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Exploring the Necessity of Technology In Architectural Design: Moving Beyond Showcasing

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EXPLORING THE NECESSITY OF TECHNOLOGY IN ARCHITECTURAL DESIGN: MOVING BEYOND SHOWCASING

A Thesis
Presented to
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In Partial Fulfillment
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Master of Science
Architecture

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by
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ABSTRACT

Advancements in technology, particularly computational design tools, have transformed the field of architectural design. However, it is crucial to evaluate the impact of technology on the core principles of problem-solving and the design process within architecture. This study aims to examine the consequences and opportunities associated with the integration of technology in architectural design, focusing on the necessity of maintaining a strong problem-solving foundation. Architectural problem-solving involves spatial organization, functional requirements, contextual integration, and user experience. These principles guide architects in addressing design challenges and achieving successful outcomes. The design process comprises stages such as research, analysis, concept development, and construction documentation. Understanding these principles and the design process is essential for assessing the impact of technology. By investigating the effects of technology on construction, parametric modeling, digital fabrication, and environmental analysis, this research analyzes how technology can enhance or hinder the problem-solving process. It explores cases where architects may become overly reliant on computational design software, leading to a prioritization of form generation based on algorithms rather than contextual and user needs.

The study examines the influence of technology on efficiency, creativity, and contextual responsiveness in problem-solving, providing insights into the role and implications of technology in architectural design. Through case studies, it explores historical and contemporary practices to contribute to the understanding of balancing technological advancements with problem-solving requirements. The research addresses several key questions, including the effects of technology on problem-solving principles, the potential neglect of essential aspects in favor of aesthetic appeal and fabrication novelty, and strategies for evaluating the appropriateness of technology in design processes. The findings highlight the importance of maintaining a balanced approach where technology serves as an enabler rather than a distraction or substitute for thoughtful design thinking.

This research focuses on the intersection of technology and architectural design, evaluating the consequences and challenges of technology integration. It emphasizes the necessity of technology supporting problem-solving principles and provides insights into effectively utilizing technology in architectural design. By maintaining a strong problem-solving foundation, architects can harness the potential of computational design to create impactful and meaningful architectural solutions.

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INTRODUCTION

Background And Context of The Study

Architectural design is a dynamic field that constantly evolves in response to societal, technological, and cultural shifts. Over the years, advancements in technology have played a pivotal role in shaping the way architects approach design, construction, and problem-solving. The integration of technology, particularly computational design tools, has opened new possibilities for innovation and efficiency in the architectural design process.

The rapid progress in computational design has introduced a wide range of tools and techniques that facilitate complex calculations, data analysis, visualization, and automation. From robotic arms and parametric modeling to digital fabrication and environmental analysis, these technologies have transformed the way architects conceptualize and materialize their designs. However, in order to assess the impact of these technological advancements, it is crucial to define the core principles of problem-solving and the design process within the field of architecture.

Problem solving, in general, is the process of finding solutions to complex or challenging issues or situations. It involves identifying a problem, gathering relevant information, analyzing the situation, and developing and implementing effective strategies to reach a desired outcome or resolution. Problem-solving in architectural design encompasses a range of fundamental principles, such as spatial organization, functional requirements, contextual integration, and user experience. These principles guide architects in identifying and addressing design challenges, and they play a crucial role in achieving successful architectural outcomes (Chan, 1990). These principles guide architects in identifying and addressing design challenges, ensuring that the solutions meet the needs of the users and respond harmoniously to the surrounding context.

The design process in architecture follows a systematic approach that integrates these principles. It involves defining the problem by understanding client requirements, conducting thorough research and analysis, and generating design concepts through ideation and conceptualization. Architects then develop the selected concepts into detailed designs, considering technical and functional aspects while refining aesthetics. Evaluation and testing of the design ensure its effectiveness and alignment with user needs and project goals. Once validated, the design moves into the implementation phase, where construction documents are prepared, bidding and negotiation take place, and architects provide on-site administration to ensure proper execution.

In this ever-evolving architectural landscape, the integration of computational design tools within the design process amplifies architects' capabilities to explore innovative solutions and optimize design outcomes. It enhances the efficiency, accuracy, and sustainability of architectural design, ultimately contributing to the creation of inspiring and impactful built environments (Parsaee et. al, 2016).

To ensure a comprehensive evaluation, this study will draw upon existing research and scholarship that has explored the core principles of problem-solving and the design process in architectural design. By synthesizing and referencing these studies, we can establish a framework for assessing the impact of technology on these foundational aspects of architectural practice. This will provide a solid foundation for drawing comparisons and deriving meaningful conclusions from the analysis of case studies.

The background and context of this study lie in the concern regarding the potential imbalance, such as an overemphasis, between technology-driven approaches and the essential problem-solving aspects in architectural design. For instance, in some cases, architects and designers may become overly reliant on computational design software and parametric modeling tools, leading to a prioritization of form generation based on algorithmic parameters rather than a deep exploration of contextual and user needs. As architects increasingly adopt advanced technological tools, it is crucial to reflect on the implications of this reliance on the overall design process and the attainment of functional, contextual, and user-centric outcomes. By examining specific instances of this potential imbalance, the study aims to shed light on the challenges and opportunities associated with the integration of technology in architectural design. These instances will serve as examples that illustrate how technology can sometimes overshadow the core problem-solving principles and how architects may prioritize technology showcase over functional and user-centric design outcomes.

The study aims to explore the intersection of technology and architectural design, with a particular emphasis on computational design. By investigating the consequences of the increasing reliance on technology in construction and assembly, parametric modeling for automation, digital fabrication, and environmental analysis and simulations, this research seeks to analyze how technology can either enhance or hinder the core problem-solving process. The problem-solving process within architectural design encompasses stages such as problem identification, analysis, ideation, iteration, and evaluation. By examining how technology influences each of these stages and its impact on the efficiency, creativity, and contextual responsiveness of the problem-solving process, this study aims to provide a nuanced understanding of the role and implications of technology in architectural design.

Through a comprehensive analysis of case studies, this study will examine the potential consequences of technology-driven approaches in architectural projects. The selected case studies will cover a range of projects that have utilized different technological tools and techniques, representing diverse typologies and design challenges. This analysis will provide insights into the historical precedent and ongoing discourse surrounding the balance between technological showcase and design necessity. By studying past examples and contemporary practices, this research aims to contribute to the understanding of how architects can navigate this delicate balance in the context of technological advancements.

By addressing these questions, this study aims to contribute to the understanding of how architects can strike a balance between leveraging technology and maintaining a strong problem-solving foundation. It will explore how technology can be effectively integrated into the design process as an enabler rather than a distraction or substitute for thoughtful design thinking.

The subsequent sections of this thesis will delve into the problem statement and research questions, outlining the significance of the study and the scope and limitations of the research. The analysis of case studies will be presented in detail, followed by a synthesis of the findings and their implications for architectural practice. Ultimately, this study aims to provide valuable insights into the effective utilization of technology in architectural design and foster a more nuanced approach to problem-solving in the field.

