98°F. The prevailing weather conditions in Kibi suggest a consistently warm and humid climate, with temperature variations throughout the year.

4.7.7.1 Average Temperature in Kyebi

The period of high temperatures spans approximately 3.0 months, starting from January 12 to April 11, with daily temperatures typically exceeding 91°F. February stands out as the hottest month, featuring an average high of 93°F and a low of 72°F, as depicted in Figure 4.83.

Conversely, the cooler season persists for about 3.2 months, running from June 10 to September 18, during which the average daily high temperature falls below 84°F. August emerges as the coldest month, with an average low of 69°F and a high of 83°F.

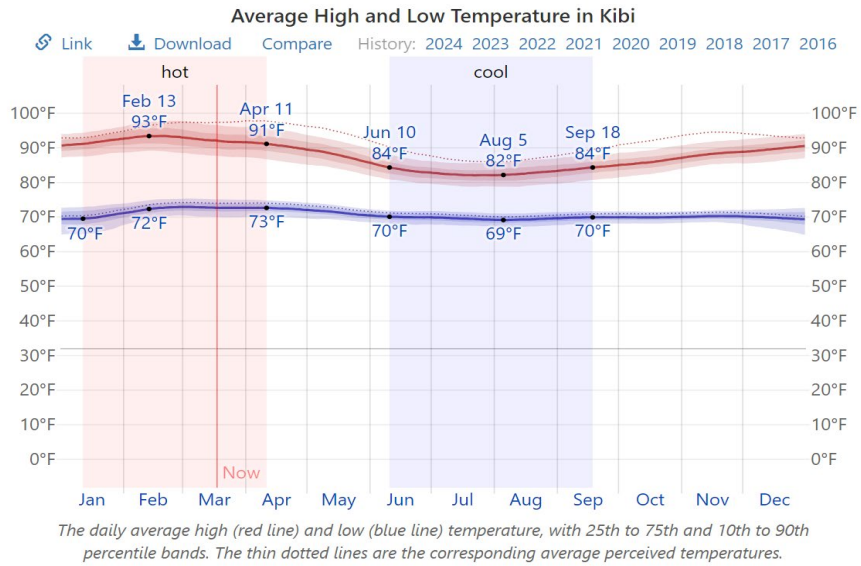


Figure 4.83 The daily average high (red line) and low (blue line) temperature in Kyebi (weatherspark.com)

4.7.7.2 Precipitation in Kyebi

In Kyebi, a wet day refers to one with at least 0.04 inches of liquid or liquid-equivalent precipitation. Throughout the year, the likelihood of encountering wet days varies considerably. The wetter season spans 7.5 months, from March 22 to November 7, with a greater than 38% chance of any given day being wet. June emerges as the month with the highest number of wet days, averaging 21.0 days with precipitation as seen in Figure 4.84.

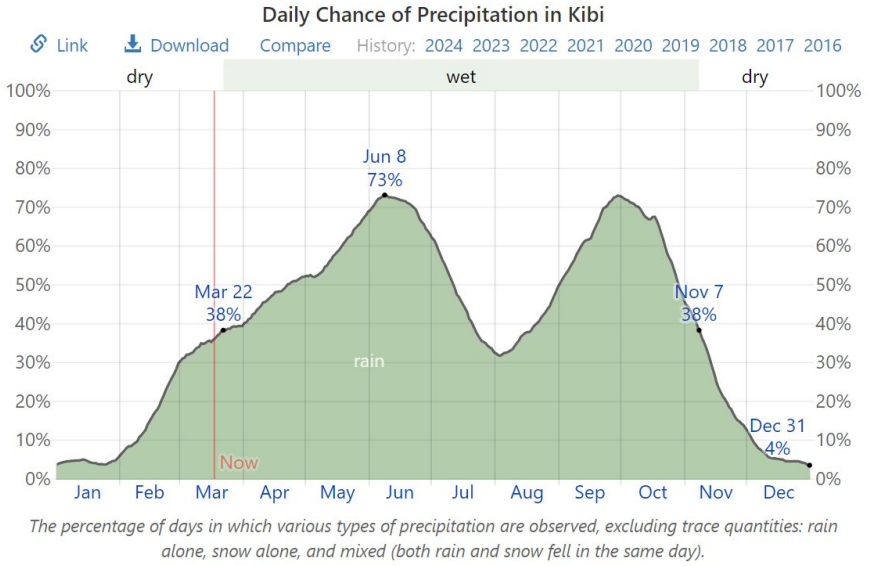


Figure 4.84 The Percentage of Days in Which Various Types of Precipitation Are Observed (weatherspark.com)

Conversely, the drier season extends over 4.5 months, from November 7 to March 22. January stands out as the month with the fewest wet days, averaging only 1.4 days with precipitation (Figure 4.84). Rain alone is the most common form of precipitation, particularly evident in June, with an average of 21.0 days. This categorization reveals that rain alone constitutes the predominant form of precipitation, reaching a peak probability of 73% on June 8.

4.7.7.3 Rainfall Pattern in Kyebi

In Kyebi, there are significant fluctuations in monthly rainfall throughout the year (Figure 4.85). The rainy season extends for 10 months, from February 4 to December 17, characterized by continuous rainfall of at least 0.5 inches over a 31-day period.

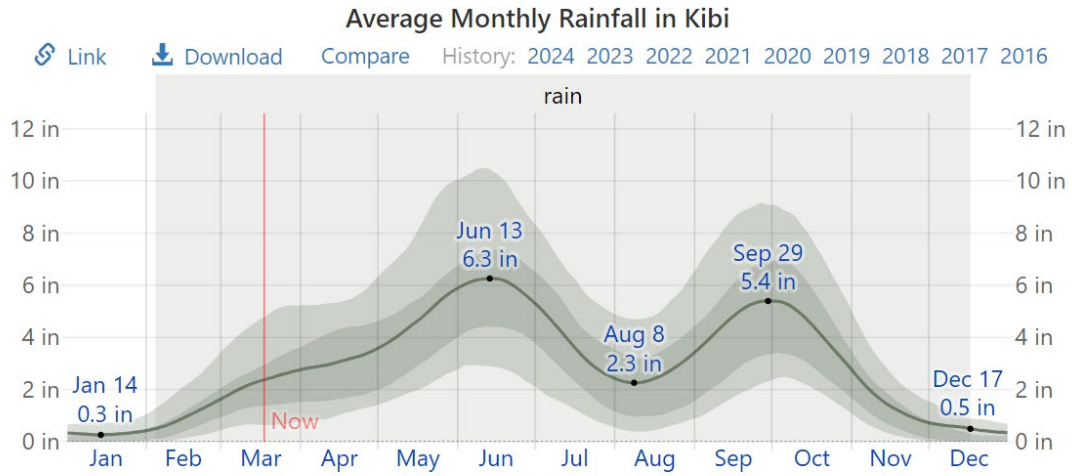
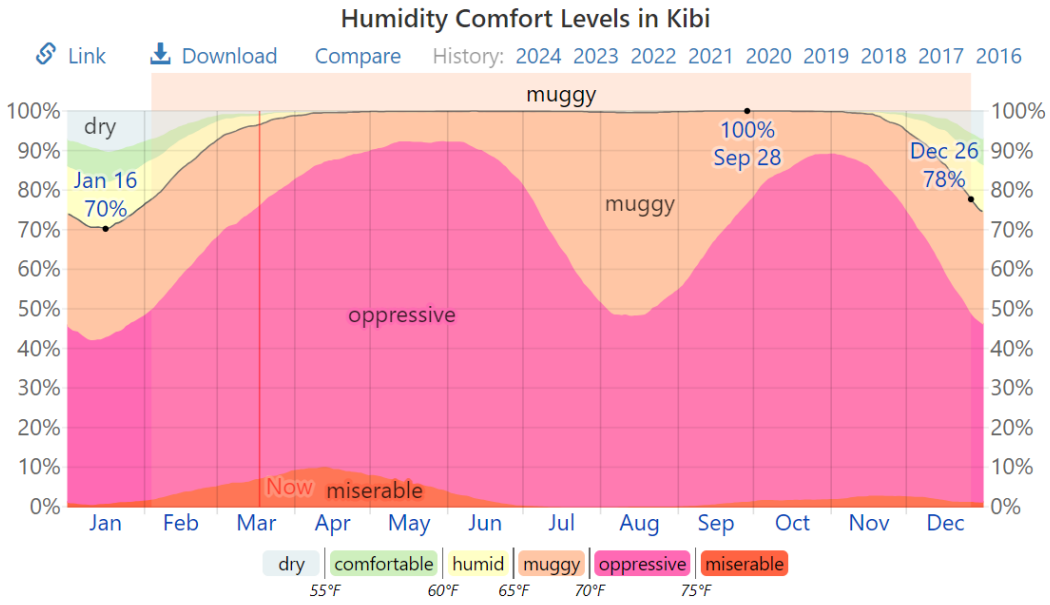


Figure 4.85 The average rainfall (solid line) accumulated over the course of a sliding 31-day period (weatherspark.com)

June receives the highest amount of rainfall in Kibi, averaging 6.3 inches. Conversely, the dry season spans 1.6 months, from December 17 to February 4, marked by minimal precipitation. January records the lowest rainfall in Kibi, with an average of 0.3 inches.

4.7.7.4 Humidity in Kyebi

Dew points, indicating humidity levels, influence how dry or humid the air feels. Unlike temperature, which fluctuates notably between night and day, dew points change more gradually (Figure 4.86). Therefore, after a humid day, nights tend to remain muggy. In Kyebi, humidity shows seasonal variation.



The percentage of time spent at various humidity comfort levels, categorized by dew point.

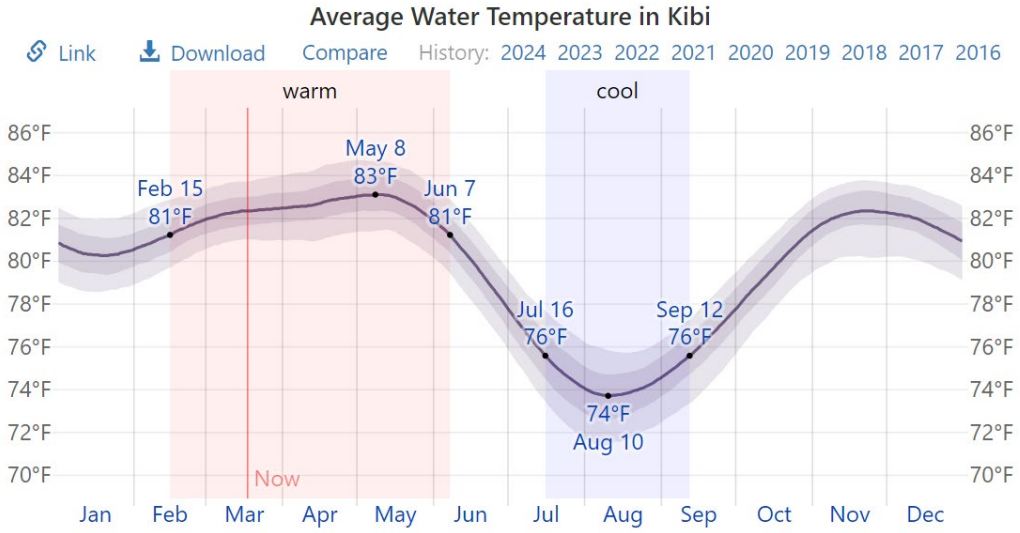
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Muggy days	22.4d	24.6d	29.9d	29.8d	31.0d	30.0d	31.0d	30.9d	30.0d	31.0d	29.6d	26.5d

Figure 4.86 The percentage of time spent at various humidity comfort levels, categorized by dew point (weatherspark.com)

From Figure 4.93, the muggiest period spans 11 months, from February 3 to December 26, characterized by muggy, oppressive, or uncomfortable conditions about 78% of the time. October stands out as the month with the highest frequency of muggy days, totaling 31.0 days. Conversely, January experiences the fewest muggy days, with 22.4 days.

4.7.7.5 Temperature of Water Bodies in Kyebi

Kibi is situated in proximity to a substantial water body, comprising the Birim River, small streams, and tributaries. The Figure 4.87 presents data on the overall surface temperature of this water body. The average water temperature undergoes seasonal fluctuations throughout the year. Warmer water conditions prevail for approximately 3.8 months, spanning from February 15 to June 7, with an average temperature exceeding 81°F.



The daily average water temperature (purple line), with 25th to 75th and 10th to 90th percentile bands.

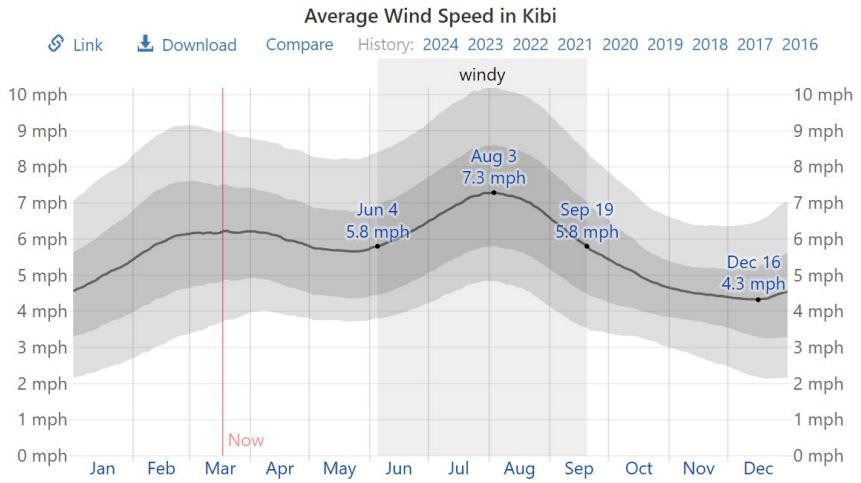
Water	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature	80°F	81°F	82°F	83°F	83°F	80°F	76°F	74°F	76°F	80°F	82°F	82°F

Figure 4.87 The daily average water temperature (purple line), with 25th to 75th and 10th to 90th percentile bands (weatherspark.com)

From the Figure 4.87, May emerges as the month with the highest water temperature in Kibi, averaging 83°F. Conversely, cooler water temperatures persist for about 1.9 months, occurring from July 16 to September 12, with an average temperature dipping below 76°F. August records the lowest water temperature, averaging 74°F.

4.7.7.6 Wind Patterns in Kyebi

The wind patterns experienced in a specific area are greatly influenced by local terrain and various factors, resulting in considerable fluctuations in instantaneous wind speed and direction compared to hourly averages. In Kyebi, the average hourly wind speed demonstrates mild seasonal changes throughout the year as illustrated in Figure 4.95. From the Figure 4.88, the windier period spans approximately 3.5 months, occurring from June 4 to September 19, characterized by average wind speeds exceeding 5.8 miles per hour. August emerges as the windiest month in Kibi, with an average hourly wind speed of 7.1 miles per hour. Conversely, a calmer period prevails for around 8.5 months, lasting from September 19 to June 4. December marks the calmest month of the year in Kibi, with an average hourly wind speed of 4.4 miles per hour.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind Speed (mph)	5.0	5.9	6.2	6.0	5.7	6.1	7.0	7.1	6.0	5.0	4.5	4.4

Figure 4.88 The average of mean hourly wind speeds (dark gray line), with 25th to 75th and 10th to 90th percentile bands (weatherspark.com)

August emerges as the windiest month in Kyebi, with an average hourly wind speed of 7.1 miles per hour (Figure 4.88). Conversely, a calmer period prevails for around 8.5 months, lasting from September 19 to June 4. December marks the calmest month of the year in Kibi, with an average hourly wind speed of 4.4 miles per hour.

Throughout the year, the prevailing average hourly wind direction in Kibi originates from the south as illustrated in the Figure 4.89. This suggests a consistent pattern of airflow that can have implications for various aspects of life in the region. For example, it may influence the dispersion of pollutants or the distribution of airborne allergens.

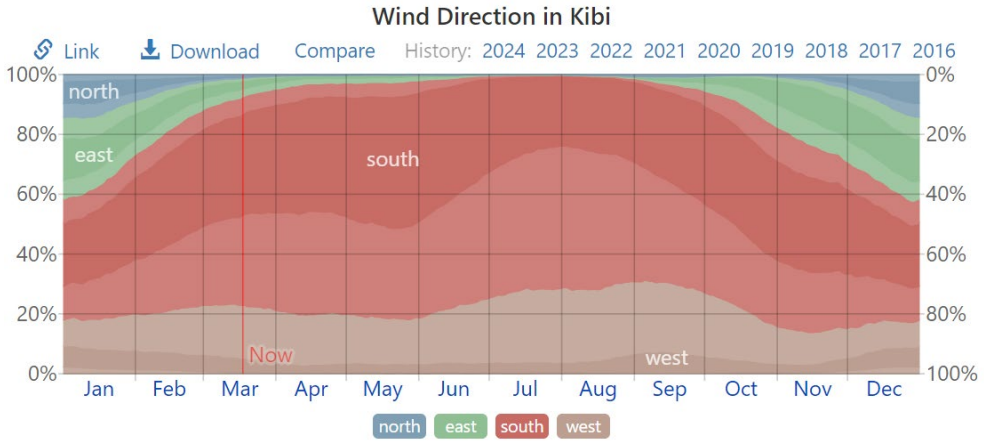


Figure 4.89 The percentage of hours in which the mean wind direction is from each of the four cardinal wind directions (weatherspark.com)

Additionally, it could impact outdoor activities and construction projects, as well as agricultural practices such as crop planting and harvesting. Understanding this prevailing wind direction is essential for urban planning, infrastructure development, and environmental management initiatives.

4.8 CHAPTER SUMMERY

This chapter presented and analyzed the research findings derived from collected data. It employed descriptive analysis and frequency techniques, utilizing the SPSS software for statistical analysis. Descriptive Statistics was the chosen method, examining central tendencies and variabilities through indices like mean, standard deviation and RII. Qualitative analyses from interviews with stakeholders supplement the quantitative data. The chapter contextualized findings with existing literature and research, identifying similarities and differences. From the analysis, it can be concluded that majority of the respondents are found to be interested in a Living-Learning Community STEAM Hub in Kyebi and would appreciate the exploration of the potential of biomimicry architecture for the design.

CHAPTER FIVE
5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CHAPTER OVERVIEW

In this concluding chapter, the findings and insights garnered from the comprehensive exploration of biomimicry for STEAM Living-Learning Communities in Ghana and the potential implications for education and community development was synthesized. The chapter begins by revisiting the research objectives and summarizing how each was addressed through the investigation and the implications of the findings, considering their relevance to the broader landscape of STEAM education, biomimicry architecture, and community engagement initiatives. By reflecting on the intersectionality of these themes, the potential for innovative approaches to education and sustainable community development was elucidated. Moreover, this chapter offers actionable recommendations informed by the research outcomes, providing guidance for policymakers, educators, community leaders, and other stakeholders interested in leveraging the insights gained from this study.

5.2 ACHIEVING RESEARCH OBJECTIVES

The study's findings are outlined in the subsequent paragraphs in the order in which the researchers set out to achieve the research objectives.

5.2.1 S.T.E.A.M. And Its Cultural Significance in Ghana

This section aimed to assess the current progress of S.T.E.A.M. education in Ghana by conducting a literature review, interviews with experts and surveying participants who were students and educators mainly from Kyebi where the study was conducted. This was to understand their perspectives on its benefits and challenges within the Ghanaian education system.

The literature review revealed that S.T.E.A.M. education in Ghana is still in its early stages, with limited integration into mainstream education. Survey respondents expressed varying levels of awareness and perception regarding S.T.E.A.M. education, highlighting its potential benefits for holistic learning and skill development, including fostering creativity, critical thinking, and problem-solving skills. However, despite these benefits, S.T.E.A.M. education faces neglect within the Ghanaian education system, attributed to factors such as curriculum constraints, inadequate teacher

training, and a preference for traditional academic subjects. These findings emphasized the need to address barriers to S.T.E.A.M. education implementation in Ghana and advocate for its integration into the education system to unlock its full potential in fostering innovation and socio-economic development.

5.2.2 Living-Learning Communities for S.T.E.A.M.

In pursuit of the second objective, this section delved into examining the potential of Living-Learning Communities (LLCs) for S.T.E.A.M. education in Ghana. Through a comprehensive literature review, the focus was on understanding the concept of LLCs, their benefits, and the challenges encountered during implementation. Interviews and surveys were subsequently conducted with participants to gather their perspectives on the topic.

The literature review revealed that LLCs offer a promising approach to S.T.E.A.M. education by creating immersive learning environments that foster collaboration, creativity, and interdisciplinary thinking among students. However, challenges such as resource constraints, organizational barriers, and the need for robust community engagement were identified as barriers to effective LLC implementation. Interviews and surveys provided insights into stakeholders' views on the potential of LLCs for S.T.E.A.M. education in Ghana, highlighting both optimism about their benefits and concerns regarding practical challenges. These findings accentuate the importance of addressing implementation barriers and leveraging LLCs' potential to enhance S.T.E.A.M. education outcomes in Ghana.

5.2.3 Biomimicry's Potential and Challenges for S.T.E.A.M.

This section examines the potential benefits and challenges of implementing biomimicry in the design of S.T.E.A.M. Living-Learning Communities in Ghana. Through extensive literature review and surveys of experts and stakeholders, it explores various biomimicry approaches, principles, and biological models relevant to educational infrastructure.

The findings highlight the potential of biomimicry to enhance sustainability, foster cultural inclusivity, promote interdisciplinary collaboration, and engage students in S.T.E.A.M. education. However, challenges such as stakeholders' lack of awareness, financial constraints, expertise shortages, cultural considerations, and maintenance

complexities pose significant obstacles to successful implementation. Community engagement emerges as a crucial aspect for ensuring the relevance, sustainability, and success of biomimicry-inspired designs. Overall, this section contributes to a nuanced understanding of the opportunities and obstacles in integrating biomimicry into educational environments in Ghana.

5.2.4 Applying Biomimicry to Design a S.T.E.A.M. Hub in Kyebi

The study focuses on developing a sustainable Living-Learning Community S.T.E.A.M. Hub in Kyebi, leveraging biomimicry principles. Stakeholder feedback reveals high interest in participating in STEAM programs, willingness to recommend them, and support for incorporating LLCs and Biomimicry Architecture.

Programs like STEAM Summer Camps and Teacher Development are particularly favored. Stakeholders also endorse Cultural Training and STEM Inspired Art Exhibitions. Coding and Robotics Clubs receive strong support, indicating a desire for hands-on learning. Overall, stakeholders perceive the Hub as an opportunity for interdisciplinary education, innovation, and sustainability, suggesting a promising environment for STEAM initiatives in Kyebi.

5.3 RESEARCH CONCLUSIONS

Based on the comprehensive analysis of stakeholder feedback and survey data on STEAM in Kyebi, the research draws the following key conclusions:

1. Stakeholders, including locals, students, educators, and advocates, exhibit high interest in participating in STEAM programs, with a majority expressing willingness to recommend them to others
2. There is widespread endorsement for incorporating LLCs into STEAM education.
3. Stakeholders demonstrate a strong appreciation for integrating Biomimicry Architecture into the design of the S.T.E.A.M. Hub.
4. Activities, such as STEAM Summer Camps, Teacher Development Programs, Art and Science Workshops, and Coding and Robotics Clubs, receive particularly high levels of support and enthusiasm.

5. While there is overall support for Cultural Training Programs and Community Art Projects, there is also a need for tailored initiatives to address varying levels of interest and concerns within the community.
6. Collaboration among stakeholders, including community members, educators, and advocates, is essential for designing and implementing effective programs and initiatives that will cater to diverse interests and needs within the community.
7. The findings collectively suggest a favorable environment in Kyebi for the promotion and advancement of STEAM education.

5.4 RECOMMENDATIONS

The following recommendations are proposed based on the findings from the opinions of students and influenced by the objectives the research aimed to achieve.

1. Conduct targeted outreach programs to address uncertainties and encourage broader participation, especially among those expressing hesitancy.
2. Foster collaboration between community members, educators, and advocates to ensure inclusive program design and implementation.
3. Develop advocacy campaigns to highlight the value and importance of STEAM education, aiming to increase awareness and support within the community.
4. Incorporate LLCs into STEAM education initiatives, leveraging their potential to enhance interdisciplinary learning, foster innovation, and create collaborative environments.
5. Design LLCs to accommodate diverse learning styles and preferences, ensuring inclusivity and engagement among participants.
6. Prioritize the integration of Biomimicry principles into the design of the STEAM Hub, emphasizing sustainability and innovation.
7. Collaborate with experts in Biomimicry to ensure effective implementation and maximize the benefits of nature-inspired design solutions
8. Allocate resources and effort towards the most favored programs, such as STEAM Summer Camps, Teacher Development Programs, and Art and Science Workshops.
9. Tailor program offerings to align with stakeholders' interests and needs, ensuring relevance and effectiveness in achieving educational goals.

10. Develop Technical and Vocational Training programs tailored to address skill gaps and support local economic development initiatives.
11. Offer diverse Cultural Training Programs to promote cross-cultural understanding and appreciation within the community.
12. Forge partnerships with educational institutions, industry stakeholders, and community organizations to leverage resources and expertise in program development and delivery.
13. Implement monitoring and evaluation mechanisms to assess the impact and effectiveness of STEAM programs over time.

5.5 CONTRIBUTION TO DESIGN

The research contributes to design by providing insights into stakeholder interest and willingness regarding STEAM programs and biomimicry architecture integration which fosters a deeper connection with nature and promotes creativity and innovation among students and community members. Overall, research on biomimicry architecture for the design contributes to a holistic and environmentally conscious design for the STEAM Hub, aligning with goals of sustainability and innovation. The research also offers valuable data on preferred programs and activities for the proposed Living-Learning Community STEAM Hub in Kyebi, helping inform the design process to align with community needs and aspirations. An illustration of the design philosophical framework informed by the research is presented in Figure 5.1

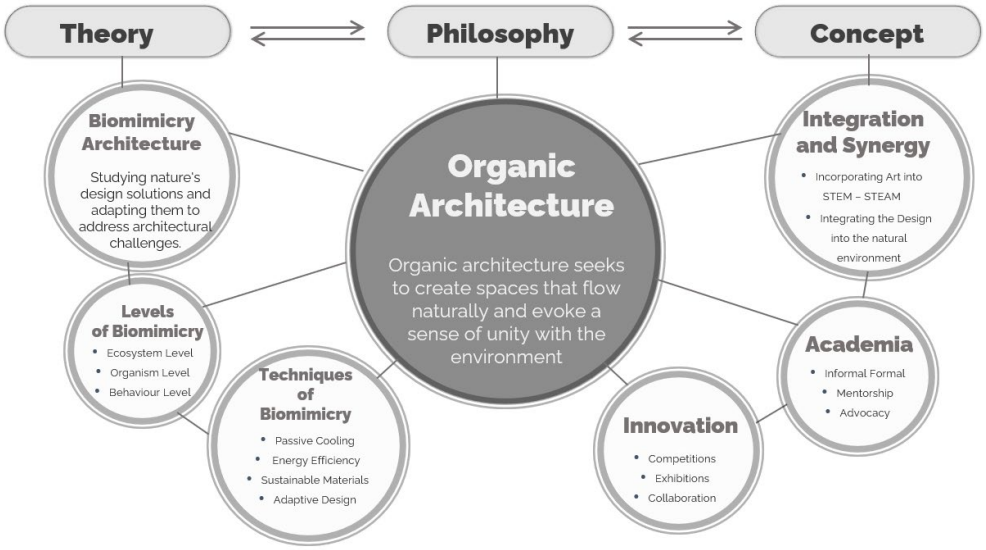


Figure 5.1 The Design Philosophical Framework for the Living-Learning Community STEAM Hub in Kyebi (Source: Author's Construct,2024)

Considering organic architecture as a design philosophy for incorporating biomimicry into the design of the Hub aligns well with the principles of both approaches. Organic architecture emphasizes synergy with the natural environment and the use of natural forms and materials, while biomimicry draws inspiration from nature's designs and strategies to create innovative and sustainable solutions. By integrating organic architectural principles with biomimetic design, the Hub can achieve a holistic approach that not only blends seamlessly with its surroundings.

5.6 RECOMMENDATIONS FOR FUTURE RESEARCH

Further research could be conducted to exploring the potential barriers or challenges faced by certain demographic groups, such as marginalized communities or individuals with disabilities, in accessing and participating in STEAM initiatives. Addressing these barriers could promote greater inclusivity and equity within STEAM education.

5.7 RESEARCH LIMITATIONS

The research faced limitations including the risk of response bias, a narrow geographic focus on Kyebi, time constraints impacting data depth, external factors influencing stakeholder perspectives, the generalizability of findings beyond the specific context of Kyebi and the subjective nature of qualitative data. These limitations were considered in the interpretation of results from the findings.

5.8 CHAPTER SUMMARY

The study’s findings and discussion were summarized in this chapter. Some recommendations aimed at improving STEAM education in Ghana were also included in the chapter with recommendations for future research. Finally, the limitations encountered during the research were also included.

CHAPTER SIX
6.0 DESIGN PROPOSAL AND APPRAISAL

6.1 CHAPTER OVERVIEW

This chapter outlines the design considerations for the Kyebi Living-Learning Community STEAM Hub, known as the Kyebi STEAM Nest, based on research insights. The primary goal of the Kyebi STEAM Nest in Asikam is to enhance existing STEAM (Science, Technology, Engineering, Arts, and Mathematics) initiatives in Kyebi. The facility aims to address the current lack of infrastructure needed for events, programs, educator training, and fostering interest and awareness in STEAM within the community and region. The design strategy focuses on establishing state-of-the-art facilities to support STEAM activities, ensuring necessary resources for effective learning, creating spaces for community involvement, and developing areas for educator training. By addressing these needs, the Kyebi STEAM Nest aims to create a sustainable environment supporting STEAM education growth in the region.

6.2 MAJOR FINDINGS FROM THE STUDY

From the research conducted, several key findings emerged that significantly influenced the design of the Kyebi STEAM Nest highlighting the need for sustainable practices like natural lighting, ventilation, use of local materials, ecosystem preservation, and efficient energy inspired by biomimicry. This led to eco-friendly features like passive cooling and green materials. The need for multifunctional spaces became evident, highlighting the importance of versatile areas that can host various events, activities, and training programs. Considerations were made for the incorporation of flexible spaces that can be easily adapted for different uses. Additionally,

The findings also emphasized the necessity for collaboration with local schools to promote STEAM education effectively. This necessitated designing spaces conducive to collaborative activities, such as shared labs, classrooms, common lounges and outdoor sitting areas. Additionally, the research highlighted the importance of creating awareness within the community and the broader region. This influenced the inclusion of public engagement areas and outreach programs within the facility to foster interest and awareness in STEAM fields.

Comprehensive library facilities were designed to support local schools, ensuring ample reading, studying, and resource access. Adequate parking for school buses, cars, and bicycles was addressed, as well as dedicated indoor and outdoor sports areas to provide a holistic learning environment. These findings collectively shaped a design that is functional, sustainable, and supportive of the STEAM educational framework while promoting community collaboration and awareness.

6.3 DESIGN PHILOSOPHY AND CONCEPT

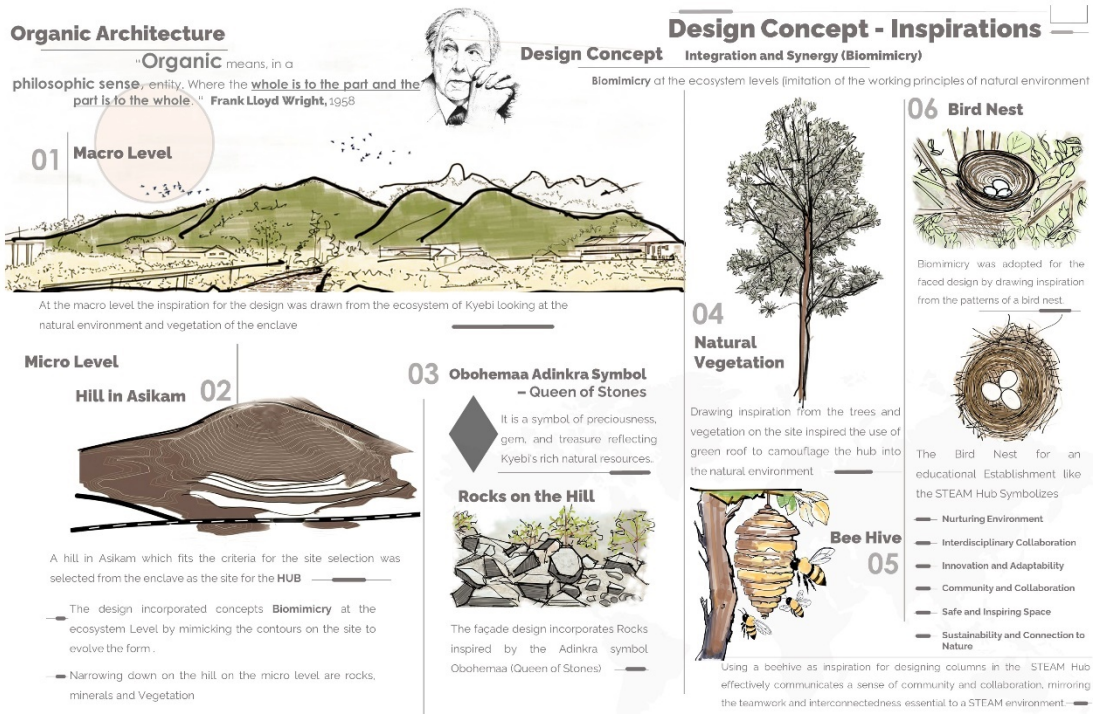
This section outlines the philosophy, design inspiration, and concept driving the proposed design. The selected philosophy and concept were inspired by nature and the context of the research emphasizing biomimicry and sustainability

6.3.1 Philosophy of the Design

The design of the Kyebi STEAM Nest is deeply rooted in the philosophy of organic architecture, as articulated by Frank Lloyd Wright (1958) where Wright famously described organic architecture as an entity where "the whole is to the part and the part is to the whole." This profound statement underscores his belief in the seamless integration of all elements within a built environment, where every detail, from materials to purpose, contributes harmoniously to the overall unity of the structure.

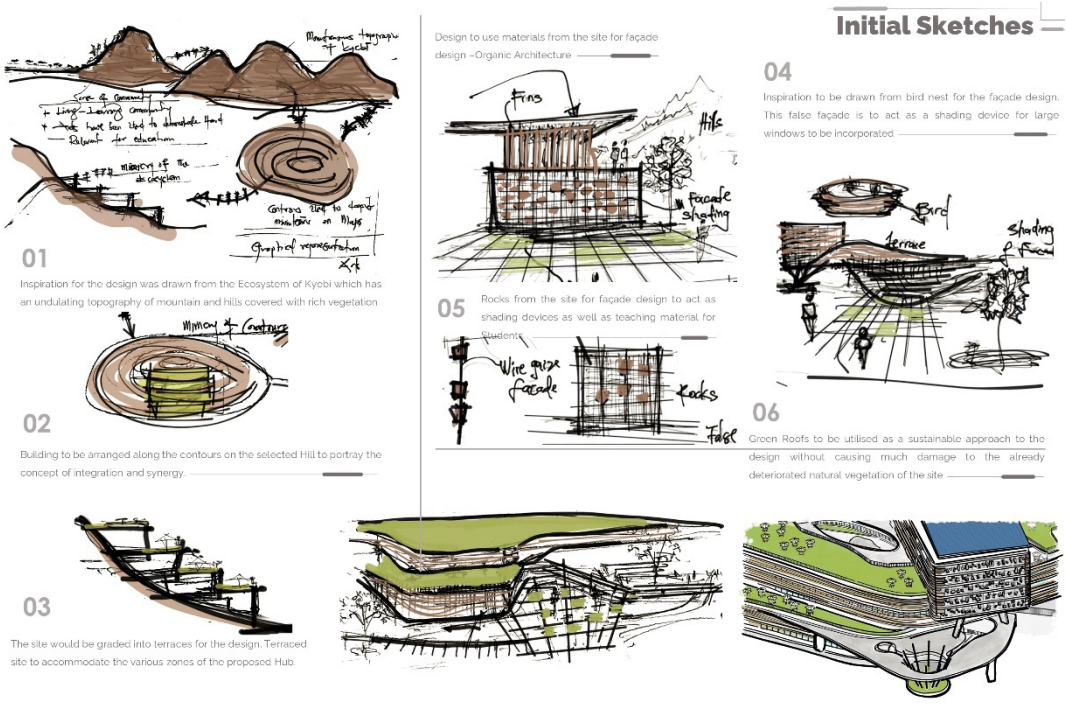
Wright emphasized that organic architecture is not just about aesthetics, but about understanding the nature of materials and the purpose they serve. He believed that the performance of a building should stem naturally from these considerations, creating a necessity that shapes its form and function.