Problem Statement and Research Questions

In recent years, the field of architecture has witnessed a remarkable transformation with the increasing integration of technology into the design process. Advancements in computational design have paved the way for new possibilities, enabling architects to explore innovative solutions and streamline complex tasks. However, amidst the growing enthusiasm for technology, it is crucial to critically examine the impact and implications of its integration in architectural design. Are architects and designers becoming overly reliant on technology, compromising the core principles of problem-solving and overshadowing the essence of creative thinking?

The focus of this master's thesis is to explore the intersection of technology and architectural design, with a specific emphasis on the role of computational design. It aims to delve into the dilemmas and challenges that arise when technology becomes a dominant force in the design process. By examining the ways in which computational design tools are utilized and their potential consequences, I seek to develop a framework that ensures technology serves as an enabler rather than a distraction or substitute for thoughtful design thinking.

This thesis sets out to address several fundamental questions that underpin the exploration of technology's role in architectural design:

- How does the increasing reliance on advanced technological tools, such as robotic arms or parametric modeling, impact the core principles of problem-solving and the overall efficiency of architectural projects?
- To what extent do technology-driven approaches, like parametric modeling for automation, influence the problem-solving process in architectural projects and stimulate creative exploration?
- Are architects and designers adequately considering essential problem-solving aspects while demonstrating the capabilities of digital fabrication techniques, or is there a need to achieve a better balance in their approach?
- What are the implications of prioritizing technology-driven solutions in environmental analysis and simulations without thoroughly aligning them with the core problem-solving objectives, and how can the integration of these tools maintain a focus on effective problem-solving?
- How can architects strike a balance between leveraging technology, such as digital fabrication, in construction and assembly, while ensuring it remains a means to effectively address design challenges rather than overshadowing the problem-solving process?
- Can cultivating a critical mindset within architectural education and practice encourage architects to question the excessive reliance on parametric modeling for automation and explore alternative approaches that better align with contextual needs and problem-solving principles?

- How can architects develop a deeper understanding of the limitations and potentials of digital fabrication techniques, allowing them to discern when and how to appropriately integrate them in construction and assembly processes?
- Are there examples of architectural projects where the excessive use of parametric modeling for automation has compromised the holistic problem-solving process, resulting in design outcomes that prioritize the showcase of technology over functional, contextual, and user-centric aspects?
- What strategies or frameworks can be implemented to evaluate the appropriateness and necessity of environmental analysis and simulations, ensuring they serve as tools for effective problem-solving rather than mere superficial displays of data visualization?
- How can the integration of construction and assembly, parametric modeling for automation, digital fabrication, and environmental analysis and simulations be approached to maintain a strong focus on problem-solving, ensuring that technology is utilized as a necessity rather than solely for showcasing purposes?

Through the exploration of these questions, this thesis aims to provide a comprehensive understanding of the benefits, limitations, and potential consequences of employing computational design in architectural practice. By analyzing case studies within the potentials of construction and assembly, parametric modeling for automation, digital fabrication, and environmental analysis and simulations, I will gain insights into the intricate relationship between technology and problem-solving principles. This research will contribute to the development of a framework for the effective integration of technology into the design process, ensuring it remains subservient to the core principles of problem-solving. By striking a balance between technology and design thinking, architects can leverage the transformative power of computational design to create innovative and contextually responsive architectural solutions.

Significance Of Study

The integration of technology into architectural design, particularly through computational design, has revolutionized the practice of architecture. Computational design utilizes advanced computational tools and techniques, such as parametric modeling, algorithmic design, scripting languages, simulation software, and data-driven analysis, to aid in the design process, analysis, and optimization of architectural projects.

This study is significant as it explores the implications of technology-driven approaches within computational design in architectural practice. It critically evaluates the impact of technology integration on the core principles of problem-solving and design thinking. By examining the intersection of technology and computational design, this research provides insights into how architects can effectively leverage technology while maintaining creative problem-solving.

Understanding the relationship between technology and computational design is crucial as it opens new avenues for exploration and innovation in architectural design. Advanced computational tools facilitate complex calculations, data analysis, visualization, and automation, enabling architects to tackle increasingly complex design challenges. These technologies have transformed the way architects conceptualize and materialize their designs, revolutionizing digital fabrication, environmental analysis, and simulation.

However, with the growing adoption of computational design tools, it becomes necessary to reflect on the potential consequences and limitations of excessive reliance on technology. This study delves into the dilemmas and challenges that arise when technology becomes a dominant force in the design process, particularly within computational design. By examining how computational design tools are utilized and their potential consequences, this research develops a framework to ensure technology serves as an enabler rather than a distraction from thoughtful design thinking.

By exploring the relationship between technology and computational design, this study sheds light on how architects can strike a balance between leveraging technology and maintaining the core problem-solving process. It provides insights into how architects can harness the transformative power of computational design while ensuring it remains subservient to the overarching design objectives. The study contributes to a nuanced understanding of the benefits, limitations, and potential consequences of employing computational design in architectural practice.

Moreover, this research addresses the need to critically evaluate the implications of technology-driven approaches in architectural design. It examines the impact of technology on the efficiency and effectiveness of architectural projects, identifying potential pitfalls and challenges that arise when technology becomes a dominant force.

Architects can make informed decisions regarding the integration of technology, ensuring it serves as an enabler rather than a distraction from thoughtful design thinking.

Additionally, the study contributes to the broader discourse on the role of technology in architectural education and practice. By questioning excessive reliance on certain technological tools and techniques, it encourages a critical mindset within the field, fostering a more holistic approach to problem-solving and exploring alternative methods that better align with contextual needs.

In summary, this study's significance lies in its contribution to understanding the implications, challenges, and opportunities presented by the integration of technology in architectural design through computational design. By exploring these dimensions, architects can navigate the complex relationship between technology and problem-solving, leading to more innovative, contextually responsive, and user-centric architectural solutions.

Scope And Limitations

The scope of this study is focused on exploring the intersection of technology and architectural design, with a particular emphasis on computational design. It aims to investigate the consequences and implications of the increasing reliance on technology in architectural projects, specifically in areas such as construction and assembly, parametric modeling for automation, digital fabrication, and environmental analysis and simulations.

To achieve the research objectives, the study will analyze a selection of case studies that represent diverse architectural projects utilizing different technological tools and techniques. These case studies will be chosen based on their relevance to the research questions and their ability to provide insights into the impact of technology on the problem-solving process.

By examining these case studies, the study aims to uncover both the positive and negative consequences of technology-driven approaches in architectural design. It will explore how the increasing reliance on advanced technological tools, such as robotic arms or parametric modeling, in construction and assembly may compromise the core problem-solving principles and the overall efficiency of architectural projects. Additionally, it will examine the effects of excessive use of technology-driven approaches, such as parametric modeling for automation, on the problem-solving process and the potential for creative exploration.

It is important to acknowledge the limitations of this study. Firstly, the vastness of the field and the rapid pace of technological advancements make it impossible to cover all aspects and applications of technology in architectural design comprehensively. The study will focus on specific areas where technology has had a significant impact, but other areas may not be extensively explored.