For the Kyebi STEAM Hub, this philosophy translates into a design that not only harmonizes with the natural landscape but also embodies sustainable principles. In practical terms, this approach manifests through the use of local materials that blend with the surroundings, promoting a sense of belonging and minimizing environmental impact.



6.1 The Design Philosophy and Inspirations (Source: Author's Construct,2024)

Natural lighting and ventilation are incorporated to reduce energy consumption while enhancing the indoor experience for users. Passive cooling systems further underscore the building's commitment to eco-friendly practices, ensuring that its environmental footprint remains minimal.

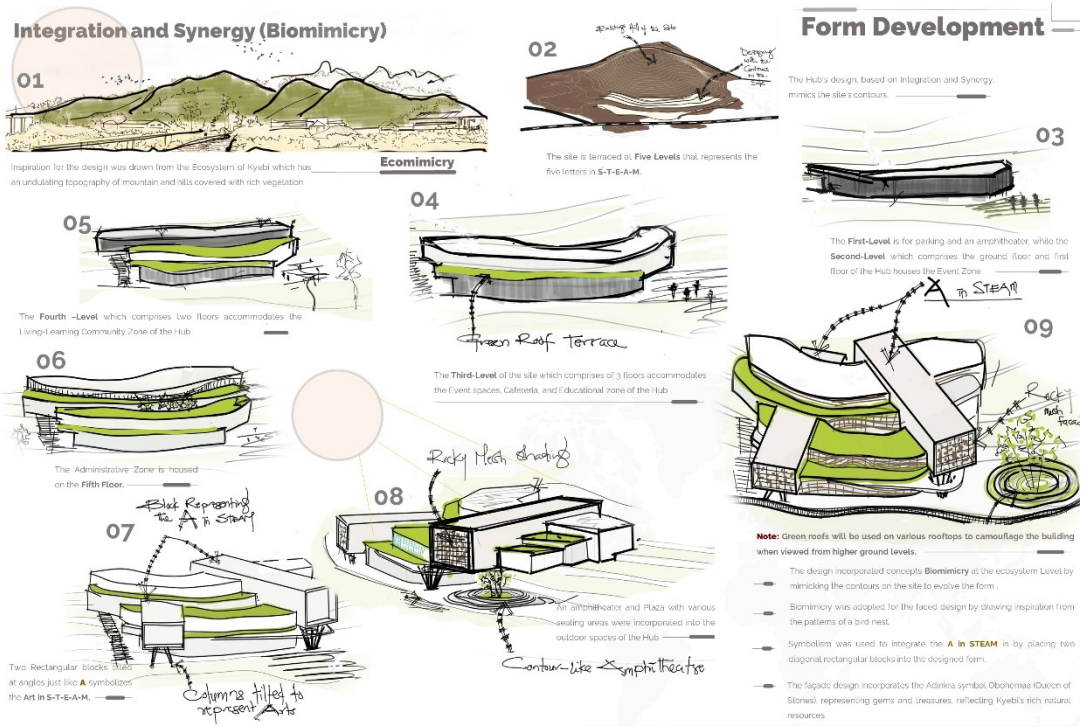


6.2 Initial Sketches with Design Philosophy (Source: Author's Construct,2024)

By adhering to the principles of organic architecture, the Kyebi STEAM Nest not only serves as a functional educational space but also as a testament to sustainability and holistic design. It fosters a deep connection between its users and the environment, promoting well-being through thoughtful integration with nature. In essence, the STEAM Nest embodies Wright's vision of architecture that is not merely constructed, but creatively crafted to resonate harmoniously with its surroundings and purpose.

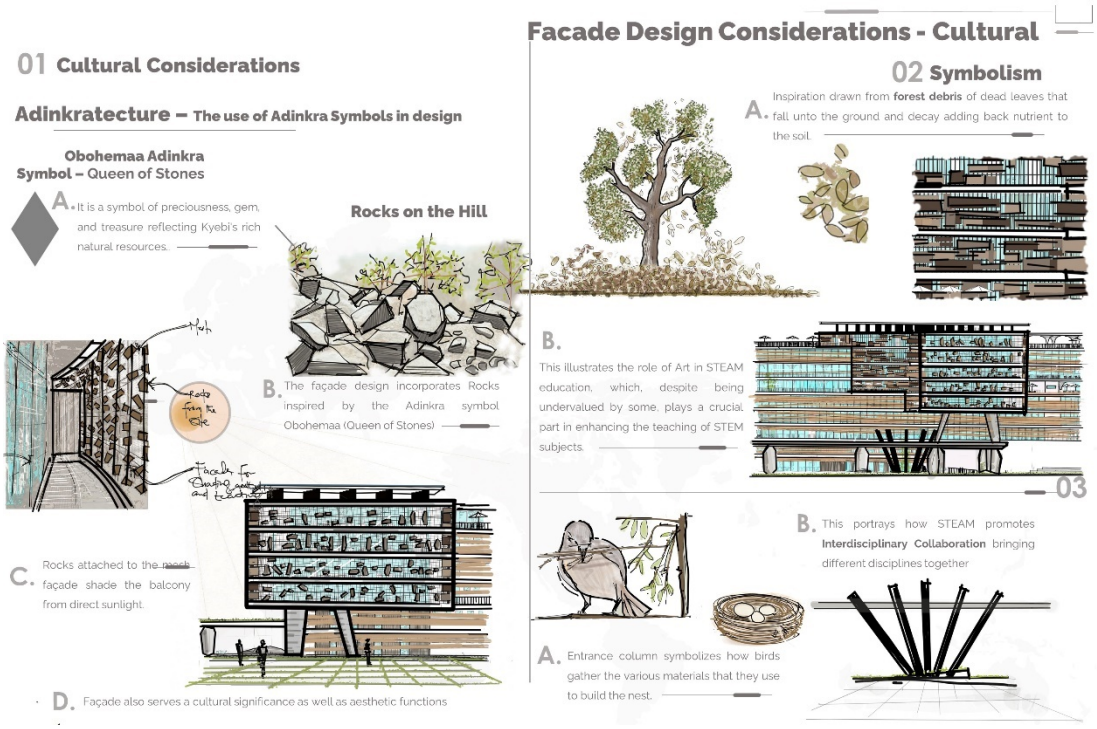
6.3.2 Concept of the Design

The design of the STEAM Hub embodies organic architecture principles through extensive use of biomimicry focused on "Integration and Synergy". Drawing inspiration from Kyebi's natural ecosystems dominated by the mountainous topography and natural vegetation, the project strategically chose a hill in Asikam as its site, seamlessly blending with the local environment.



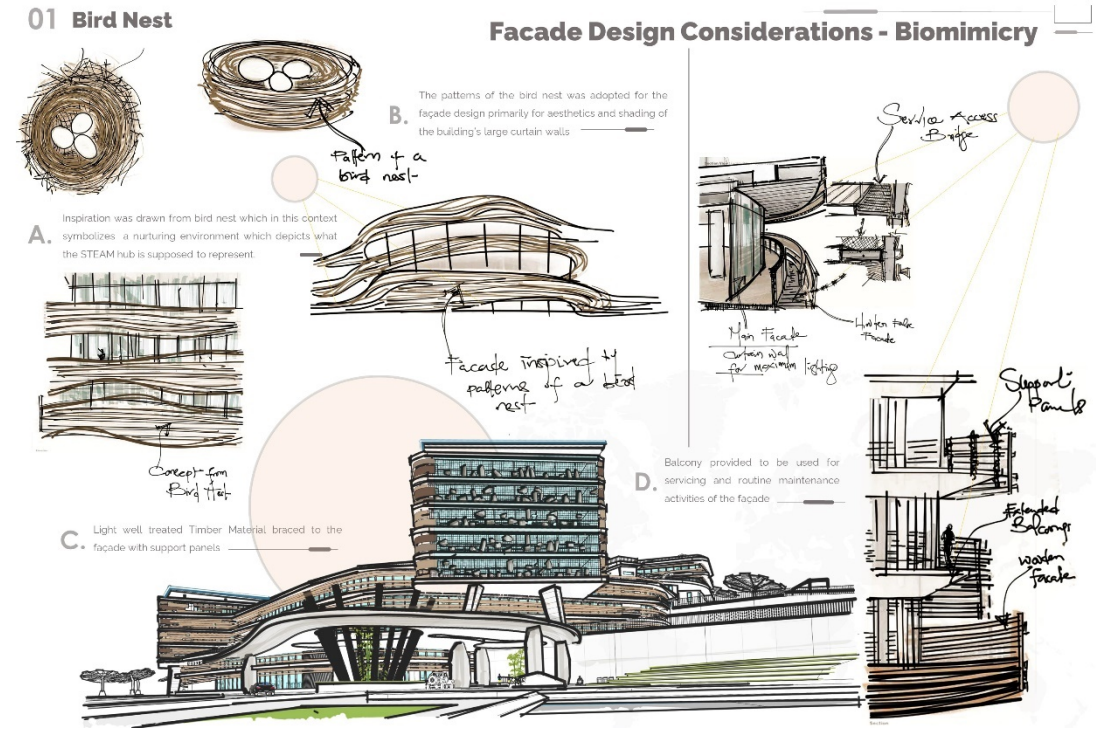
6.3 Form Development Sketches (Source: Author's Construct,2024)

Biomimicry guided the form of the building, with the site's contours shaping its overall structure and local materials such as rocks, and vegetation influencing detailed design elements. Symbolically, the facade incorporates the Obohemaa Adinkra Symbol, symbolizing Kyebi's cultural heritage and natural wealth.



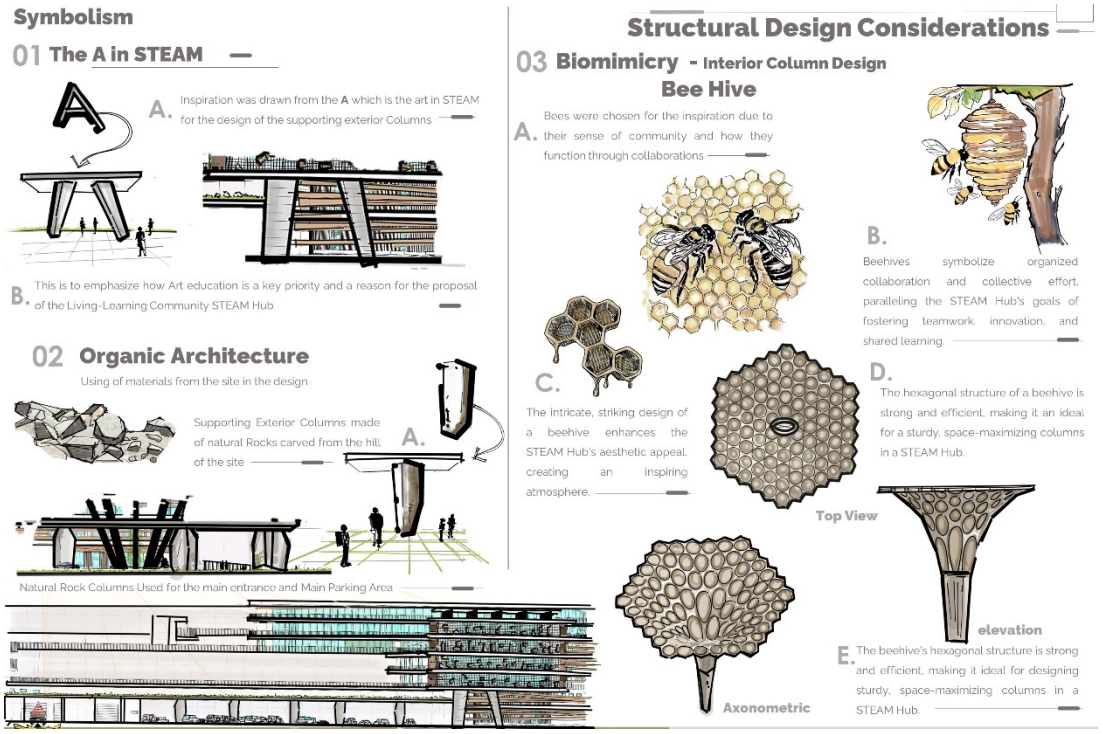
6.4 Façade considerations with inspiration from the Site (Source: Author's Construct,2024)

In addition, indigenous trees inspired a green roof that integrates the hub into its surroundings. Biomimetic principles extend to the architectural facade, mirroring bird nest patterns to symbolize nurturing and interdisciplinary collaboration inherent in STEAM education.



6.5 Bird Nest Inspired Façade considerations (Source: Author's Construct,2024)

Further enhancing the hub's design, its form symbolically represents STEAM education through terraced levels corresponding to each letter in STEAM. Two diagonal position blocks inspired by the letter 'A' create dynamic spatial connections linking the various levels. The architecture reflects both functionality and symbolism, with 'A'-shaped exterior columns emphasizing structural unity.



6.6 Structural Design Inspirations (Source: Author's Construct,2024)

The major entrance column, inspired by birds gather sticks and other raw materials for their nest construction, underscores the hub's role in fostering knowledge and collaboration.

Additionally, exterior columns crafted from site-sourced rocks enhance local authenticity and sustainability. A double roof system and green roofs integrate energy efficiency and environmental benefits, while facade shading devices mimic forest debris decay, enriching the ecosystem.

The interior structure draws from hexagonal honeycomb patterns, fostering community and creativity within collaborative spaces. This holistic design supports innovation and cultural identity, exemplified by the Adinkra symbol's significance. The STEAM Hub thus demonstrates how architecture, culture, and education can harmoniously coexist, promoting exploration, innovation, and sustainable practices.

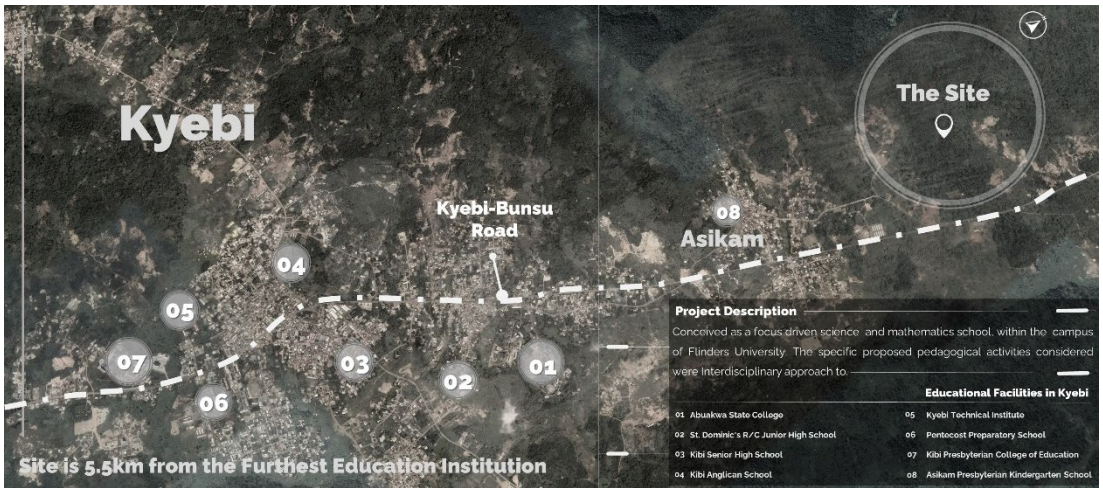
This integrated approach not only enhances the STEAM Hub's aesthetic and environmental impact but also reinforces its commitment to sustainable practices and educational excellence.

6.4 TARGET GROUP OF STUDY

Based on discussions and findings surrounding the design of the STEAM Hub, the target group for this innovative research and educational space encompasses a diverse range of stakeholders. Primarily, it caters to students and educators engaged in STEAM disciplines from the local schools in the municipality, promoting interdisciplinary learning and collaboration. Beyond academia, the hub targets local communities in Kyebi, aiming to integrate cultural heritage and environmental stewardship into educational practices. It also appeals to researchers and professionals interested in sustainable architecture and biomimetic design, providing a practical example of how these principles can be applied in real-world settings. By fostering a holistic learning environment that blends innovative design with cultural sensitivity, the STEAM Hub strives to inspire future generations and promote a deeper connection to both academic pursuits and the natural world.

6.5 THE SITE

The selected site spans 70,000 square meters, measuring 350 meters by 200 meters, and is situated in Asikam, approximately 4.65 km from Kyebi, within the Abuakwa South Municipality. Figure 6.3 below graphically represents the chosen location for the design. The Site is approximately 5.5km from the Furthest Educational Institution in coming from Kyebi



6.7 The site (Source: Author's Construct,2024)

6.5.1 Site Selection and Justification

The proposed site for the STEAM Hub is a hill located in Asikam along the Kyebi-Bonsu road, meeting all the criteria established for site selection. The site is approximately 5.5 km from the furthest educational institution when coming from Kyebi. Key criteria include accessibility with views, proximity to public transit, and sufficient road infrastructure; environmental context with access to green spaces and potential for renewable energy adoption; educational synergy with nearby educational and cultural centers; and a site size and configuration adequate for the facility and future expansion. Additionally, the site selection considered the environmental impact to minimize disruption to local biodiversity, infrastructure availability for essential utilities, resilience and adaptability to climate conditions, safety and security measures, and respect for cultural and historical contexts, including the incorporation of indigenous knowledge and techniques. Table 6.1 summarizes these criteria, derived from research, ensuring the optimal location for the design.

Site Selection Criteria	**Description**	**√ or ×**
1. Accessibility	i. Views. ii. Proximity to public transit for easy access. iii. Sufficient Road infrastructure for traffic flow.	√
2. Environmental Context	i. Access to green spaces for biomimicry integration. ii. Potential for renewable energy adoption (solar/wind).	√
3. Educational Synergy	i. Nearby educational/cultural centers for collaboration. ii. Access to scientific/artistic communities for interdisciplinary learning.	√
4. Site Size & Configuration	i. Adequate land for facility and outdoor areas.	√

	ii. Flexible layout for future expansion	
5. Environmental Impact	i. Consideration of local biodiversity to minimize disruption. ii. Mitigation of environmental risks through sustainable practices.	√
6. Infrastructure/Utilities Impact	i. Availability of water, electricity, and sewage systems. ii. Access to high-speed internet and telecom infrastructure.	√
7. Resilience & Adaptability	i. Consideration of climate resilience in planning and design. ii. Implementation of adaptable architecture for changing needs	√
8. Safety and Security	i. Evaluation of flooding, seismic, and industrial risks. ii. Implementation of safety measures for all.	√
9. Cultural and Historical Context	i. Respect for local heritage in site development. ii. Potential for incorporating indigenous knowledge or techniques	√

(Source: Author's Construct,2024)

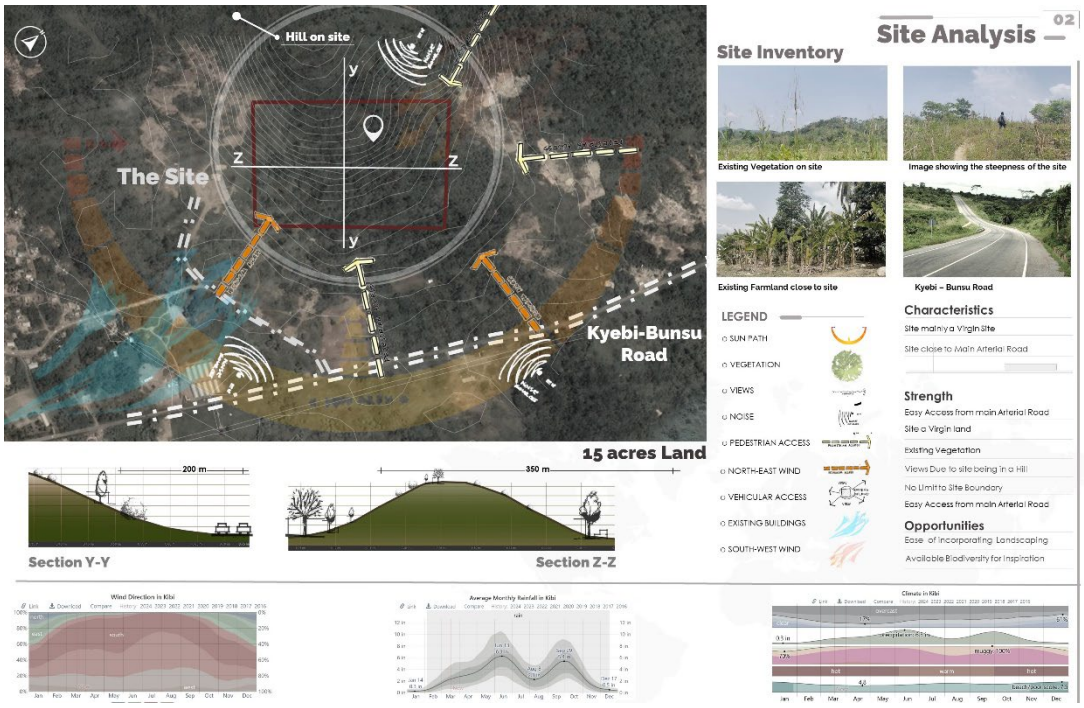
Table 6.1 clearly indicates that the selected site possesses significant potential for hosting the proposed STEAM Hub. The site is distinguished by its exceptional views, robust infrastructure, and convenient access for both vehicular and pedestrian traffic. Furthermore, its prominent and easily identifiable location enhances its overall suitability for the facility.

6.5.2 Site Inventory and Peripheral Studies

The site is situated near a proposed Eco-Industrial Park, located on the opposite side of the Kyebi-Bunsu Road. This undeveloped land offers an expansive, open area with a backdrop of mountain ranges and the Atiwa forest. The pristine nature of the site, coupled with its proximity to the upcoming industrial park, presents a unique opportunity for integrating natural and industrial landscapes.

6.5.3 Site Analysis

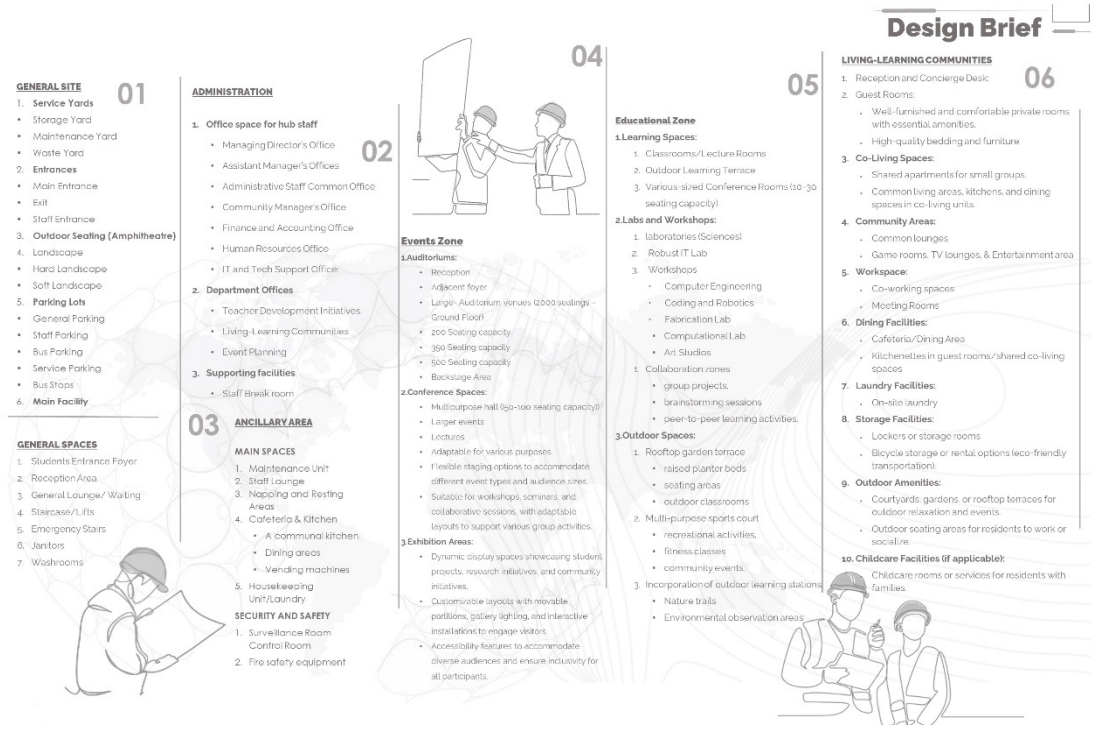
Situated near a planned Eco-Industrial Park and approximately 5.5 km from the furthest educational institution in Kyebi, the site is highly accessible Kyebi-Bunsu arterial road. It features a pristine, undeveloped landscape with scenic mountain ranges and the Atiwa Forest, offering a tranquil environment conducive to learning and innovation. The area's rich biodiversity and favorable climate, characterized by a warm, humid year-round weather pattern with distinct wet and dry seasons, further enhance its appeal. Ongoing infrastructure developments, including new road construction, improve connectivity and accessibility, making this site an optimal choice for fostering interdisciplinary collaboration and sustainable development within the community. The site has a steep slope making it visible from afar. The prevalent wind comes from the south through the site



6.8 Site Analysis (Source: Author's Construct,2024)

6.6 BRIEF DEVELOPMENT AND ACCOMMODATION SCHEDULE

The design incorporates various programs and activities tailored to enrich the educational experience and community engagement. These include S.T.E.A.M. Summer Camps, teacher development programs, art and science workshops, STEM-inspired art exhibitions, a coding and robotics club, technical and vocational training, community arts projects, and cultural training programs. These initiatives are seamlessly integrated into the hub's architecture and mission, fostering a dynamic environment that encourages exploration, innovation, and a deeper connection to both academic pursuits and the natural world.

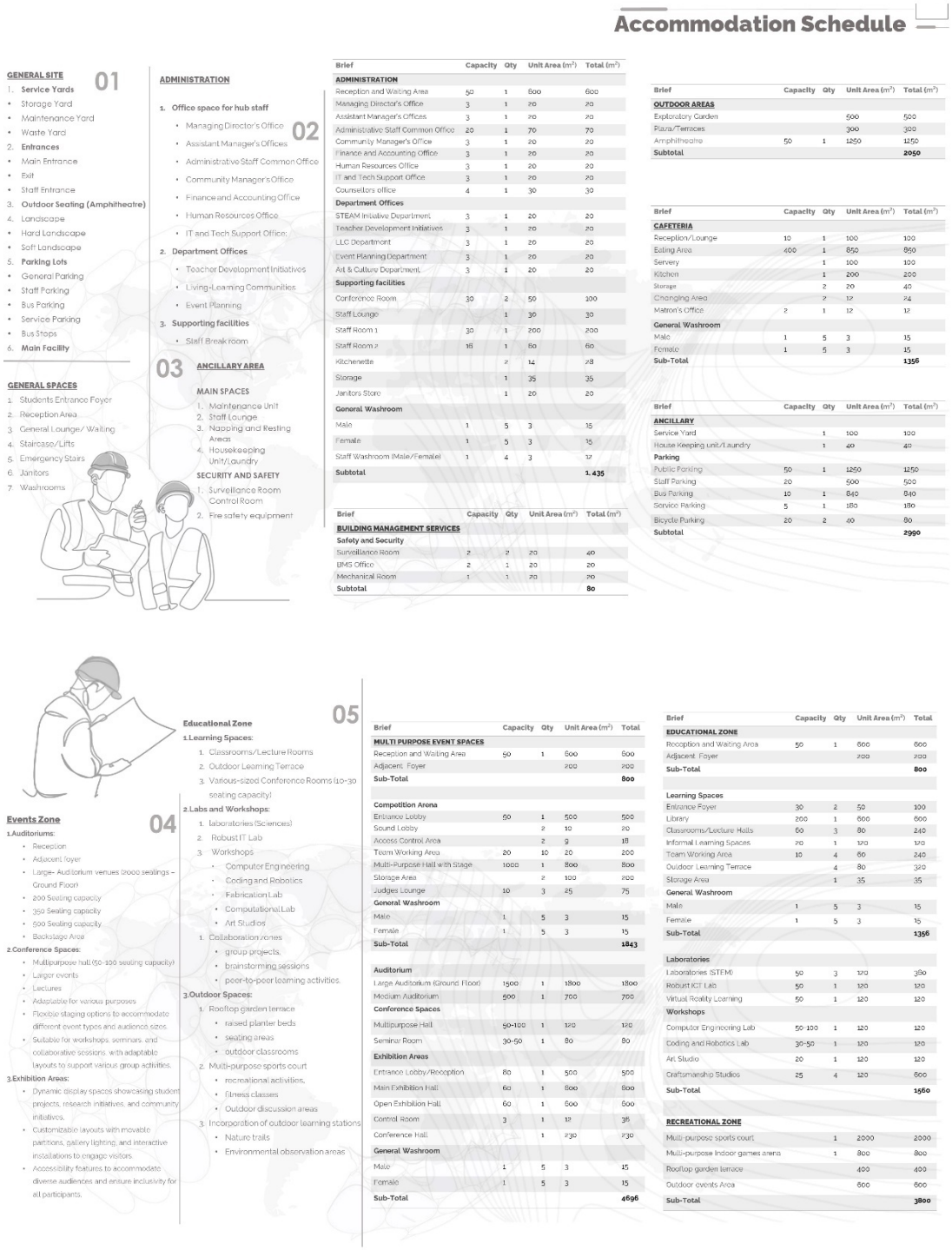


6.9 Design Brief categorized into zones (Source: Author's Construct,2024)

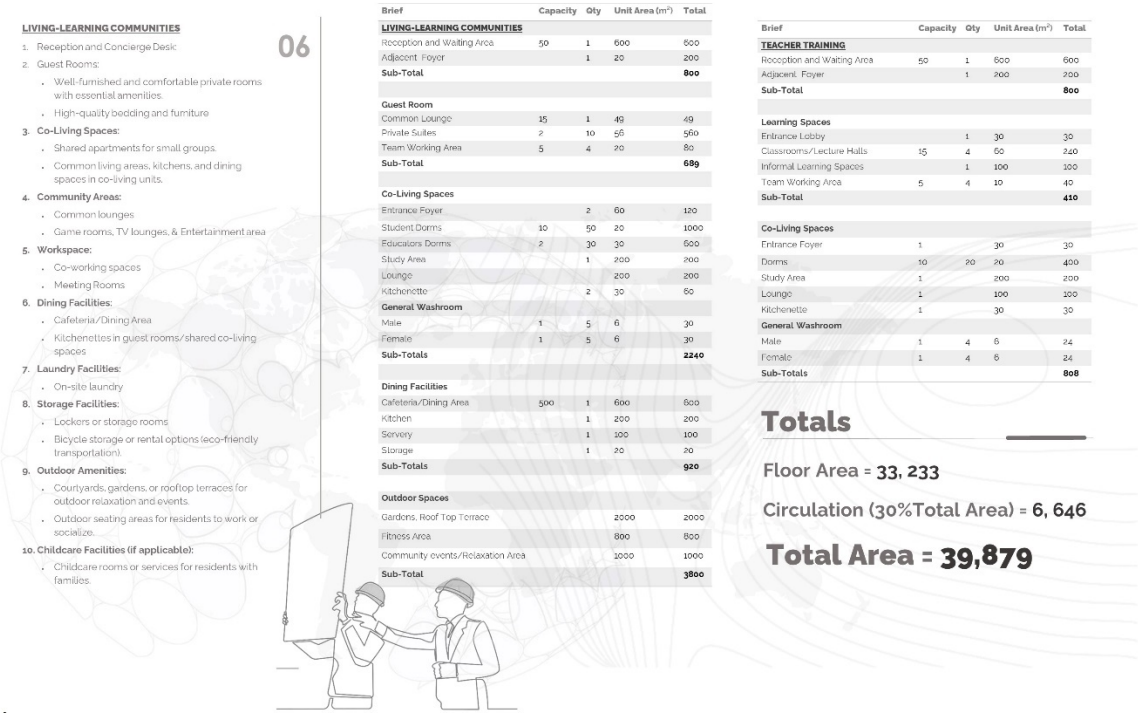
The design for the STEAM Hub is divided into several functional zones to enhance efficiency and user experience. The General Site includes, multiple entrances, outdoor seating, landscaped areas, ample parking and service yards. The Main Facility features a student entrance foyer, reception, lounges, staircases, lifts, and washrooms. The Events Zone includes versatile auditoriums, conference rooms, and exhibition areas for diverse activities.

The Educational Zone offers innovative learning environments, including classrooms, labs, workshops, and outdoor learning spaces. The Living-Learning Communities zone provides residential amenities, including guest rooms, co-living spaces,

community areas, workspaces, dining facilities, and outdoor amenities. The Administration Zone supports administrative operations with offices for staff and various departments, along with supporting facilities like a staff break room. The Ancillary Area ensures user comfort with maintenance units, lounges, a cafeteria, and security measures. These zones work together to create a dynamic, inclusive, and sustainable STEAM Hub



6.10 Accommodation Schedule of the various zones (Source: Author's Construct,2024)



LIVING-LEARNING COMMUNITIES

06

1. Reception and Concierge Desk:
2. Guest Rooms:
   - Well-furnished and comfortable private rooms with essential amenities.
   - High-quality bedding and furniture.
3. **Co-Living Spaces:**
   - Shared apartments for small groups.
   - Common living areas, kitchens, and dining spaces in co-living units.
4. **Community Areas:**
   - Common lounges.
   - Game rooms, TV lounges, & Entertainment area
5. **Workspace:**
   - Co-working spaces
   - Meeting Rooms
6. **Dining Facilities:**
   - Cafeteria/Dining Area
   - Kitchenettes in guest rooms/shared co-living spaces
7. **Laundry Facilities:**
   - On-site laundry
8. **Storage Facilities:**
   - Lockers or storage rooms
   - Bicycle storage or rental options (eco-friendly transportation).
9. **Outdoor Amenities:**
   - Courtyards, gardens, or rooftop terraces for outdoor relaxation and events.
   - Outdoor seating areas for residents to work or socialize.
10. **Childcare Facilities (if applicable):**
    - Childcare rooms or services for residents with families.

Brief	Capacity	Qty	Unit Area (m²)	Total
LIVING-LEARNING COMMUNITIES				
Reception and Waiting Area	50	1	600	600
Adjacent Foyer		1	20	200
Sub-Total				**800**
Guest Room				
Common Lounge	15	1	49	49
Private Suites	2	10	56	560
Team Working Area	5	4	20	80
Sub-Total				**689**
Co-Living Spaces				
Entrance Foyer		2	60	120
Student Dorms	10	50	20	1000
Educators Dorms	2	30	30	600
Study Area		1	200	200
Lounge			200	200
Kitchenette		2	30	60
General Washroom				
Male	1	5	6	30
Female	1	5	6	30
Sub-Totals				**2240**
Dining Facilities				
Cafeteria/Dining Area	500	1	600	600
Kitchen		1	200	200
Servery		1	100	100
Storage		1	20	20
Sub-Totals				**920**
Outdoor Spaces				
Gardens, Roof Top Terrace			2000	2000
Fitness Area			800	800
Community events/Relaxation Area			1000	1000
Sub-Total				**3800**

Brief	Capacity	Qty	Unit Area (m²)	Total
TEACHER TRAINING				
Reception and Waiting Area	50	1	600	600
Adjacent Foyer		1	200	200
Sub-Total				**800**
Learning Spaces				
Entrance Lobby		1	30	30
Classrooms/Lecture Halls	15	4	60	240
Informal Learning Spaces		1	100	100
Team Working Area	5	4	10	40
Sub-Total				**410**
Co-Living Spaces				
Entrance Foyer	1		30	30
Dorms	10	20	20	400
Study Area	1		200	200
Lounge	1		100	100
Kitchenette	1		30	30
General Washroom				
Male	1	4	6	24
Female	1	4	6	24
Sub-Totals				**808**

Totals

Floor Area = 33, 233

Circulation (30%Total Area) = 6, 646

Total Area = 39,879

6.11 Accommodation Schedule of the various zones Continued
(Source: Author's Construct,2024)

6.7 SITE PLANNING

The site planning for the STEAM Hub is meticulously organized into multiple terraces, each serving distinct functions. The first terrace, at the ground level, serves as a buffer space with landscaping, vehicular and pedestrian access, and various parking options including general, private, and bus parking. This level also features an outdoor lawn area, plaza, porte-cochere entrance, children's play area, football pitch, and mechanical room.