Secondly, while case studies provide valuable insights, they are limited to specific projects and may not fully represent the entire spectrum of architectural practice. The findings from the case studies should be interpreted within their respective contexts and may not be universally applicable.

Furthermore, the study will rely on existing literature, research, and documented projects to analyze the implications of technology in architectural design. It is important to acknowledge the limitations and biases inherent in the available sources and to critically evaluate the reliability and validity of the information.

Lastly, while the study aims to provide recommendations and frameworks for the effective integration of technology in architectural design, the implementation and success of these recommendations may vary depending on various factors, including project requirements, available resources, and individual design approaches.

Despite these limitations, this study seeks to contribute to a deeper understanding of the role of technology in architectural design and its impact on problem-solving principles. By analyzing case studies and exploring the consequences of technology integration, it aims to provide valuable insights for architects and designers to navigate the complex relationship between technology and design thinking. Building on the historical precedent of technology as a problem-solving tool, this research endeavors to foster a balanced and thoughtful approach to the utilization of technology in architectural design.

BACKGROUND

Definition of technology in architecture and design

In today’s architecture and design, technology plays a fundamental role, encompassing a diverse array of tools, techniques, and processes that revolutionize the creation, analysis, and implementation of architectural projects. Beyond mere materials and conventional instruments, technology in architecture extends to both physical and digital advancements, empowering the field with unprecedented possibilities (Gattupalli, 2023).

Technology in architecture can be defined as the application of scientific knowledge, engineering principles, and innovative methodologies to address design challenges and enhance the efficiency, functionality, and aesthetics of architectural endeavors. It encompasses a wide range of facets, including computational design, digital fabrication, environmental analysis, simulation software, automation, and advanced construction techniques.

Computational design stands at the forefront of technological integration in architecture. By harnessing algorithms, scripting languages, and parametric modeling, architects can generate and manipulate intricate geometries, optimize performance parameters, and explore design potentials (Menges and Ahlquist, 2011). The power of computation enables architects to tackle complex design challenges with precision and efficiency.

Digital fabrication represents another prominent aspect of technology in architecture. It entails the utilization of computer-controlled machines like 3D printers, robotic arms, CNC routers, and laser cutters to fabricate architectural components and assemblies with remarkable accuracy and customization. Digital fabrication serves as a bridge between digital modeling and construction, allowing architects to seamlessly translate their digital designs into physical manifestations (Kolarevic, 2001).

Environmental analysis and simulations serve as invaluable tools within architectural technology, enabling architects to assess the performance and sustainability of their designs. Through advanced software and analytical techniques, architects can simulate and evaluate parameters such as daylighting, energy consumption, thermal performance, and acoustics. These simulations provide crucial insights into the interaction between architectural interventions and the environment, informing design decisions that optimize comfort, energy efficiency, and occupant well-being (Sadeghipour Roudsari et al., 2013).

Moreover, technology in architecture unfolds innovative construction and assembly methods that capitalize on advanced materials, structural systems, and construction techniques. These methods include pre-fabrication, modular construction, robotic construction, and emerging methodologies that bolster construction efficiency, reduce waste, and expand the world of architectural expression.

In essence, technology in architecture and design enhances the integration of scientific knowledge, engineering principles, computational tools, digital fabrication methods, and advanced construction techniques. By leveraging these diverse components, architects can enhance the design process, optimize performance parameters, and push the boundaries of architectural innovation. Computational design, digital fabrication, environmental analysis and simulations, and innovative construction practices collectively drive the evolution and transformation of architectural practice in the modern era.

Role of computational design in architecture and design

Today in architecture and design, computational design emerges as a transformative force that propels innovation and revolutionizes the creative process. By harnessing the immense power of algorithms, scripting languages, and parametric modeling, computational design empowers architects to navigate intricate design challenges with precision and efficiency, while expanding the horizons of creative exploration. At its essence, computational design represents the seamless integration of computational tools and methodologies into the architectural design process, redefining the traditional approach and opening up new avenues for exploration.

A fundamental strength of computational design lies in its ability to conceive and manipulate complex geometries (Kolarevic, 2001). Through the utilization of algorithms, architects are empowered to craft intricate architectural forms that would be arduous, if not impossible, to achieve through traditional design methods alone. This opens a boundless perspective of architectural potential, where structures and spaces manifest as visually captivating compositions that simultaneously uphold functionality and purpose.

Furthermore, computational design facilitates the exploration of diverse design alternatives by establishing a parametric framework (Gallas et al., 2015). Architects are able to define and manipulate a range of parameters, including material properties, environmental conditions, and user preferences, in order to generate multiple design iterations. This iterative approach empowers architects to swiftly test and evaluate various design options, leading to informed decision-making and ultimately enhancing the quality of design outcomes.

Beyond its capabilities in design exploration, computational design plays a pivotal role in performance optimization. By seamlessly integrating simulation and analysis tools, architects gain the ability to comprehensively assess the performance of their designs across numerous parameters (Xuehan et al., 2022). These parameters may include aspects such as daylighting, energy consumption, thermal comfort, and structural integrity. By employing a data-driven approach, architects can fine-tune their designs to achieve elevated levels of performance, sustainability, and user comfort.

Moreover, computational design serves as a catalyst for collaboration and interdisciplinary exchange. Through its digital nature, computational design facilitates seamless communication and knowledge-sharing among architects, engineers, and various stakeholders involved in the design process. This interdisciplinary collaboration fosters the integration of expertise from diverse fields, leading to holistic and well-informed design solutions that encapsulate a comprehensive understanding of the project's requirements.

In the final stage of the design process, computational design aids architects in generating detailed construction documentation. Architects utilize computational tools to create accurate drawings, specifications, and schedules, ensuring consistency and reducing errors. These tools also automate repetitive tasks, streamlining the documentation process and enhancing efficiency during the construction phase. Computational design becomes a valuable asset in translating the design vision into practical instructions for builders and contractors.

Problem-solving in architecture is another domain where computational design plays a crucial role. It starts with the identification of challenges and constraints through computational tools, leveraging data-driven insights and analysis to simulate and assess the impact of design variables on performance parameters. By quantifying and visualizing the implications of design decisions, computational tools help architects identify potential issues that require resolution, enabling effective problem-solving.

By running simulations and visualizing outcomes, architects gain a deeper understanding of the implications of design decisions. This data-driven approach allows for informed choices that address identified problems effectively, resulting in optimized design solutions.

Computational design empowers architects to explore creative design alternatives in problem-solving. By leveraging computational tools, architects can generate innovative solutions, experiment with complex geometries, explore parametric design possibilities, and test unconventional approaches. Computational design enables architects to break free from traditional constraints and discover unique solutions that creatively address problems. This creative exploration nurtures design thinking and fosters innovation in architecture.

Throughout the design process, computational design facilitates iterative refinement. Architects continuously analyze, evaluate, and refine their designs based on feedback and insights gained from computational tools. This iterative approach allows for the development of optimized and well-informed design solutions that effectively address identified problems, elevating the overall quality of architectural outcomes.