6.12 Sketches of the site conceptualization process (Source: Author's Construct,2024)

The second terrace, aligning with the ground floor level of the building, houses the Events Zone, extending up to the first floor. The third terrace starts from the second floor and includes parts of the Events Zone as well as the Educational Zone on the

third and fourth floors. This level also incorporates an outdoor skating park, green spaces, and an outdoor network satellite dish.



6.13 Sketches of the site conceptualization process (Source: Author's Construct,2024)

The fourth terrace is dedicated to additional educational spaces, an outdoor solar park, basketball and tennis courts. The fifth terrace accommodates the Administration Zone and the Living-Learning Communities Zone, ensuring a comprehensive residential experience for users. This terrace also includes service areas with water tanks. These terraces collectively contribute to a dynamic, inclusive, and sustainable STEAM Hub, fostering a seamless integration of various functions and activities.



6.14 Site plan of the LLC STEAM Hub (Source: Author's Construct,2024)

6.8 STRUCTURE AND CONSTRUCTION DETAILS

The hub incorporates a variety of structural systems to support its primary framework. Key elements include post and beam systems, retaining walls, load-bearing walls, and freestanding columns designed for long-span spaces. The predominant construction method utilizes a skeletal system with post and beam structures and concrete slabs, particularly effective for facades featuring curtain walls that maximize natural lighting. The primary roofing system consists of flat concrete waffle slabs, supported by columns across large spans, while the secondary roofing system employs wooden purlins and rafters, with vertical hollow metal steel posts suspending the roof.

To address major lateral forces from prevailing winds, the facade shading devices are constructed from sturdy, lightweight wood, fastened to the building with steel structural members. The roof is strategically open in places to facilitate air escape. The main facade structures are supported by a braced frame framework, ideal for resisting lateral loads such as wind and seismic pressure due to its composition of structural steel, which excels in both tension and compression.

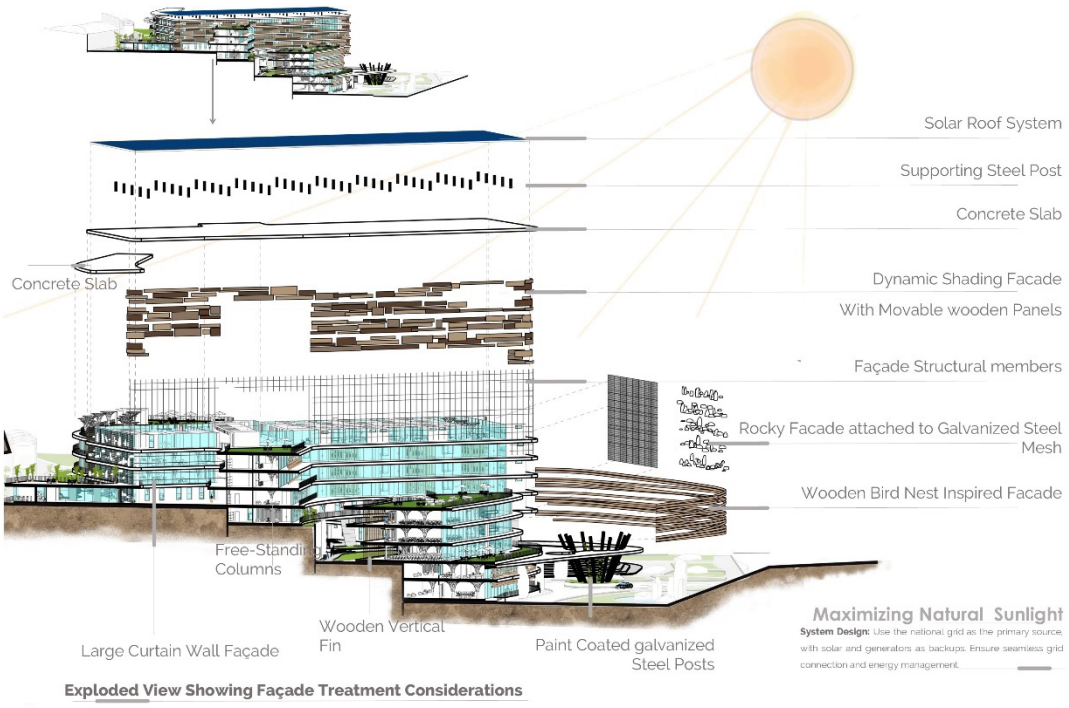


Figure 6.15 Exploded Cladding Axonometric Diagram (Source: Author's Construct,2024)

The flooring system utilizes waffle slabs to accommodate their expansive spans and the terraces and green roof systems. A waffle slab, or ribbed slab, features a grid-like pattern on its bottom surface and a plain top surface, with thin upper layers and intersecting ribs of equal depth below. This two-way reinforcement makes waffle slabs

particularly suitable for buildings like the innovation hub, which benefit from reduced vibration.

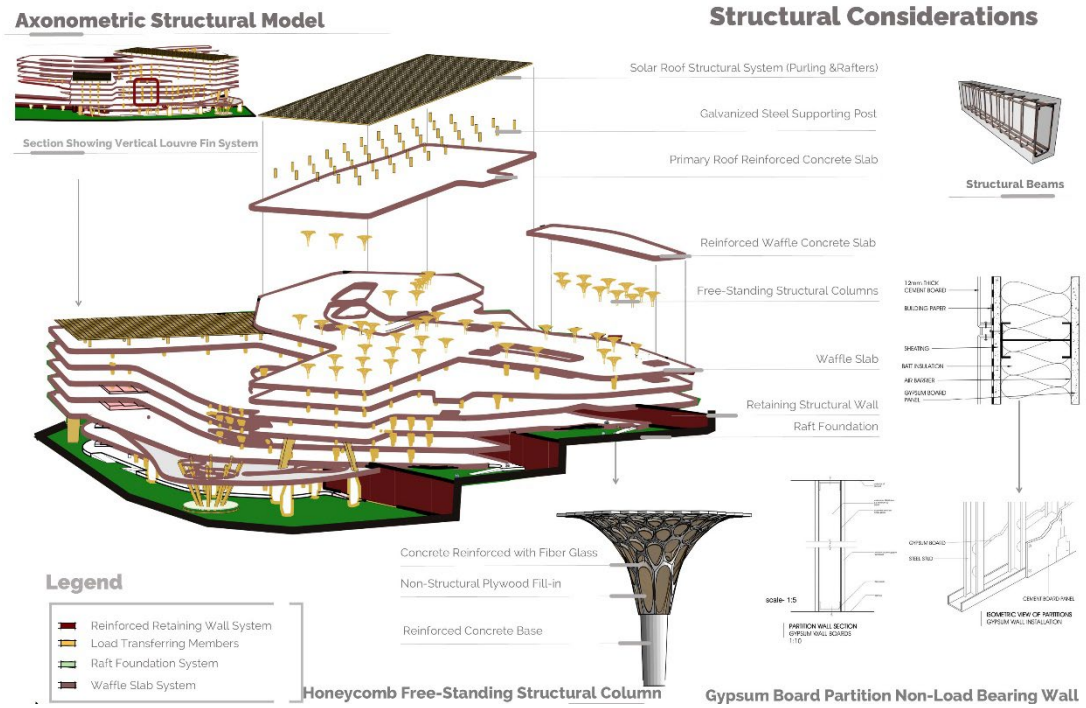


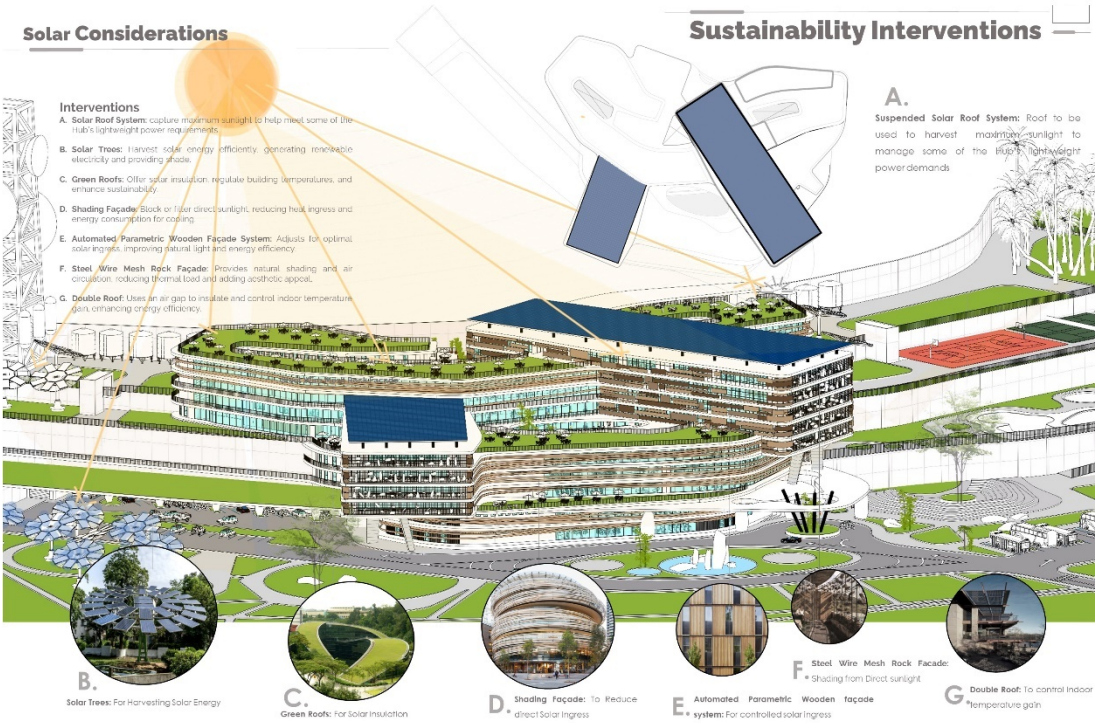
Figure 6.16 Exploded Structural Axonometric Diagram (Source: Author's Construct,2024)

This design achieves larger spans with less material, resulting in cost savings and environmental benefits. The overall structural approach combines efficiency, strength, and sustainability, ensuring the hub's resilience and functionality.

6.9 SUSTAINABILTY CONSIDERATIONS

The design of the STEAM Hub prioritizes sustainability through a comprehensive approach incorporating biomimicry, organic architecture, and energy efficiency. Drawing inspiration from Kyebi's natural ecosystems, the project is strategically sited on Asikam Hill, ensuring seamless integration with the local environment.

Inspired by biomimicry, the design integrates natural systems and processes. The use of curtain walls for maximum natural lighting emulates the efficient energy use of plant leaves, reducing the need for artificial lighting and lowering energy consumption.



6.17 Solar Considerations of the Hub (Source: Author's Construct,2024)

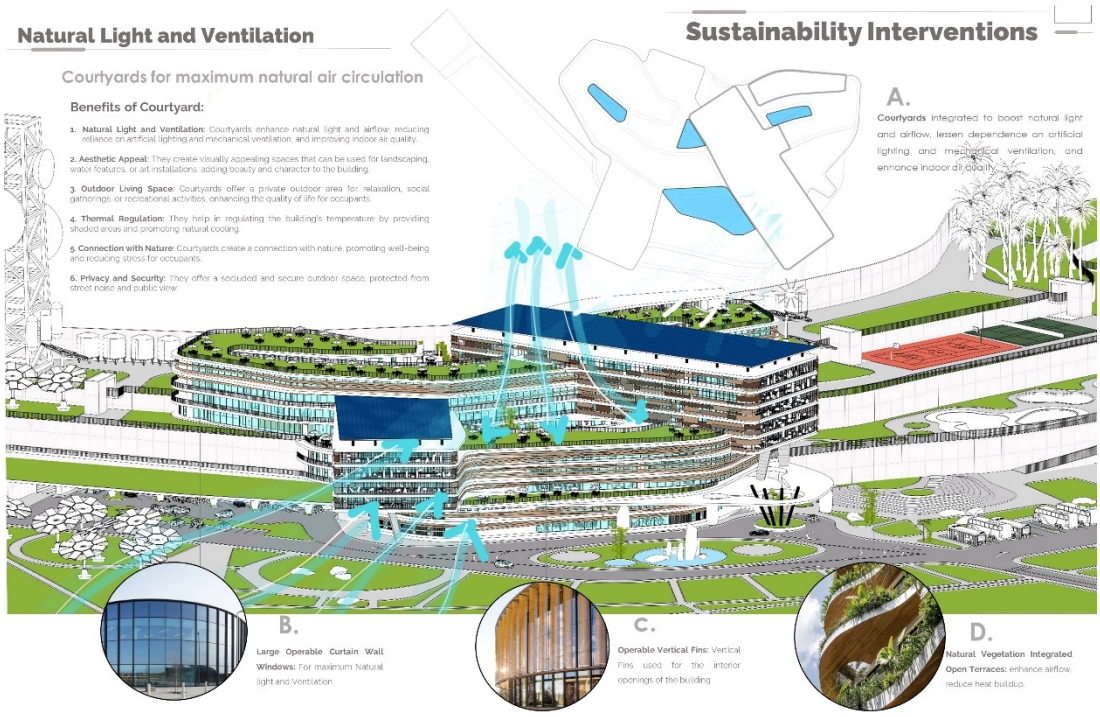
The construction methods leverage sustainable materials, such as structural steel in braced frames and wood for shading devices, mirroring the resourcefulness found in nature. Wood, used for the facade shading devices, is fastened to the building by steel structural members, reflecting the way natural elements combine strength and flexibility. These devices also function like tree canopies, providing shade and reducing heat gain, enhancing the building's energy efficiency.

The integration of green roof systems and solar parks aligns with the principles of photosynthesis, harnessing solar energy for power and promoting green space for environmental health.

The structural design employs post and beam systems, retaining walls, load-bearing walls, and freestanding columns, ensuring strength and flexibility with minimal material use which was also achieved in the interior's designed free-standings columns that drew inspiration from the hexagonal structure of beehives honeycomb structure which also resulted in the use of less materials while still achieving structural integrity for the design. The primary roof system, comprising concrete flat waffle slabs, provides extra support over large spans, while the secondary roof system utilizes wooden purlins and rafters locally sourced from the site, with vertical hollow metal steel posts suspending the roof. The hub's double roof system and green roofs enhance energy efficiency and environmental benefits, while facade shading devices mimic the

natural decay of forest debris, contributing to the ecosystem. This consideration reduces direct sunlight from heating up the primary concrete slap roof resulting less artificial cooling for the building.

Courtyards and natural vegetation integrated open terraces significantly enhance a building's environment by boosting natural light and airflow, thus reducing reliance on artificial lighting and mechanical ventilation. Courtyards allow sunlight to penetrate deeper, creating a bright and airy atmosphere while facilitating natural ventilation, which helps maintain comfortable indoor temperatures and improves air quality. Similarly, open terraces with vegetation enhance air movement and reduce heat buildup, lowering the need for air conditioning and making the space more comfortable and energy-efficient. These features also mitigate urban heat island effects, improve air quality, and add aesthetic value, promoting a greener, more sustainable urban landscape.

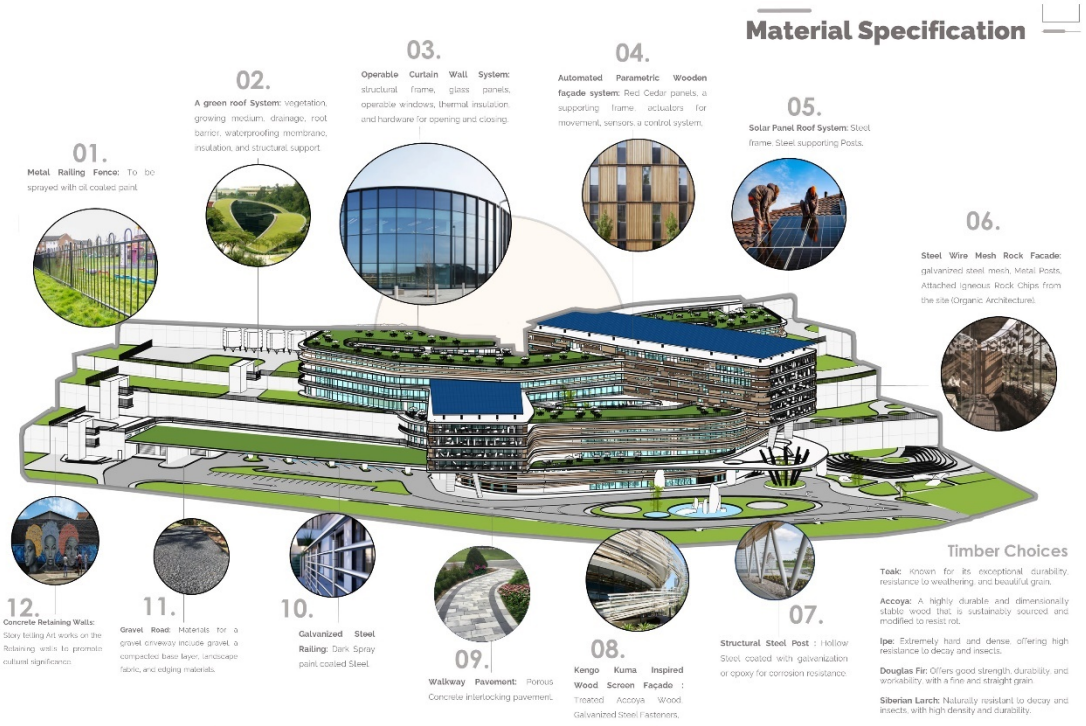


6.18 Natural Lighting and Ventilation considerations of the Hub

(Source: Author's Construct,2024)

Sustainability is further enhanced through efficient water management, with rainwater harvested and used for irrigation, mirroring natural ecosystems' water utilization. Native plants are incorporated into the landscaping, requiring minimal water and maintaining local biodiversity.

These thoughtful integrations demonstrate a comprehensive approach to sustainability, emphasizing energy efficiency, resource conservation, and environmental harmony. By incorporating biomimicry, the hub not only reduces its environmental footprint but also creates a space that resonates with the natural world, promoting sustainability and innovation in every aspect of its design. The design exemplifies how architecture, culture, and education can harmoniously coexist to promote exploration, innovation, and sustainable living.