Advantages and limitations of computational design in architecture and design

As computational design takes center stage in the realm of architecture and design, it brings forth a multitude of advantages that empower architects to push the boundaries of creativity and innovation. However, it is essential to acknowledge that along with these advantages come certain limitations that warrant careful consideration and thoughtful application.

One of the primary advantages of computational design lies in its ability to enhance design exploration and iteration. By leveraging algorithms and parametric modeling, architects can swiftly generate and evaluate a vast array of design alternatives. This iterative approach allows for the discovery of novel solutions and the refinement of design concepts with a level of precision and efficiency previously unattainable. Through computational design, architects are equipped to explore design possibilities in a dynamic and adaptable manner, ultimately leading to more robust and informed design decisions.

Additionally, computational design empowers architects to optimize performance parameters with greater accuracy and reliability. By integrating simulation and analysis tools into the design process, architects can assess various performance aspects, including energy efficiency, structural integrity, and occupant comfort. This data-driven approach enables architects to fine-tune their designs to achieve optimal outcomes, striking a balance between functionality, sustainability, and user experience. Computational design becomes a valuable tool for architects to align their designs with stringent performance requirements and achieve high levels of quality and efficiency.

Moreover, computational design facilitates the seamless integration of interdisciplinary collaboration. With its digital nature, computational design enables architects, engineers, and other stakeholders to work together in a shared virtual environment. This collaboration promotes a holistic understanding of the project, combining expertise from multiple fields to address complex design challenges. By fostering effective communication and knowledge exchange, computational design promotes a synergistic approach to design, resulting in innovative and well-informed solutions.

However, it is important to acknowledge the limitations of computational design as well. One such limitation is the potential over-reliance on computational tools, which may overshadow the significance of architectural intuition and creativity. While computational design offers powerful capabilities, it is crucial for architects to maintain a balance between data-driven analysis and subjective judgment. Architectural design is an inherently complex and multi-faceted endeavor that cannot be reduced solely to computational algorithms (Derix, 2009). Architects must exercise their expertise and artistic sensibilities to ensure that the human element remains central to the design process.

Another limitation arises from the potential complexity and steep learning curve associated with computational design tools. As a lecturer and continuous learner of these tools, I can say it’s often required specialized skills and training, which may pose a barrier for architects and/or students who are not well-versed in computational methods. Additionally, the reliance on software and hardware infrastructure introduces a degree of technological dependency, which can be a challenge in terms of accessibility, compatibility, and ongoing maintenance.

Despite these limitations, the advantages of computational design in architecture and design far outweigh the challenges. By harnessing the power of algorithms, parametric modeling, and simulation tools, architects gain unprecedented capabilities to explore, optimize, and collaborate. With a mindful approach that balances computational analysis and creative intuition, computational design emerges as a transformative force that reshapes the field of architecture, propelling it towards new horizons of innovation and excellence.

In summary, computational design offers numerous advantages, such as enhanced design exploration, optimized performance parameters, and interdisciplinary collaboration. However, it is important to acknowledge the limitations, including the risk of over-reliance, the complexity of tools, and the need for balancing computational analysis with human judgment. By understanding these advantages and limitations, architects can effectively harness the potential of computational design, paving the way for groundbreaking advancements in the field of architecture and design.

Overview of the four main areas of focus: Construction & Assembly, Parametric Modelling for Automation, Digital Fabrication, and Environmental Analysis & Simulations

In this section, an overview of the four main areas of focus that will be explored in the subsequent chapters will be provided. These areas demonstrate the significant role of computational design in architecture and design. The four main areas are:

- *Construction & Assembly:* This area examines the relationship between technology, computational modeling, and the construction process. Specifically, it explores the integration of holographic projection and extended reality (XR) technologies, such as augmented reality (AR), virtual reality (VR), and mixed reality (MR), to enhance the construction and assembly of architectural structures. By leveraging computational tools, parametric modeling, and digital fabrication, stakeholders are provided with immersive experiences, real-time visualization, and interactive capabilities to facilitate the construction process. This area focuses on advancements in construction methodologies, precision, efficiency, safety, and the potential for exploring complex and innovative architectural designs.

- *Parametric Modelling for Automation:* This area highlights the automation capabilities of computational design within the context of parametric modeling. It explores how technology can assist in automating tedious tasks and calculations in the design process. By incorporating specific design requirements and constraints, parametric modeling tools can monitor and evaluate designs in real-time, allowing designers to make informed decisions and optimize their designs. This area showcases how computational design can streamline the design process, improve efficiency, and enhance accuracy by automating complex calculations, ensuring compliance with design boundaries, and enabling rapid iterations.
- *Digital Fabrication:* This area focuses on the transformative impact of digital fabrication technologies in architectural design and construction. It explores the integration of robotics, advanced manufacturing techniques, and additive manufacturing (3D printing) to create intricate and complex architectural forms. Digital fabrication allows architects and designers to achieve a higher level of precision, customization, and efficiency in the

construction process. By leveraging the capabilities of robotic arms and advanced fabrication techniques, architects can create structures with intricate connections, minimal waste, and reduced construction time. This area examines how technology-driven fabrication processes enable the realization of innovative designs that were once challenging or impossible to construct using traditional methods.

- *Environmental Analysis & Simulations:* This area delves into the use of computational tools for environmental analysis and simulations in architectural design. It focuses on the evaluation and optimization of design performance, particularly in relation to natural lighting, energy efficiency, and environmental sustainability. By employing simulation software and tools, architects and designers can assess various design iterations, analyze daylight factors, predict energy consumption, and optimize building performance. This area showcases the benefits of utilizing computational analysis and simulations to inform design decisions, identify potential design improvements, and create more sustainable and environmentally conscious architectural solutions.

By exploring these four main areas of focus, it’s aimed to have a comprehensive understanding of the advantages, limitations, and transformative potential of computational design in architecture and design. Each area contributes to the advancement of the architectural field by leveraging technology and computational tools to enhance the design process, optimize performance, and push the boundaries of architectural innovation.

CASE STUDIES

Enhancing Construction and Assembly through Holographic Technology: Pioneering Project and Personal Application

The integration of technology in construction and assembly processes has significantly transformed the industry, enhancing efficiency, accuracy, and overall project outcomes. This chapter explores the utilization of augmented reality (AR), virtual reality (VR), and mixed reality (MR) technologies in construction and assembly, focusing on two notable case studies: "Holographic Construction" and "Enhancing Construction of Complex Compression-Based Structures through Holographic-Assisted Assembly." The former project serves as a pioneering example in the field, while the latter represents a personal application that builds upon its success. This chapter discusses the merits of using holographic technology in these projects, highlighting the advantages it offers in terms of design information, visualization, precision, and collaboration.

Holographic Construction: A Pioneer Project

The "Holographic Construction" project, conducted by Gwyllim Jahn, Cameron Newnham, Nick van den Berg, Melissa Iraheta, and Jackson Wells, introduces a groundbreaking method for generating holographic construction information from parametric models. This innovative approach replaces traditional 2D drawings and templates with holographic models, providing unambiguous, contextual, shared, and interactive design information. By leveraging holographic technology, the project revolutionizes the construction process and sets the stage for further advancements in the field.