6.19 Material specifications of the Hub (Source: Author's Construct,2024)

6.10 BARRIER-FREE CONSIDERATIONS

The design of the STEAM Hub places a strong emphasis on barrier-free and inclusive considerations, ensuring accessibility for all users while integrating advanced technologies to enhance the friendly environment and usability for persons with disabilities. Multiple entrances are equipped with ramps and wide doorways to accommodate wheelchairs and other mobility devices, facilitating easy access to all areas. Elevators and staircases are strategically placed to provide convenient vertical circulation, and tactile paving guides visually impaired individuals through key routes. Interior spaces are designed with open layouts, ensuring ample room for maneuvering, while furnishings are arranged to allow unimpeded movement.

Washrooms are equipped with accessible features such as grab bars, lower sinks, and ample turning space for wheelchairs. Additionally, the facility incorporates modern

technologies such as automated doors, voice-activated systems, and adjustable-height desks to enhance usability. Visual and auditory aids, including Braille signage, audio cues, and hearing loops, support individuals with sensory impairments. Advanced lighting controls and acoustic treatments are implemented to create a comfortable environment for users with neurodiverse conditions.

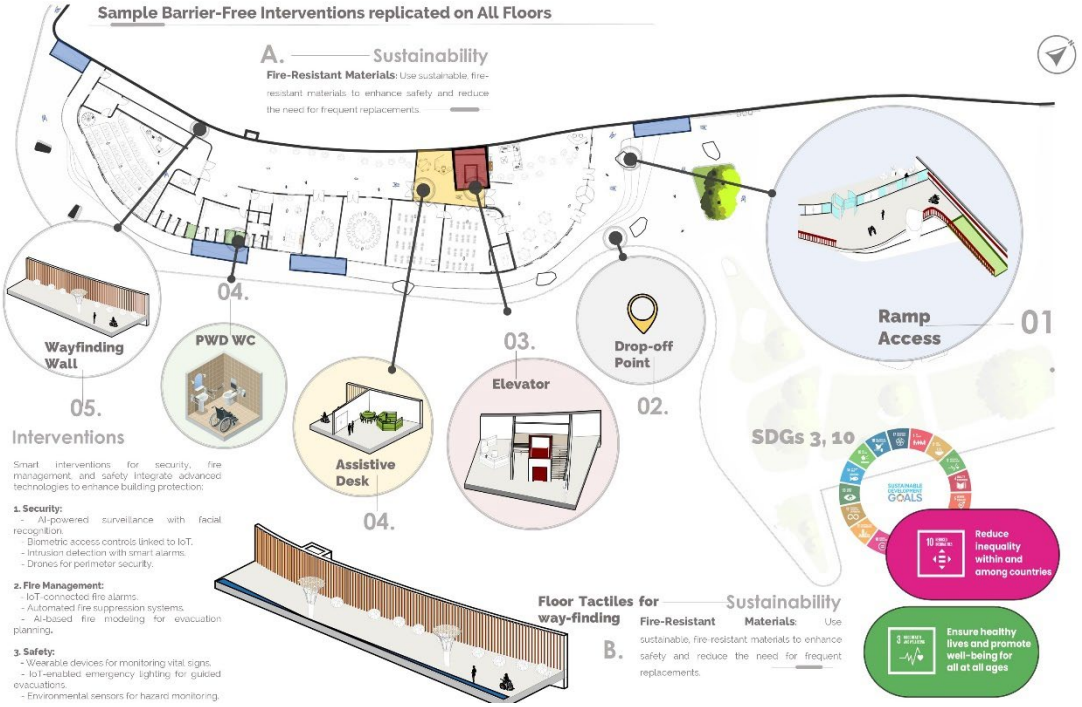


Figure 6.20 Schematic Diagram of some Barrier-Free Interventions Utilised

(Source: Author's Construct,2024)

Outdoor areas, including the amphitheater and landscaped zones, are designed with smooth, even surfaces and accessible seating options. Parking lots feature designated accessible parking spaces located near building entrances. The hub's design also incorporates inclusive learning and community spaces, providing adjustable furniture, flexible layouts, and assistive technology such as screen readers and interactive whiteboards to cater to diverse needs. This comprehensive approach ensures that the STEAM Hub is a welcoming and functional environment for everyone, reflecting a commitment to inclusivity, equal access, and technological integration.

6.11 BUILDING SERVICES

Building services considerations for the STEAM Hub encompass essential systems ensuring functionality, comfort, and sustainability. Key focuses include HVAC systems for optimal air quality and temperature control across diverse spaces, efficient electrical infrastructure to support modern technological needs, and sustainable

plumbing systems with water-saving fixtures and greywater recycling. Fire safety measures include comprehensive alarm systems and fire-resistant materials, while robust security systems integrate access controls and surveillance. High-speed internet and smart technologies form the backbone of ICT infrastructure, enhancing educational and administrative operations. Accessibility features are integrated throughout, ensuring barrier-free access and usability for all users. Energy efficiency strategies include passive design, renewable energy sources like solar panels, and energy monitoring systems. Acoustic comfort is prioritized through strategic acoustic treatments, crucial for educational environments. Lastly, durable materials and maintenance-friendly design support long-term operational efficiency and sustainability goals.

6.11.1 Electricity

Several key considerations were made in designing the electrical infrastructure for the STEAM Hub to ensure it meets diverse operational needs while promoting sustainability and inclusivity. The system was meticulously planned to accommodate the high electricity demands typical of educational and administrative facilities, employing robust distribution networks to deliver reliable power across various zones. Advanced technologies such as smart meters and energy management systems were integrated to optimize energy usage in real-time, reducing waste and enhancing overall efficiency. Renewable energy sources, notably solar photovoltaic panels, were strategically incorporated to supplement grid power, aligning with sustainability goals and minimizing the hub's environmental impact.

Safety measures were prioritized through the installation of modern circuit protection devices, surge suppressors, and grounding systems to mitigate electrical hazards and ensure the well-being of occupants and equipment. Backup power solutions, including uninterruptible power supplies (UPS) and emergency generators, were implemented to maintain continuity during power outages, safeguarding critical operations and data integrity.



Figure 6.21 Power Supply Layout and Considerations
(Source: Author's Construct,2024)

The design also focused on scalability, anticipating future expansions and technological advancements to accommodate evolving energy needs seamlessly. In adherence to inclusive design principles, the electrical system features were enhanced to improve accessibility for all users, incorporating well-lit pathways, accessible outlets and switches, and provisions for individuals with visual and auditory impairments. These considerations collectively contribute to creating a safe, efficient, and inclusive environment at the STEAM Hub, supporting its mission of fostering learning, research, and innovation while promoting sustainability.

6.11.2 Water Supply and Fire Management

Considerations for water supply and fire management at the STEAM Hub were carefully integrated to ensure sustainable practices, safety, and operational resilience. The water supply system was designed to meet the diverse needs of the facility while minimizing environmental impact. High-efficiency plumbing fixtures and fittings were selected to conserve water usage, supported by a robust greywater recycling system to reuse water for non-potable purposes such as irrigation and toilet flushing. Rainwater harvesting infrastructure was also implemented to capture and store rainwater for landscape irrigation and other non-potable uses, reducing dependency on municipal water sources and promoting sustainability.

Fire management strategies were comprehensive and compliant with stringent safety standards. The hub features state-of-the-art fire detection and alarm systems, strategically positioned throughout the facility to ensure early detection and rapid response to potential fire incidents. Automatic sprinkler systems were installed in critical areas to suppress fires effectively, supported by fire hydrants and hose reels for manual firefighting capabilities. Emergency evacuation routes and signage were meticulously planned to facilitate safe and orderly evacuation in case of fire emergencies, with accessibility considerations integrated to accommodate individuals with mobility challenges.

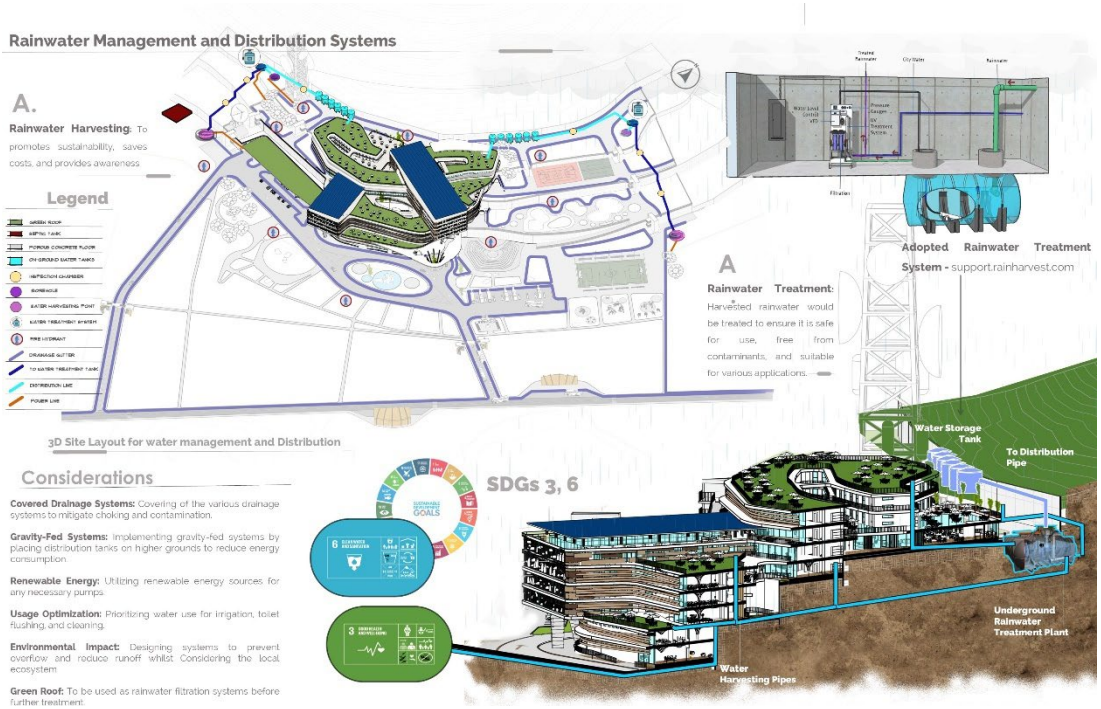


Figure 6.22 Water Supply Layout and Considerations
(Source: Author's Construct,2024)

Additionally, fire-resistant building materials and construction techniques were employed to enhance structural fire safety, mitigating fire spread and protecting occupants and assets. These comprehensive measures ensure that the STEAM Hub maintains a safe, sustainable, and resilient environment, supporting its mission as a leading educational and innovation center.

6.11.3 Waste Management

Considerations for waste management at the STEAM Hub were designed to ensure sustainability and efficiency. The hub implemented a centralized waste collection system with designated areas for sorting recyclables, organic waste, and general waste, encouraging responsible disposal and recycling. On-site composting facilities handled organic waste, providing compost for landscaping. Hazardous waste was managed safely and in compliance with regulations. The hub also minimized waste generation through digital documentation and durable, reusable materials. Regular waste audits and educational programs promoted environmental responsibility, supporting the hub's sustainability goals.

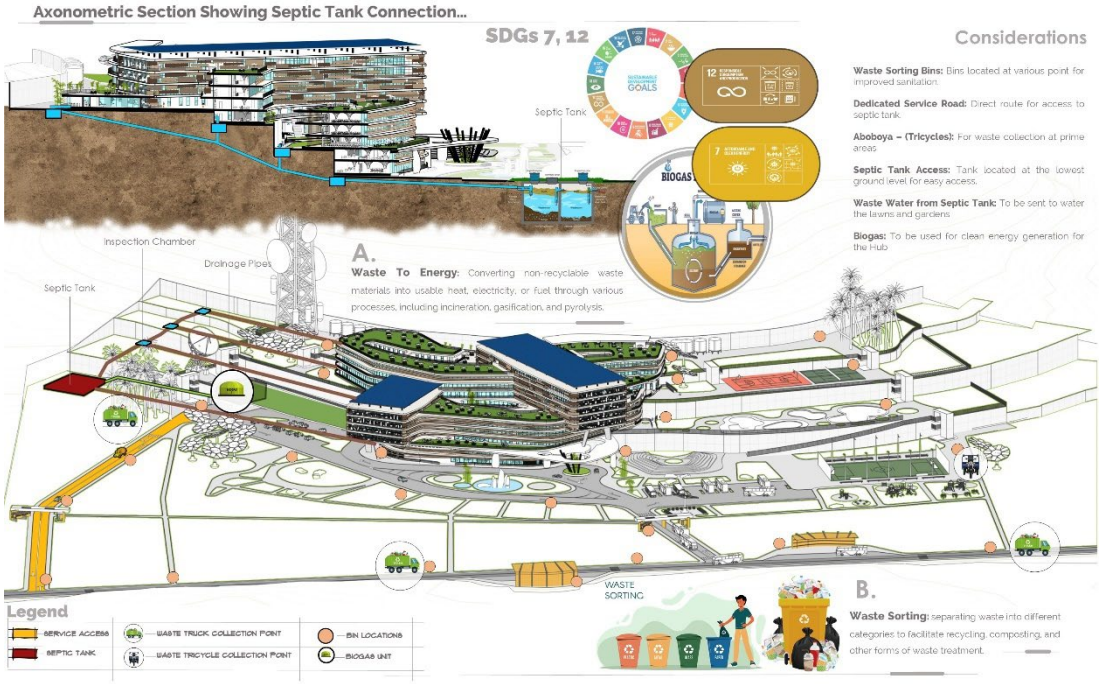


Figure 6.23 Waste Management Layout and Considerations
(Source: Author's Construct,2024)

6.12 PROJECT PHASING

Designed to integrate seamlessly with its natural surroundings and cultural heritage, the project's construction plan follows a meticulously phased approach to ensure efficient progress and adherence to sustainability principles, the construction plan for the STEAM Hub is meticulously phased over 60 months (5 years) to ensure seamless integration with its natural surroundings and cultural heritage while prioritizing sustainability.

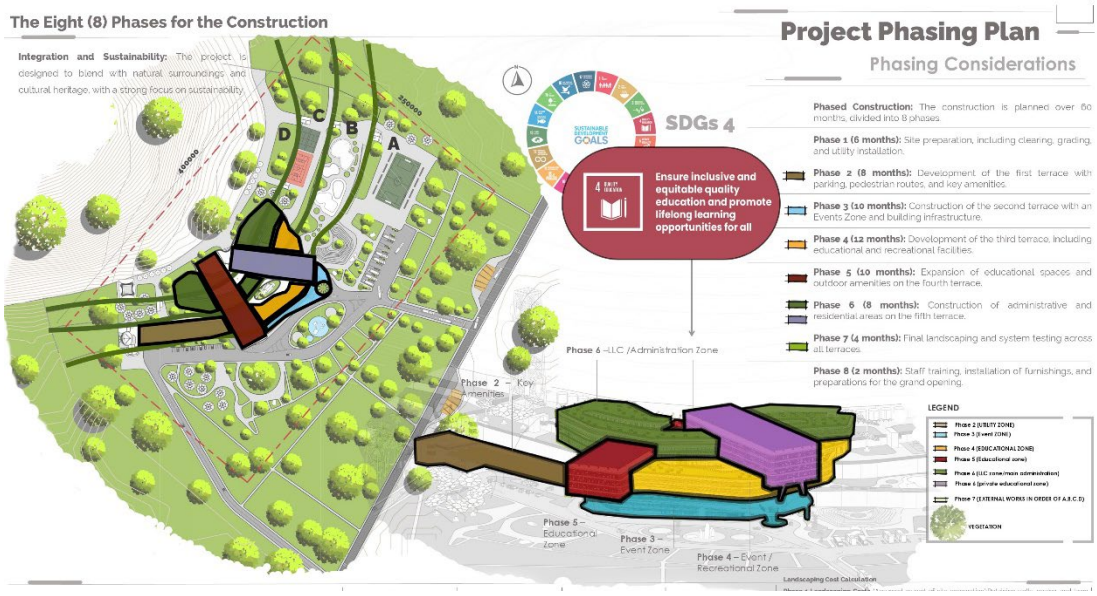
The site planning for the STEAM Hub is structured across multiple terraces, each strategically allocated for specific functions. Beginning with **Phase 1**, the project will commence with comprehensive site preparation activities over a six-month period. This initial phase encompasses clearing and grading of the site, establishment of temporary facilities, and installation of essential utilities such as water, electricity, and sewage connections. The groundwork laid in Phase 1 sets the foundation for subsequent construction phases, laying the groundwork for the development of the first terrace.

Phase 2 focuses on the development of the ground-level first terrace, slated for completion within eight months. This phase will see the construction of critical infrastructure including various parking facilities—general, private, and bus parking—alongside pedestrian access routes and landscaped areas. Key features such as the porte-cochere entrance, children's play area, football pitch, and mechanical room will also be integrated into this phase, ensuring a functional and welcoming environment.

Moving into **Phase 3**, spanning ten months, attention turns to the second terrace encompassing the ground and first floors of the building. Here, the Events Zone takes shape, designed to accommodate diverse activities and events. Structural elements such as elevators, staircases, and foundational building systems like HVAC and plumbing will be meticulously installed, setting the stage for operational functionality.

Phase 4 extends over twelve months and focuses on the development of the third terrace, spanning the second and third floors. This phase marks the integration of both the Events Zone and the Educational Zone, which includes classrooms, laboratories, and workshops. Innovative features such as an outdoor skating park, green spaces, and outdoor network satellite dish are incorporated, blending educational facilities with recreational opportunities.

The subsequent **Phase 5**, spanning ten months, extends to the fourth terrace, dedicated to additional educational spaces and outdoor amenities. This phase includes the implementation of an outdoor solar park, basketball and tennis courts, and outdoor learning stations, promoting active and sustainable lifestyles among students and faculty.