Holographic Construction demonstrates several key benefits that contribute to its success. Firstly, the use of holographic models offers contextual design information, enabling stakeholders to grasp the project's intricacies with greater clarity. Similarly, the personal application project, "Enhancing Construction of Complex Compression-Based Structures through Holographic-Assisted Assembly," builds upon this concept by overlaying holographic elements onto physical structures. Both projects emphasize the importance of providing workers with precise visual guidance during the construction and assembly phases.

Furthermore, holographic models in the "Holographic Construction" project enable shared and interactive design experiences. Collaborative decision-making is enhanced through real-time interaction with holographic models, fostering effective coordination among project stakeholders. This collaborative aspect is also a key element in the personal application project, where holographic-assisted assembly promotes improved collaboration among workers, leading to seamless communication, coordination, and problem-solving on-site (Jahn, Gwyllim, et al., 2019).

Personal Application: Enhancing Construction of Complex Compression-Based Structures through Holographic-Assisted Assembly (APPENDIX A)

Building upon the success of the "Holographic Construction" project, this personal application focuses on enhancing the construction and assembly of complex compression-based structures using holographic-assisted assembly.

The personal application project seeks to leverage holographic technology to improve the construction process of complex compression-based structures (Figure 1).

Figure 1. Perspectives of the structure

By overlaying holographic elements onto the physical structure, workers are provided with precise visual guidance and real-time feedback during assembly, ensuring accurate placement and alignment of components (Figure 2).

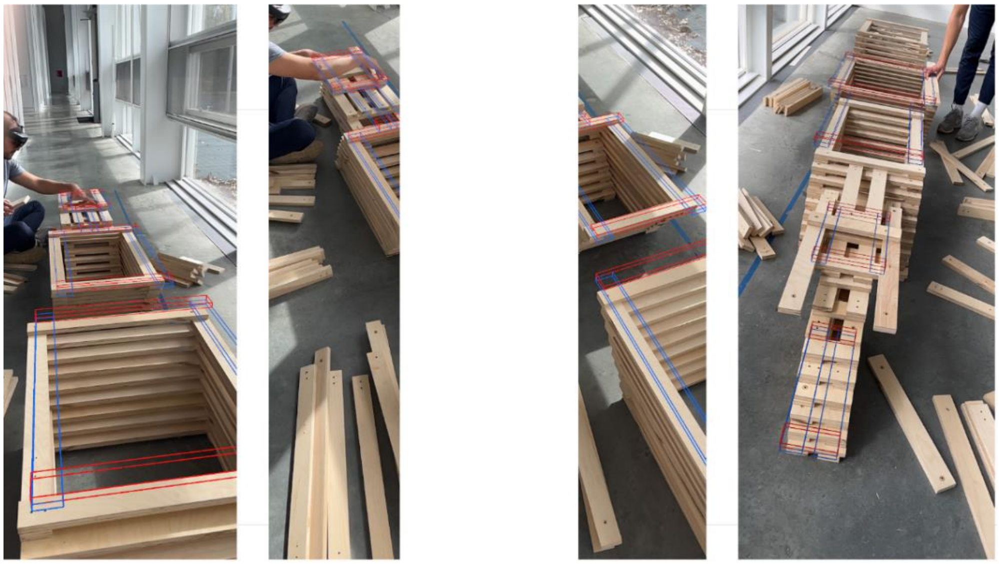


Figure 2. Holographic projection during the assembly

This experience shares similarities with the "Holographic Construction" project, particularly in terms of visualization and precision. Holographic-assisted assembly enhances visualization by superimposing holographic elements onto the physical structure, enabling workers to have a clear understanding of the assembly process. This helps minimize errors and rework, a key aspect in both projects.

Moreover, both projects benefit from real-time feedback. In the "Holographic Construction" project, comparative analysis of digital models to 3D point cloud scans provides immediate feedback on construction tolerances. Similarly, the personal application project utilizes holographic technology to offer immediate feedback on the accuracy of component placement during assembly. This capability empowers workers to make adjustments on the spot, improving efficiency and minimizing errors.

Overlaps and Comparisons

The two case studies, "Holographic Construction" and "Enhancing Construction of Complex Compression-Based Structures through Holographic-Assisted Assembly," share common elements that highlight the efficacy of holographic technology in construction and assembly.

Both projects emphasize the importance of improved visualization, where holographic models or elements aid in providing workers with a clear understanding of the project design and assembly process. This enhanced visualization minimizes errors, rework, and the need for constant reference to traditional 2D drawings or templates.

Collaboration is another shared aspect. The "Holographic Construction" project promotes collaborative decision-making through real-time interaction with holographic models. Similarly, the personal application project harnesses holographic technology to foster improved collaboration among workers during assembly, enabling effective communication and problem-solving on-site.

The integration of AR, VR, and MR technologies in construction and assembly, exemplified by the "Holographic Construction" and "Enhancing Construction of Complex Compression-Based Structures through Holographic-Assisted Assembly" case studies, presents a promising future for the industry. These projects demonstrate the potential of holographic technology in providing contextual design information, enhancing visualization, improving precision, and facilitating collaboration. As the construction sector continues to embrace technological advancements, holographic technology stands out as a pioneering solution that can revolutionize construction and assembly processes, leading to increased efficiency and improved project outcomes.

Leveraging the Power of Customized Parametric Modeling: Enhancing Automation in Information Modeling (APPENDIX B)

In the field of architecture, the fusion of digital technologies and design methodologies has ushered in a new era of creativity, efficiency, and precision. Parametric Modeling, a groundbreaking approach that leverages computational algorithms, has emerged as a powerful tool for architects to generate, manipulate, and optimize complex design solutions (Heike, 2007). This chapter explores the concept of Customized Parametric Modeling, which takes the capabilities of parametric modeling a step further by tailoring it to specific architectural needs and objectives. Complementing this paradigm is the concept of Building Information Modeling (BIM), which provides a comprehensive framework for organizing, visualizing, and analyzing building information throughout the project lifecycle. This case study focuses on Customized Parametric Modeling and explores its application in daily architectural practice, showcasing the symbiotic relationship between automation and Building Information Modeling for enhanced design outcomes.

Building Information Modeling: A Pioneer Guide

Building Information Modeling stands at the forefront of architectural innovation, spearheading a transformative shift in the industry. This pioneering approach revolutionizes the architectural landscape by harnessing the power of digital technologies to establish a comprehensive and dynamic representation of building information.

Through the construction of a rich 3D model, architects can capture and integrate a myriad of crucial data, ranging from geometric and spatial aspects to material properties and performance metrics (Lorek, 2023).

The digital model serves as an invaluable repository of information, acting as a central hub where architects, engineers, contractors, and other stakeholders can converge and collaborate seamlessly. By providing a holistic view of the project, Building Information Modeling enables interdisciplinary teams to work in harmony, fostering effective communication, knowledge sharing, and informed decision-making throughout the project lifecycle.

One of the key advantages of Building Information Modeling lies in its ability to streamline design processes. By digitizing and consolidating information, architects can navigate the complexities of a project with greater ease and efficiency. They can rapidly iterate design iterations, test different scenarios, and evaluate the impact of design choices in real-time. This iterative design approach empowers architects to refine and optimize their solutions, enhancing the overall quality and performance of the final design.

Personal Application: Urban Modeling Assistant (APPENDIX B)

One exceptional personal application of Customized Parametric Modeling and Information Modeling is the Urban Modeling Assistant. Developed for everyday use in an international architectural office, this digital tool extends the capabilities of parametric modeling by seamlessly integrating layer information and providing real-time feedback tailored to the specific needs of architects and designers. The Urban Modeling Assistant serves as an indispensable companion, empowering architects to navigate the intricacies of designing in urban scale.

To achieve this, the Urban Modeling Assistant offers a wealth of real-time information at both the Massing & Terrain Scale and the Urban Scale. At the Massing & Terrain Scale, architects can access critical details such as building function (by layer), building name, building height, number of floors per building, height of the floors per building, floor plates, square meter of the geometry, unit size, and the number of units that can fit onto that massing. This granular information facilitates precise analysis and visualization, enabling architects to gauge the impact of different parameters on the design and ensuring compliance with project or competition briefs (Figure 3).

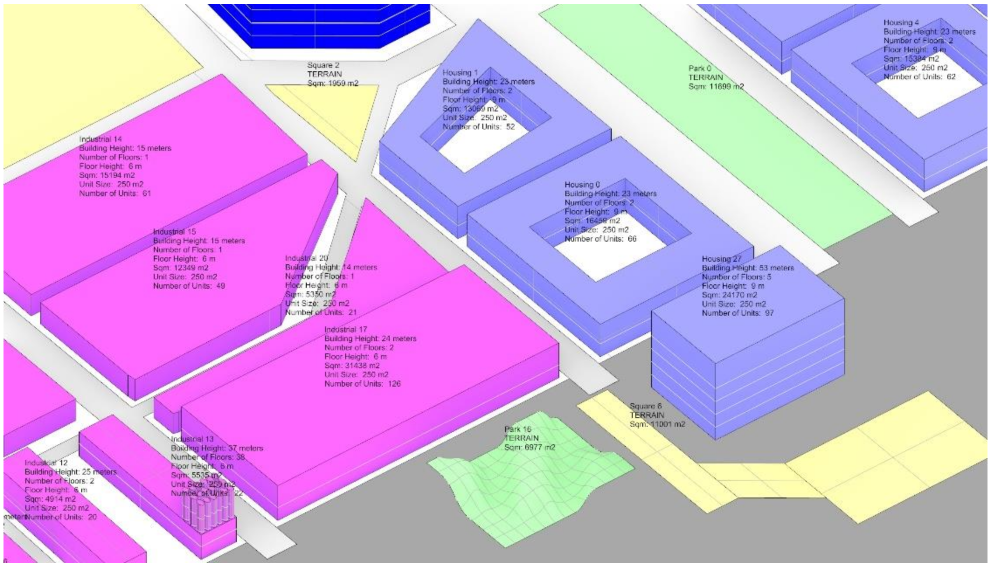
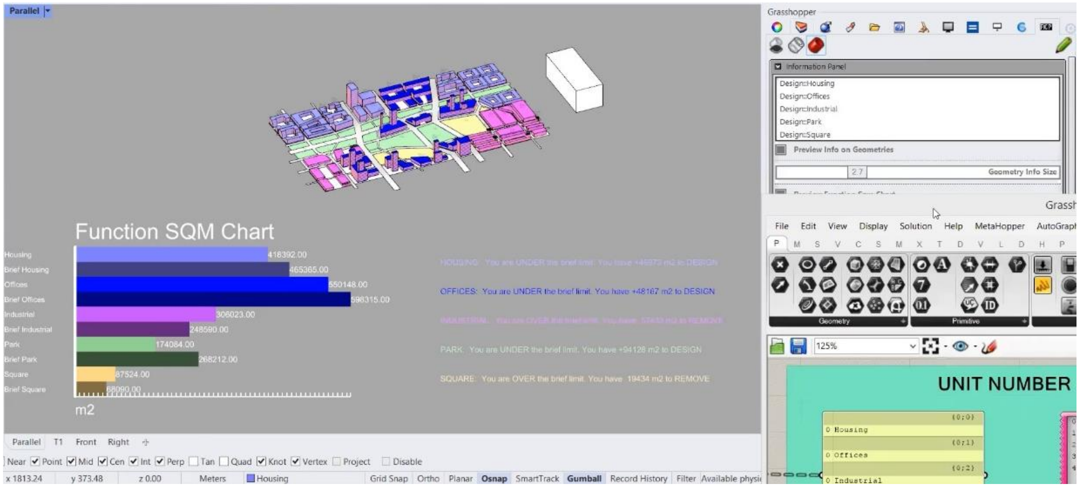


Figure 3. Urban Modelling Assistant in Terrain & Modelling Scale

Simultaneously, the Urban Modeling Assistant provides heads-up displays of essential information at the Urban Scale, including square-meter limits, instant design status in square meters, unit limits, and instant design status in units. Architects can seamlessly monitor their designs in real-time, comparing them to the specified requirements and making adjustments as needed (Figure 4.). By incorporating this level of real-time feedback and assistance, the Urban Modeling Assistant amplifies the capabilities of architects, enhancing their ability to meet design requirements accurately and efficiently.



HOUSING: You are UNDER the brief limit. You have +46973 m2 to DESIGN

OFFICES: You are UNDER the brief limit. You have +48167 m2 to DESIGN

INDUSTRIAL: You are OVER the brief limit. You have -57433 m2 to REMOVE

PARK: You are UNDER the brief limit. You have +94128 m2 to DESIGN

SQUARE: You are OVER the brief limit. You have -19434 m2 to REMOVE

Figure 4. HUD(Heads up Display) of Urban Modelling Assistant in Urban Scale

The Urban Modeling Assistant excels in accommodating diverse project needs and constraints. It can differentiate between mass and terrain geometries, seamlessly integrating square meter limits from any project or competition brief. The information is presented in a user-friendly text format, allowing architects to swiftly compare their designs against the specified requirements. By automating tedious tasks and providing real-time feedback, the Urban Modeling Assistant exemplifies how computational design tools can streamline and optimize the architectural design process.

Overlaps and Comparisons

While Building Information Modeling provides a broader guide encompassing the entire lifecycle of a building project, the Urban Modeling Assistant focuses on specific design tasks, augmenting the capabilities of architects in real-time design exploration and optimization. By customizing Building Information Modeling through tools like the Urban Modeling Assistant, architects can establish a symbiotic relationship between Customized Parametric Modeling and Information Modeling, leveraging their respective strengths to maximize design efficiency, collaboration, and innovation.

The synergistic integration of Customized Parametric Modeling and Building Information Modeling heralds a new era in architectural practice. Architects can be armed with the power of automation and real-time feedback can push the boundaries of design, unravel intricate complexities, and deliver exceptional spaces that transcend the ordinary. Through case studies like the Urban Modeling Assistant, the transformative impact of Customized Parametric Modeling in conjunction with Information Modeling becomes increasingly evident, empowering architects to reshape the built environment and unlock creative potential.