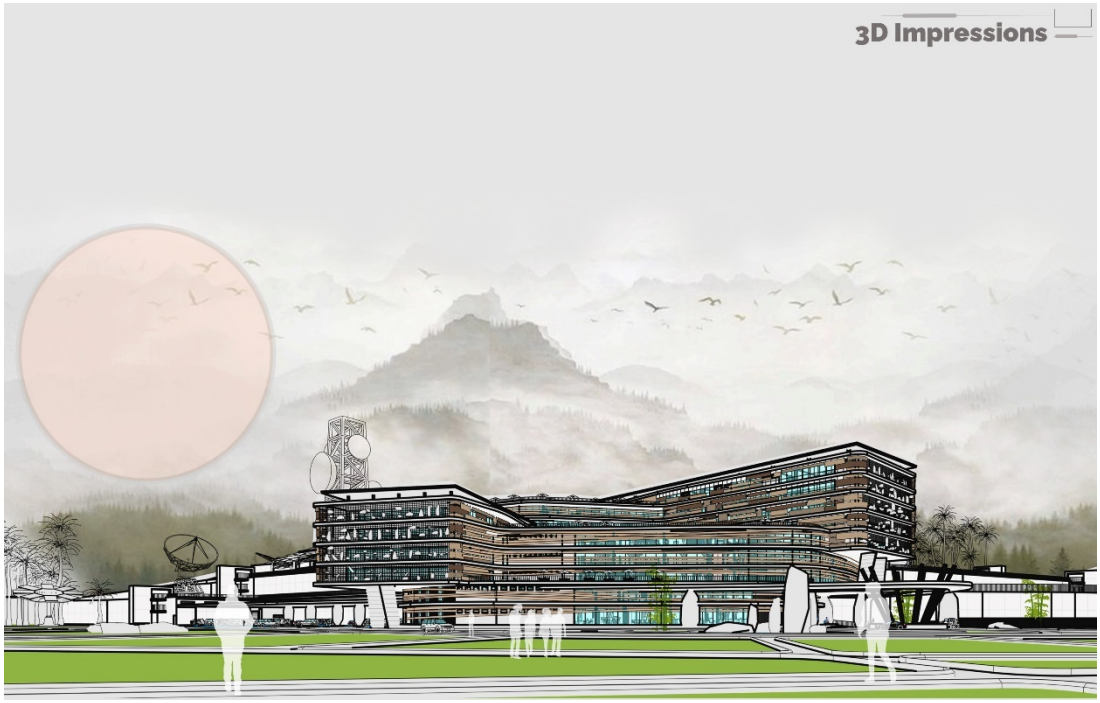


6.24 Phasing illustration for the Hub's construction
(Source: Author's Construct,2024)

Phase 6, lasting eight months, focuses on the fifth terrace accommodating the Administration Zone and Living-Learning Communities Zone. This phase emphasizes the construction of administrative offices, residential amenities, and essential service areas, including water tanks, ensuring a comprehensive and supportive environment for both administrative staff and residents.

In Phase 7, spanning four months, final landscaping and site finishing activities are undertaken across all terraces. This includes the installation of outdoor seating areas, completion of pathways, and meticulous testing and commissioning of building systems to ensure optimal operational efficiency and sustainability.

The culmination of **Phase 8**, spanning two months, involves staff training, installation of furniture, fixtures, and equipment, and final preparations for the grand opening. This final phase marks the completion and handover of the STEAM Hub, culminating in an inaugural ceremony that celebrates the project's achievement and its potential to foster exploration, innovation, and sustainable practices in Kyebi.



6.25 A 3D Impression of the Hub (Source: Author's Construct,2024)

6.13 CHAPTER SUMMARY

This chapter provides a comprehensive overview of the STEAM Hub project, beginning with major findings that informed its design. Emphasizing a philosophy rooted in integrating with the natural and cultural environment through biomimicry, the design concept aims to cater to students, faculty, and the community. Site selection at Asikam Hill is justified by its natural and cultural significance, detailed through site inventory, peripheral studies, and thorough site analysis. The brief development outlines space allocation and requirements, while site planning organizes functions across multiple terraces. Structural details highlight diverse systems supporting the building, complemented by sustainability considerations focusing on renewable energy, water conservation, and waste management. Barrier-free design integrates modern inclusivity and assistive technologies, and building services encompass electricity, water supply, and fire management. Project phasing outlines a systematic 60-month construction plan, ensuring adherence to sustainability and accessibility standards throughout the development process.

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APPENDICES

APPENDIX 1: LETTER OF INTRODUCTION TO QUESTIONNAIRE

Department of Architecture

College of Art and Built Environment

KNUST, Kumasi

May January, 2024

Dear Sir/ Madam,

A HUMBLE REQUEST FOR YOUR PARTICIPATION IN MY ACADEMIC RESEARCH

These questionnaires are part of the prerequisites for completing a Master of Architecture degree at the Department of Architecture, Kwame Nkrumah University of Science and Technology, Kumasi.

The research is being undertaken by Michael Mawuena Baccah, a second-year Master's student within the Department of Architecture. The focus of this research revolves around the topic, "EXPLORING THE POTENTIAL OF BIOMIMICRY FOR S.T.E.A.M. LIVING-LEARNING COMMUNITIES IN GHANA: THE CASE OF KYEBI."

Despite ongoing endeavors to promote innovation and sustainability in architectural design, conventional approaches exhibit limitations requiring attention. The untapped potential of biomimicry, a design methodology inspired by nature, present a crucial dimension in the Ghanaian context, particularly in the design of educational facilities like S.T.E.A.M. Living-Learning Communities in Ghana. The lack of exploration not only impedes the development of creative, cultural, and sustainable solutions but also constrains educational and experiential opportunities for students engaged in S.T.E.A.M. education. Therefore, an in-depth examination of the feasibility and benefits of incorporating biomimicry principles into S.T.E.A.M. living-learning communities in Ghana becomes imperative, offering innovative avenues to address pressing challenges and cultivate a holistic learning environment. As an integral part of this academic inquiry, participants will be queried about their background. Participation in this study is entirely voluntary, and any personal information disclosed will be treated confidentially and utilized solely for academic purposes. We appreciate your time and cooperation.

For further clarification on this matter, please reach out to Michael Mawuena Baccah at 0245545057 or via baccahmike@gmail.com

APPENDIX 2: SAMPLE OF INTERVIEWS AND QUESTIONNAIRES

INTERVIEW GUIDE FOR MUNICIPAL AUTHORITY / GES

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF ART AND BUILT ENVIRONMENT

DEPARTMENT OF ARCHITECTURE

By: Michael Mawuena Baccah Supervisor: Dr. Ing. Alexander Boakye Marful

This interview is designed to aid the researcher in data collection towards providing a better understanding of the topic "Exploring the Potential of Biomimicry for S.T.E.A.M. Living-Learning Communities in Ghana: The Case of Kyebi, Design of a Living-Learning Community S.T.E.A.M. Hub" in order to ascertain the impacts and challenges of implementing biomimicry architecture for the design of a Living-Learning Community S.T.E.A.M. Hub in Kyebi and how the implementation can help enhance the cultural significance of Art in S.T.E.A.M. education and sustainable development.

Your kind co-operation is much needed and any information given will be handled with confidentiality.

SECTION A: Background Information

1. What is your position at the Municipal? ……

2. How long have you been doing this job? ……...

a. Less than 5yrs [ ] b. 6 to 10yrs [ ] c. 11 to 15yrs [ ] d. 16 to 20yrs[ ] e. over 20yrs[ ]

SECTION B: Current State of S.T.E.A.M. Education

3. Kindly give a brief description of S.T.E.A.M. education in Kyebi.

……

……

4. In what ways does the ministry support or promote S.T.E.A.M. education in Kyebi?

……

……

5. What benefits do the community derive as a result of the development of S.T.E.A.M. education in Kyebi?

a. Enhanced Education [ ] b. Career Readiness [ ] c. Community Development [ ]

d. Innovation/Entrepreneurship [ ] e. Inclusive Education [ ] f. Cultural Enrichment [ ]

SECTION C: Challenges and Measures of S.T.E.A.M. Education in Kyebi

6. What are the challenges facing S.T.E.A.M. education in Kyebi?

a. Infrastructure/Resource Limitations [ ] b. Teacher Training/Capacity Building [ ]

c. Curriculum Alignment/Integration [ ] d. Community Engagement and Support [ ]

e. Socioeconomic Disparities [ ] f. Sustainability and Long-term Funding [ ]

7. What measures have been put in place by government?

a. Ensure easy access to S.T.E.A.M. education (in terms of funding and scholarships)

c. Promote awareness on the importance of Art education in Kyebi

d. Protect the cultural heritage of Kyebi through education

d. Provide infrastructure and facilities needed for the promotion of S.T.E.A.M. education in the area

g. Others, please specify……

8. Is there any form of assistance or funds set aside to promote S.T.E.A.M. education?

Yes [ ] No [ ]

3a. If yes, specify…….

9. What are some strategies or measures you think are needed to improve S.T.E.A.M. education in Kyebi?

……

……

10. Do you have any other comments or suggestions?

……

THANK YOU FOR YOUR TIME

INTERVIEW GUIDE – AKYEM ABUAKWA TRADITIONAL COUNCIL

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
COLLEGE OF ART AND BUILT ENVIRONMENT
DEPARTMENT OF ARCHITECTURE

By: Michael Mawuena Baccah Supervisor: Dr. Ing. Alexander Boakye Marful

This interview is designed to aid the researcher in data collection towards providing a better understanding of the topic "Exploring the Potential of Biomimicry for S.T.E.A.M. Living-Learning Communities in Ghana: The Case of Kyebi, Design of a Living-Learning Community S.T.E.A.M. Hub" in order to ascertain the impacts and challenges of implementing biomimicry architecture for the design of a Living-Learning Community S.T.E.A.M. Hub in Kyebi and how the implementation can help enhance the cultural significance of Art in S.T.E.A.M. education and sustainable development.

Your kind co-operation is much needed and any information given will be handled with confidentiality.

---

1. How important is the role of culture in education within the context of Kyebi?

……

……

2. What are some challenges pertaining to S.T.E.A.M. education in the community?

……

……

3. What role does the traditional council play in running of affairs relating to Culture and education in this community?

……

……

VI. Living-Learning Community S.T.E.A.M. Hub in Kyebi

This research's aim is to design a Living-Learning Community S.T.E.A.M. Hub for Kyebi,

4. What are your thoughts on a Living-Learning Community S.T.E.A.M. Hub in Kyebi?

……

……

5. Programs and activities to be include into the S.T.E.A.M. Hub

For each statement, please indicate the extent to which you agree or disagree using the scale: **1=Strongly Disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly Agree**

	1	**2**	**3**	**4**	**5**
a. Technical and Vocational training	☐	☐	☐	☐	☐
b. S.T.E.A.M. Teacher Development Programs	☐	☐	☐	☐	☐
c. STEAM Summer Camps (all levels of education)	☐	☐	☐	☐	☐
d. Cultural Training Programs	☐	☐	☐	☐	☐
e. Art and Science Workshops	☐	☐	☐	☐	☐
f. Community Arts Projects	☐	☐	☐	☐	☐
g. STEM-Inspired Art Exhibitions	☐	☐	☐	☐	☐
h. STEAM Challenges and Exhibitions	☐	☐	☐	☐	☐
i. Coding and Robotics Club	☐	☐	☐	☐	☐

6. Any other comments or suggestions?

……

…..……..……...

THANK YOU FOR YOUR TIME

INTERVIEW GUIDE FOR S.T.E.A.M. EDUCATORS IN KYEBI

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
COLLEGE OF ART AND BUILT ENVIRONMENT
DEPARTMENT OF ARCHITECTURE
By: Michael Mawuena Baccah Supervisor: Dr. Ing. Alexander Boakye Marful

This interview is designed to aid the researcher in data collection towards providing a better understanding of the topic "Exploring the Potential of Biomimicry for S.T.E.A.M. Living-Learning Communities in Ghana: The Case of Kyebi, Design of a Living-Learning Community S.T.E.A.M. Hub" in order to ascertain the impacts and challenges of implementing biomimicry architecture for the design of a Living-Learning Community S.T.E.A.M. Hub in Kyebi and how the implementation can help enhance the cultural significance of Art in S.T.E.A.M. education and sustainable development.

Your kind co-operation is much needed and any information given will be handled with confidentiality.

SECTION A: Background Information

1. Age range:

a. Below 25 [ ] b. 25 to 40 [ ] c. 41 to 60 [ ] d. Over 60 [ ]

2. Level of education:

a. Diploma [ ] b. Degree [ ] c. Masters [ ] d. Doctorate Degree [ ]

e. Other, specify …….

3. Are you a native of Kyebi? a. Yes [ ] b. No [ ]

3a. If yes, how long have you stayed in this community?

…….

4. S.T.E.A.M. field of specialty

a. Science [ ] b. Technology [ ] c. Engineering [ ] d. Art [ ] e. Mathematics

5. which level of education do you teach at?

a. Primary [ ] b. J.H.S. [ ] c. S.H.S [ ] d. Vocational/Technical [ ] e. Tertiary [ ]

f. Other,

specify……...

6. How long have you been teaching a S.T.E.A.M. related course?

a. Below 5yrs [ ] b. 5 to 10yrs [ ] c. 11 to 20yrs [ ] d. Over 20yrs [ ]

7. Kindly state the name of the institution you belong to

SECTION B: Rate your level of familiarity with the Various Concepts.

8. For each statement, please indicate your level of familiarity using the scale: **1=Not familiar at all 2=Slightly familiar 3=Moderately Familiar 4= Very Familiar 5=Extremely familiar**

	1	2	3	4	5
a. The concept of S.T.E.A.M. education	☐	☐	☐	☐	☐
b. Living-Learning Communities Programs	☐	☐	☐	☐	☐
c. Biomimicry Architecture (Nature-Inspired Design)	☐	☐	☐	☐	☐

SECTION C: Current State of S.T.E.A.M. education

9. How has the teaching experience been like?

10. What facilities are available at your institution to assist in the teaching of your program?

……..

11. How many Students are you currently handling?

……

12. Are they all local residents of Kyebi? a. Yes [ ] b. No [ ]

13. Is there any special form of training or workshop done for teachers in your institution?

a. Yes [ ] b. No [ ]

14a. If yes, what is the goal for the training?

……...……

……

15. Are there any social or cultural activities integrated in the teaching process?

a. Yes [ ] b. No [ ]

16a. If yes, what are some of these activities?

……

17. Could art be integrated into your program to enhance the cultural significance?

a. Yes [ ] b. No [ ]

17b. If yes, how can this be made possible?

……

SECTION C: Significance of S.T.E.A.M. education in Ghana

18. For each statement, please indicate the extent to which you agree or disagree using the scale: **1=Strongly Disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly Agree**

	1	2	3	4	5
a. fosters creativity and Innovation	☐	☐	☐	☐	☐
b. Bridges STEM and Arts	☐	☐	☐	☐	☐
c. Prepare Students for Diverse Career Paths	☐	☐	☐	☐	☐
d. Enhance Student Engagement	☐	☐	☐	☐	☐
e. Promote Visual and Verbal Expression	☐	☐	☐	☐	☐
f. Encourage Interdisciplinary Project-Based Learning	☐	☐	☐	☐	☐
g. Integrate and encourage the Exploration and Expression of Cultural Elements in teaching	☐	☐	☐	☐	☐

II. Neglect of S.T.E.A.M. education

19. There is a neglect for the potentials of the Concept S.T.E.A.M. Education and the relevance of Art related courses and their Cultural significance due to ...

	1	2	3	4	5
a. Lack of awareness of S.T.E.A.M. education in Ghana	☐	☐	☐	☐	☐
b. The lack of effectiveness in integrating the concept across the different levels of the education system.	☐	☐	☐	☐	☐
c. Lack of professional development opportunities for educators in the field	☐	☐	☐	☐	☐
d. Limited resources (Financial, Infrastructure)	☐	☐	☐	☐	☐

SECTION E: Challenges facing S.T.E.A.M. education and Mitigation Measures

20. What are some challenges facing the improvement of your course?

a. Infrastructure/Resource Limitations. [ ] b. Teacher Training/Capacity Building [ ]

c. Curriculum Alignment/Integration. [ ] d. Community Engagement and Support [ ]

e. Socioeconomic Disparities. [ ] f. Sustainability and Long-term Funding [ ]

21. Has there been attempt to find solutions to these challenges?

a. Yes [ ] b. No [ ]

21a. If yes, what progress have been made?

……

…….

SECTION F: Incorporation of Living-Learning Community Concept into S.T.E.A.M

For each statement, please indicate the extent to which you agree or disagree using the scale: **1=Strongly Disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly Agree**

22. The concept of educators and students living and studying together in a Living-Learning Community (LLC) will enhance S.T.E.A.M. education by

	1	2	3	4	5
a. Foster collaboration among students and educators	☐	☐	☐	☐	☐
b. Encourage interdisciplinary projects and research.	☐	☐	☐	☐	☐
c. Promote creativity and innovation through diverse perspectives.	☐	☐	☐	☐	☐
d. Enable the integration of arts and cultural perspectives into S.T.E.A.M. education through collaborative projects and discussions.	☐	☐	☐	☐	☐

Any other comments or suggestions?

……

……

……

VI. Living-Learning Community S.T.E.A.M. Hub in Kyebi

23. What are your thoughts on a Living-Learning Community S.T.E.A.M. Hub in Kyebi?

……

24. Programs and activities to be include into the S.T.E.A.M. Hub

For each statement, please indicate the extent to which you agree or disagree using the scale: **1=Strongly Disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly Agree**

	1	2	3	4	5
a. Technical and Vocational training	☐	☐	☐	☐	☐
b. S.T.E.A.M. Teacher Development Programs	☐	☐	☐	☐	☐
c. STEAM Summer Camps (all levels of education)	☐	☐	☐	☐	☐
d. Cultural Training Programs	☐	☐	☐	☐	☐
e. Art and Science Workshops	☐	☐	☐	☐	☐
f. Community Arts Projects	☐	☐	☐	☐	☐
g. STEM-Inspired Art Exhibitions	☐	☐	☐	☐	☐
h. STEAM Challenges and Exhibitions	☐	☐	☐	☐	☐
i. Coding and Robotics Club	☐	☐	☐	☐	☐

25. Any other comments or suggestions?

……

……

THANK YOU FOR YOUR TIME

INTERVIEW GUIDE FOR S.T.E.A.M. ADVOCATES

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
COLLEGE OF ART AND BUILT ENVIRONMENT
DEPARTMENT OF ARCHITECTURE
By: Michael Mawuena Baccah Supervisor: Dr. Ing. Alexander Boakye Marful

This interview is designed to aid the researcher in data collection towards providing a better understanding of the topic "Exploring the Potential of Biomimicry for S.T.E.A.M. Living-Learning Communities in Ghana: The Case of Kyebi, Design of a Living-Learning Community S.T.E.A.M. Hub" in order to ascertain the impacts and challenges of implementing biomimicry architecture for the design of a Living-Learning Community S.T.E.A.M. Hub in Kyebi and how the implementation can help enhance the cultural significance of Art in S.T.E.A.M. education and sustainable development.

Your kind co-operation is much needed and any information given will be handled with confidentiality.