From Complexity to Simplicity: Robotic Fabrication's Influence on Enhanced Fabrication and Assembly

The integration of technology in architecture has led to remarkable advancements in design and construction processes. Robotic fabrication, specifically the use of robotic arms, has emerged as a transformative tool, reshaping the approach to intricate designs. This chapter explores the application of robotic arms in architectural projects, focusing on their effectiveness in creating complex 3D mortise and tenon joints. By examining the challenges posed by traditional woodworking techniques and highlighting the capabilities of robotic arms, we uncover how this cutting-edge technology is revolutionizing architectural craftsmanship.

Pioneer Guide: Overcoming the Hardness of Crafting 3D Mortise and Tenon Joints

Traditional woodworking techniques have long been the hallmark of fine craftsmanship in architectural projects. Handmade 3D wood joinery, such as mortise and tenon joints, requires immense skill, precision, and attention to detail. Craftsmen utilize a variety of hand tools, including saws, chisels, and mallets, to carefully shape the wooden components and create joints that provide both structural integrity and visual appeal.

However, crafting 3D mortise and tenon joints manually poses certain challenges. The intricate nature of these joints, particularly when incorporated into complex forms, demands meticulous measurement, careful planning, and exceptional woodworking skills (Daunas and Spaeth, 2014). Achieving the desired level of intricacy and accuracy can be time-consuming and labor-intensive, often limiting the complexity of designs that can be realized.

Personal Application: Robotic Fabrication as a Catalyst for Efficiency and Assembly (APPENDIX D)

Robotic fabrication techniques offer a paradigm shift in the creation of 3D mortise and tenon joints, complementing and augmenting the capabilities of traditional woodworking. By employing robotic arms, architects and craftsmen can leverage advanced algorithms and digital modeling to precisely carve out the necessary wood cuts and shapes. The robotic arm's ability to execute repetitive tasks with consistent precision and speed significantly enhances efficiency and accuracy in the creation of complex joints.

In personal experience, the integration of a robotic arm in woodworking projects has been transformative. In the construction of a “Bits and Wholes”, the use of a robotic arm enabled the realization of intricate 3D mortise and tenon joints with a level of precision and complexity that would have been challenging to achieve solely through manual woodworking techniques (Figure 5-6.).

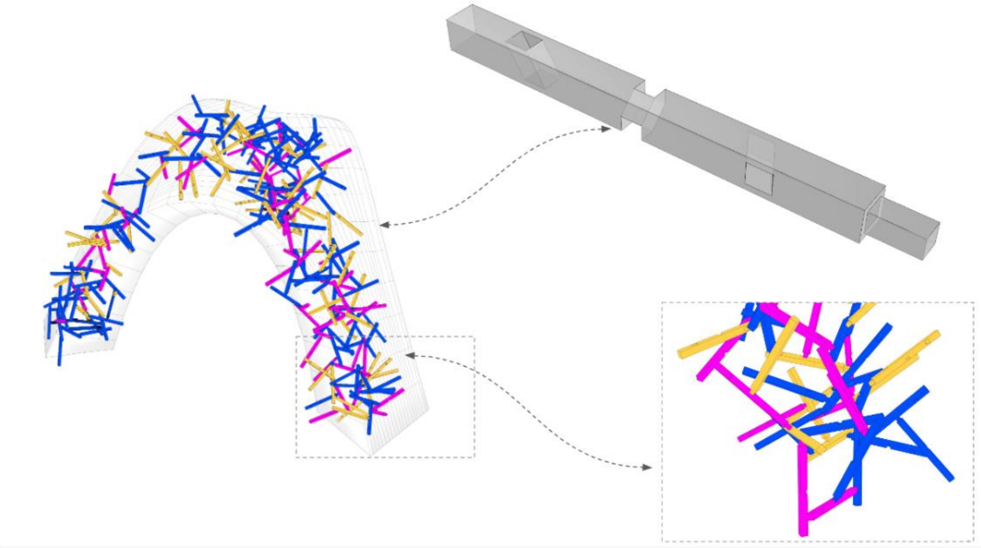


Figure 5. Bits and Wholes Design

Figure 6. Finished Structure

The robotic arm's agility and adaptability allowed it to navigate the intricacies of the design, executing each cut with remarkable accuracy (Figure 7.).

Figure 7. Robotically fabricated joints

To streamline the assembly process and enhance accuracy, holographic projection is employed. The holographic projection visualizes the entire structure, guiding the assembly with unparalleled accuracy.

Through the use of holographic projection, workers can see virtual overlays of the wooden parts, precisely indicating their placement and alignment. This augmented reality technique eliminates guesswork, reduces errors, and ensures that the assembly process aligns with the intended design. The combination of robotic fabrication and holographic projection revolutionizes the workflow, enhancing both efficiency and precision (Figure 8.).

Figure 8. Holographic Projection for Assembly

Furthermore, the robotic arm's ability to automate repetitive tasks accelerated the construction process, reducing labor-intensive efforts and allowing craftsmen to focus on higher-level aspects of the project. This efficiency gains not only expedited production but also enhanced overall project outcomes in terms of quality, accuracy, and structural integrity.

Overlaps and Comparisons

When comparing robotic fabrication with traditional woodworking techniques, it is important to recognize the unique strengths and values of each approach. Traditional woodworking embodies the craftsmanship and artistic sensibilities that have been honed over centuries. Handmade 3D wood joinery carries a tactile quality and attention to detail that can create a distinct aesthetic appeal in architectural projects. It fosters a deep connection between the craftsman and the material, resulting in a unique and personalized outcome.

On the other hand, robotic fabrication with the use of robotic arms offers unparalleled precision, repeatability, and efficiency. It allows for the creation of intricate and complex joints with a level of accuracy that can be challenging to achieve manually. Robotic arms excel in executing precise cuts, navigating intricate geometries, and automating repetitive tasks, resulting in increased productivity and improved project outcomes.

The integration of robotic fabrication techniques in architectural projects does not seek to replace traditional woodworking but rather to complement and enhance it. By leveraging the capabilities of robotic arms, architects and craftsmen can push the boundaries of design complexity, optimize efficiency, and achieve outcomes that may have been unattainable through traditional techniques alone. The marriage of traditional woodworking skills with robotic fabrication technology paves the way for new possibilities, allowing for the creation of breathtaking architectural forms with a level of precision and efficiency that was once unimaginable.

The utilization of robotic arms in architectural projects represents a groundbreaking approach to overcoming the challenges associated with crafting 3D mortise and tenon joints using traditional woodworking techniques (Daunas and Spaeth, 2014).. Robotic fabrication techniques offer unmatched precision, efficiency, and the ability to realize complex designs. While traditional woodworking techniques possess intrinsic value and tactile quality, the integration of robotic arms expands the creative potential, efficiency, and precision in architectural craftsmanship. By combining the strengths of traditional woodworking with the capabilities of robotic fabrication, architects and craftsmen can usher in a new era of complexity, efficiency, and innovation in architectural projects.