SECTION A: Background Information

1. Age range:

a. Below 25 [ ] b. 25 to 40 [ ] c. 41 to 60 [ ] d. Over 60 [ ]

2. Level of education:

a. Diploma [ ] b. Degree [ ] c. Masters [ ] d. Doctorate Degree [ ]

e. Other, specify……..

3. What is the name of the institution you belong to?

…….

SECTION B: Current State of S.T.E.A.M. education

4. Can you provide an overview of your involvement or advocacy in the field of S.T.E.A.M. education in Ghana …….

…….

5. What is the current condition of S.T.E.A.M. education in Ghana.

…….

…….

6. How best can S.T.E.A.M. education in Ghana be promoted?

……....

……..……

7. What facilities are needed to assist in the teaching of S.T.E.A.M. programs?

…….

…….

8. Is there any special form of training or workshop done for teachers by your institution?

a. Yes [ ] b. No [ ]

8a. If yes, what is the goal for the training?

…….

…….

SECTION C: Cultural significance of Art in S.T.E.A.M. education

9. How do you perceive the cultural significance of Art within S.T.E.A.M. education in Ghana?

……....

…….

10. Can you share any experiences or examples where the integration of art has positively impacted S.T.E.A.M. education in a cultural context?

…….

……..……

11. What are some cultural activities that can be integrated in S.T.E.A.M. education in Ghana?

…….

……..……...

SECTION D: Incorporation of Living-Learning Community Concept into S.T.E.A.M

12. Can you share your perspective on the concept of Living-Learning Communities (LLCs) and their role in fostering collaborative and immersive educational experiences?

……

…..……

13. In your experience, what elements might contribute to the success of a Living-Learning Community, especially in the context of S.T.E.A.M. education?

……

…..……

14. In the context of Ghana, what cultural aspects should be taken into account when planning and implementing a Living-Learning Community?

……

…..……

15. How can a Living-Learning Community contribute to the holistic development of individuals within the S.T.E.A.M. fields?

……

…..……

SECTION E: Implementation Impact Assessment

16. What, in your view, could be the potential impacts of implementing biomimicry architecture in a Living-Learning Community S.T.E.A.M. Hub in Ghana?

……

……

17. Are there any concerns or considerations related to the cultural aspects that should be taken into account during the implementation of biomimicry design for S.T.E.A.M. education?

……

…..……

18. How can the incorporation of biomimicry in the design of a Living-Learning Community S.T.E.A.M. Hub enhance the sense of community and collaboration among students and educators?

……...…

…….……...……

19. Any other comments or suggestions?

INTERVIEW GUIDE FOR BUILT ENVIRONMENT PROFESSIONALS

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
COLLEGE OF ART AND BUILT ENVIRONMENT
DEPARTMENT OF ARCHITECTURE
By: Michael Mawuena Baccah Supervisor: Dr. Ing. Alexander Boakye Marful

This interview is designed to aid the researcher in data collection towards providing a better understanding of the topic "Exploring the Potential of Biomimicry for S.T.E.A.M. Living-Learning Communities in Ghana: The Case of Kyebi, Design of a Living-Learning Community S.T.E.A.M. Hub" in order to ascertain the impacts and challenges of implementing biomimicry architecture for the design of a Living-Learning Community S.T.E.A.M. Hub in Kyebi and how the implementation can help enhance the cultural significance of Art in S.T.E.A.M. education and sustainable development.

Your kind co-operation is much needed and any information given will be handled with confidentiality.

SECTION A: Background Information

1. Level of education:

a. Bachelor's degree [ ] b. Master's degree [ ] c. Doctorate degree [ ]

d. Other, specify……..

2. What is your profession?

a. Architect [ ] b. Urban planner [ ] c. Building Construction Specialist [ ]

d. Engineer [ ] e. Environmental Designer f. Other, specify……

3. How long have you been practicing?

a. Below 5yrs [ ] b. 5 to 10yrs [ ] c. 11 to 20yrs [ ] d. Over 20yrs [ ]

SECTION B: Incorporation of Living-Learning Community Concept into S.T.E.A.M

4. Can you share your perspective on the concept of Living-Learning Communities (LLCs) and their role in fostering collaborative and immersive educational experiences?

……

…..……

5. In the context of Ghana, what cultural aspects should be taken into account when designing for a Living-Learning Community?

……

…..……

6. How can a Living-Learning Community contribute to the holistic development of individuals within the S.T.E.A.M. fields?

…….

…..……

7. How can the physical design of a space contribute to a sense of community and collaborative learning?

…….

…….

SECTION C: Biomimicry for a S.T.E.A.M. Living-Learning Community Design

I. Biomimicry in Design:

8. How familiar are you with the concept of biomimicry, especially in the context of architecture and design? …….

…….

9. From your experience, how might biomimicry principles be integrated into the design of a Living-Learning Community S.T.E.A.M. Hub?

…….

…….

10. Are there particular biomimetic strategies or technologies you find promising for educational spaces?

…….

…….

II. Cultural Considerations:

11. Are there any concerns or considerations related to the cultural aspects of Kyebi that should be taken into account during the implementation of biomimicry design for S.T.E.A.M. education?

…….

..……...

12. How can biomimicry contribute to creating culturally sensitive and inclusive built environments?

…….

…….

III. Challenges and Opportunities:

13. Are there specific opportunities or advantages that biomimicry may offer in this context?

…….

…….

14. What challenges do you foresee in implementing biomimicry in the design of educational spaces, particularly in a community like Kyebi?

…….

…….

14a. In your professional opinion, what measures can you recommend to mitigate these challenges?

……...

……

V. Sustainability Aspects:

15. How can biomimicry contribute to sustainable practices in the design and construction of educational facilities?

…….

…….

16. Are there particular environmental or energy-related considerations that biomimicry can address effectively?

…….

…….

VI. Community Engagement:

17. From your perspective, how important is community engagement in the design and implementation of educational projects, especially in a cultural context like Kyebi?

…….

…….

18. Can you share experiences where community input significantly influenced the success of a project?

…….

…….

VII. Future Trends and Recommendations:

19. What trends do you foresee in the integration of biomimicry in the future of architectural and educational design?

…….

…….

20. Based on your expertise, what recommendations would you provide for successfully incorporating biomimicry into a Living-Learning Community S.T.E.A.M. Hub in Kyebi?

…….

…….

21. Any other comments or suggestions?

…….

THANK YOU FOR YOUR TIME

SELF-ADMINISTERED QUESTIONNAIRE
BIOMIMICRY ARCHITECTURE FOR S.T.E.A.M LIVING-LEARNING COMMUNITIES SURVEY QUESTIONNAIRE

These questionnaires are part of the prerequisites for completing a Master of Architecture degree at the Department of Architecture, Kwame Nkrumah University of Science and Technology, Kumasi. I would be grateful if you could take a few moments out of your busy schedule to answer to the following questions to enable me to write on the stated topic. This research aims to explore the potential of biomimicry architecture for the design of S.T.E.A.M. Living-Learning Communities in Ghana.

For this research, the following terminologies have been defined:

Biomimicry Architecture Biomimicry in architecture involves using nature-inspired principles for designing sustainable and efficient built environments, drawing inspiration from natural forms, systems, and processes.

S.T.E.A.M stands for Science, Technology, Engineering, Arts, and Mathematics and is an interdisciplinary approach that integrates these disciplines to promote creativity, cultural significance, problem-solving, and innovation in education and various fields.

Living-Learning Communities (LLCs) are residential spaces that bring together students and tutors with common academic interests or goals, fostering a collaborative and immersive learning environment within a shared living space.

Participation in this study is entirely voluntary, and any personal information provided will be kept confidential and used solely for academic purposes.

Your participation in this study could aid in determining the potential of Biomimicry architecture for S.T.E.A.M. Living-Learning Communities in Kyebi, as well as provide a foundation of information for the initiation of similar future developments in Ghana. Thank you so much for your time and effort.

For more clarification concerning this request, please contact:

Michael Mawuena Baccah
+233 (0) 24 554 5057
Gmail: baccahmike@gmail.com

PART 1: DEMOGRAPHIC BACKGROUND

This section aims to acquire background information about the participants and establish whether the participants have an experience in the topic being discussed.

1. What is your gender?

[ ] Female [ ] Male

2. Which category do you belong to?

[ ] Resident of Kyebi [ ] Educator [ ] KNUST Student [ ] STEAM Advocate

2a. If a resident of Kyebi, specify your level of education

a. J.H.S. [ ] b. S.H.S [ ] c. Vocational/Technical [ ] d. Tertiary [ ] e. Teacher Training [ ]

f. Educator [ ] g. Other, specify ……

2b. If a professional in the built environment, specify your profession

a. Architect [ ] b. Urban planner [ ] c. Building Construction Specialist [ ] d . Engineer [ ] e. Environmental Designer [ ] f. Other, specify……

2c. If a KNUST student, specify your faculty

[ ] Faculty of Built Environment

[ ] Faculty of Educational Studies (FES)

[ ] Faculty of Arts

[ ] Faculty of Civil and Geo-Engineering

[ ] Faculty of Mechanical and Chemical Engineering

[ ] Faculty of Electrical and Computer Engineering

[ ] Faculty of Allied Health Sciences

[ ] School of Medicine and Dentistry

Other,

specify……

SECTION B: Participants knowledge on the topics

For each statement, please indicate your level of familiarity using the scale: **1=Not familiar at all 2=Slightly familiar 3=Moderately Familiar 4= Very Familiar 5=Extremely familiar**

3. How familiar are you with the following concepts?

	1	2	3	4	5
a. The concept of S.T.E.A.M. education	☐	☐	☐	☐	☐
b. Living-Learning Communities Programs	☐	☐	☐	☐	☐
c. Biomimicry Architecture (Nature-Inspired Design)	☐	☐	☐	☐	☐

PART 2: S.T.E.A.M. EDUCATION AND ITS CULTURAL SIGNIFICANCE IN GHANA

This section aims to identify the current state of S.T.E.A.M. education and its cultural significance in Ghana. Read statements and check the one answer that best represents your opinion.

4. For each statement, please indicate the extent to which you agree or disagree using the scale: **1=Strongly Disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly Agre**

	1	2	3	4	5
a. fosters creativity and Innovation	☐	☐	☐	☐	☐
b. Bridges STEM and Arts	☐	☐	☐	☐	☐
c. Prepare Students for Diverse Career Paths	☐	☐	☐	☐	☐
d. Enhance Student Engagement	☐	☐	☐	☐	☐
e. Promote Visual and Verbal Expression	☐	☐	☐	☐	☐
f. Encourage Interdisciplinary Project-Based Learning	☐	☐	☐	☐	☐
g. Integrate and encourage the Exploration and Expression of Cultural Elements in teaching	☐	☐	☐	☐	☐

II. Neglect of S.T.E.A.M. education

5. There is a neglect for the potentials of the Concept S.T.E.A.M. Education and the relevance of Art related courses and their Cultural significance due to ...

	1	2	3	4	5
a. Lack of awareness of S.T.E.A.M. education in Ghana	☐	☐	☐	☐	☐
b. The lack of effectiveness in integrating the concept across the different levels of the education system.	☐	☐	☐	☐	☐
c. Lack of professional development opportunities for educators in the field	☐	☐	☐	☐	☐
d. Limited resources (Financial, Infrastructure)	☐	☐	☐	☐	☐

PART 3: POTENTIAL OF BIOMIMICRY FOR S.T.E.A.M. LIVING-LEARNING COMMUNITIES IN GHANA

This section aims to investigate the perspectives of educators, professionals, students, and community members on the potential of biomimicry in S.T.E.A.M. living-learning communities in Ghana.

Section A: Living-Learning Communities for S.T.E.A.M.

For each statement, please indicate the extent to which you agree or disagree using the scale: **1=Strongly Disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly Agree**

6. The concept of educators and students living and studying together in a Living-Learning Community (LLC) will enhance S.T.E.A.M. education by

	1	2	3	4	5
a. Foster collaboration among students and educators	☐	☐	☐	☐	☐
b. Encourage interdisciplinary projects and research.	☐	☐	☐	☐	☐
c. Promote creativity and innovation through diverse perspectives.	☐	☐	☐	☐	☐
d. Facilitate hands-on learning experiences within a supportive community.	☐	☐	☐	☐	☐
e. Provide opportunities for peer mentoring and tutoring across S.T.E.A.M. fields.	☐	☐	☐	☐	☐
f. Cultivate a sense of belonging and shared purpose among learners interested in S.T.E.A.M. disciplines.	☐	☐	☐	☐	☐
g. Enable the integration of arts and cultural perspectives into S.T.E.A.M. education through collaborative projects and discussions.	☐	☐	☐	☐	☐

7. What are some possible challenges and barriers in creating a S.T.E.A.M. Living-Learning Community

	1	2	3	4	5
a. Difficulty Integrating Academic and Residential Life	☐	☐	☐	☐	☐
b. Adapting to Changing Student Interests	☐	☐	☐	☐	☐
c. Faculty and Staff Turnover	☐	☐	☐	☐	☐
d. Balancing Academic and Social Needs	☐	☐	☐	☐	☐
e. Addressing Issues of Low Participation	☐	☐	☐	☐	☐
f. Implementing Effective Conflict Resolution Strategies	☐	☐	☐	☐	☐
g. Maximizing Impact with Limited Resources	☐	☐	☐	☐	☐

Section B: Biomimetic Design for Living-Learning Community S.T.E.A.M. Hub

Read statements and check the one answer that best represents your opinion in relation to the impact biomimicry architecture will have on the design of a Living-Learning Community S.T.E.A.M. Hub.

For each statement, please indicate the extent to which you agree or disagree using the scale: **1=Strongly Disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly Agree**

8. Impacts Biomimicry Architecture will have on the design of a Living-Learning Community S.T.E.A.M. Hub

Biomimicry Architecture will...

	1	2	3	4	5
a. Positively impact the design and functionality of learning spaces.	☐	☐	☐	☐	☐
b. Influences students' interest and participation in S.T.E.A.M. education.	☐	☐	☐	☐	☐
c. Foster a sense of environmental responsibility among students.	☐	☐	☐	☐	☐
d. Create a collaborative opportunity between educational institutions and built environment professionals	☐	☐	☐	☐	☐
e. Contribute to the overall wellbeing and Cultural identity of the community.	☐	☐	☐	☐	☐
f. Contribute to sustainable practices in the design and construction of educational facilities	☐	☐	☐	☐	☐

PART 4. LIVING-LEARNING COMMUNITY S.T.E.A.M. HUB IN KYEBI

9. Programs and activities to be include into the S.T.E.A.M. Hub

For each statement, please indicate the extent to which you agree or disagree using the scale: **1=Strongly Disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly Agree**

	1	**2**	**3**	**4**	**5**
a. Technical and Vocational training (Certificate/Diploma)	☐	☐	☐	☐	☐
b. S.T.E.A.M. Teacher Development Programs	☐	☐	☐	☐	☐
c. STEAM Summer Camps (all levels of education)	☐	☐	☐	☐	☐
d. Cultural Training Programs	☐	☐	☐	☐	☐
e. Art and Science Workshops	☐	☐	☐	☐	☐
f. Community Arts Projects	☐	☐	☐	☐	☐
g. STEM-Inspired Art Exhibitions	☐	☐	☐	☐	☐
h. STEAM Challenges and Exhibitions	☐	☐	☐	☐	☐
i. Coding and Robotics Club	☐	☐	☐	☐	☐

THANK YOU FOR YOUR TIME

APPENDIX 3: OBSERVATION GUIDE FOR CASE STUDIES

(BIOMIMICRY ARCHITECTURE, LIVING-LEARNING COMMUNITIES AND S.T.E.A.M. EDUCATIONAL FACILITIES)

Objective 4: To apply the concept of biomimicry to design a sustainable Living-Learning Community S.T.E.A.M. Hub in Kyebi.

Data	Remarks	√ **or** ×
Accessibility		☐ ☐ ☐ ☐ ☐
Landscape		☐ ☐ ☐ ☐ ☐
Preservation of natural environment		☐ ☐ ☐ ☐ ☐
Spaces		☐ ☐ ☐ ☐ ☐
Biomimetic Approaches		☐ ☐ ☐ ☐ ☐
Biomimicry Level		☐ ☐ ☐ ☐ ☐
Biomimicry Principle		☐ ☐ ☐ ☐ ☐
Environmental/Sustainable Impacts		☐ ☐ ☐ ☐ ☐
Sustainable Building Materials		☐ ☐ ☐ ☐ ☐
Maintenance		☐ ☐ ☐ ☐ ☐
Security		☐ ☐ ☐ ☐ ☐
Technology Integration		☐ ☐ ☐ ☐ ☐

APPENDIX 4: STATE OF COMMUNITY REPORT GUIDE

(KYEBI)

1. Maps and Images
    - Base maps of Kyebi
    - Aerial photographs (google maps)
    - GIS map layers
2. Natural Environment
    - Climate
    - Topography
    - Soil
    - Ecology (Biodiversity)
    - Water features
    - Habitat Area
3. Exiting Land uses
    - Residential
    - Commercial
    - Industrial
    - Educational
    - Institutional
    - Open spaces
    - Vacant urban lands
    - Farmlands
4. Housing
    - Housing types
    - Roof types
    - Skyline
    - Energy Sources
    - Maintenance culture

5. Transportation (Routes)
    - Street network
    - Steet Capacity
    - State of transport network
    - Mode of transportation

- Parking Supply and Demands
- Pedestrian Networks

6. Public utilities
    - Water supply
    - Electricity Supply
    - Wastewater disposal
    - Storm water management
    - Solid waste management
    - Telecommunication services
7. Community services
    - Administrative centers
    - Education facilities
    - Parks and recreation facilities
    - Health services
    - Public safety facilities
8. Population and Employment
    - Population size
    - Population characteristics
    - Labor force characteristics
9. Local Economy
    - Employment
    - Cost of living
10. Special Topics
    - History and Culture
    - S.T.E.A.M. education
    - Biodiversity of Kyebi
    - Patterns, Texture, and Grains

APPENDIX 5: RELEVANT INFORMATION ON THE SITE

Kyebi is the capital of the state of Akyem Abuakwa as well as the seat of the Abuakwa South Municipal Assembly, which serves Ghana's eastern region (Figure 1.2). It is a mineral-rich town located in the Atiwa mountain range at an elevation of 318m, with a population of approximately 12,000 people in 2013. The Abuakwa South Municipality has a total population of approximately 168,000 people (Ghana Statistical Service, 2012).



Figure 0.1 The Map of Kyebi (Source: SPAYSIS, 2019)