A User-Friendly Daylight Simulation Tool: A Catalyst for Optimal Design Performance

This case study aims to explore the development of a user-friendly daylight simulation tool that revolutionizes the way architects and designers assess and optimize design performance related to daylighting. By simplifying the process of analyzing daylight in architectural design, this innovative tool empowers professionals to create sustainable and energy-efficient buildings while enhancing occupant well-being and productivity.

A Pioneer Guide: Significance of Daylight in Architecture and the Easiness of Daylight Factor Analysis

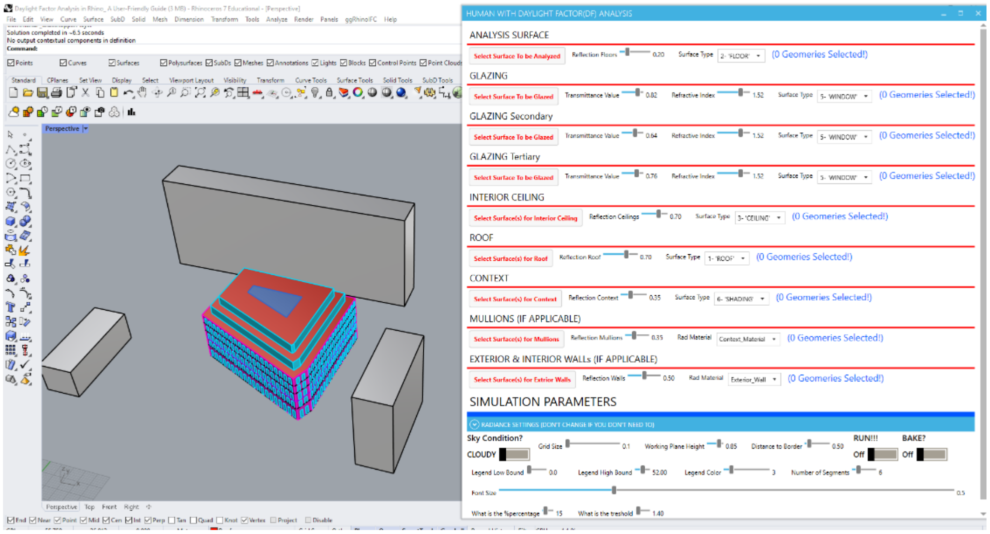
The importance of daylight in architecture can be traced back to ancient civilizations, where architects and builders recognized its transformative qualities. Throughout history, architects have leveraged daylight to shape spaces, evoke emotions, and enhance the functionality of buildings. The realization that natural light impacts human health, mood, and productivity has propelled daylighting to the forefront of design considerations.

Daylight factor analysis, a traditional method for evaluating natural lighting in architectural design, has played a significant role in understanding and optimizing daylighting strategies. This approach focuses on calculating the ratio of interior illuminance to exterior illuminance, providing a straightforward measure of how well a space is lit by natural light (Barbara, 2010). Architects have used daylight factor analysis to inform design decisions, such as window placement, shading devices, and interior finishes, to maximize daylight penetration and ensure occupant comfort.

Before the advent of computational modeling, daylight factor analysis relied on simplified empirical models and manual calculations. Architects would estimate illuminance levels by considering factors such as window area, reflectance of surfaces, and the orientation of the building. These methods required a deep understanding of daylighting principles and significant experience to achieve accurate results.

Personal Application: "Daylight Factor Analysis in Daily Practice: A User-Friendly Guide" (APPENDIX C)

To address the challenges faced by architectural designers in conducting daylight analysis and to provide a solution that is accessible to all, the development of the "Daylight Factor Analysis in Rhino: A User-Friendly Guide" tool was undertaken. This humble yet powerful tool has been designed to cater to the needs of an international architectural office, enabling employees to independently run their own daylight simulations without the requirement of complex computational design skills. The guide offers a simplified and intuitive interface within a familiar environment, allowing designers to effortlessly evaluate the daylighting performance of their designs (Figure 9.).



Reflection Floors 0.20 Surface Type 2- 'FLOOR' (0 Geomeries Selected!)

Transmittance Value 0.82 Refractive Index 1.52 Surface Type 5- 'WINDOW' (0 Geomeries Selected!)

Transmittance Value 0.64 Refractive Index 1.52 Surface Type 5- 'WINDOW' (0 Geomeries Selected!)

Transmittance Value 0.76 Refractive Index 1.52 Surface Type 5- 'WINDOW' (0 Geomeries Selected!)

Reflection Ceilings 0.70 Surface Type 3- 'CEILING' (0 Geomeries Selected!)

Reflection Roof 0.70 Surface Type 1- 'ROOF' (0 Geomeries Selected!)

Reflection Context 0.35 Surface Type 6- 'SHADING' (0 Geomeries Selected!)

Reflection Mullions 0.35 Rad Material Context_Material (0 Geomeries Selected!)

Reflection Walls 0.50 Rad Material Exterior_Wall (0 Geomeries Selected!)

Sky Condition? CLOUDY Grid Size 0.1 Working Plane Height 0.85 Distance to Border 0.50 RUN!!! Off BAKE? Off

Legend Low Bound 0.0 Legend High Bound 52.00 Legend Color 3 Number of Segments 6

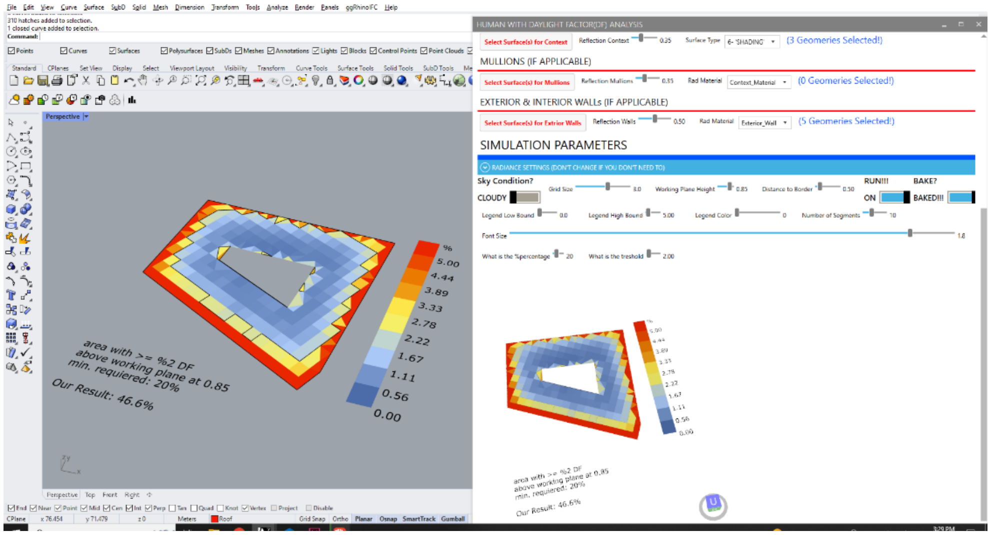
Font Size 0.5

What is the %percentage 15 What is the treshold 1.40

Figure 9. Interface of Daylight Factor Analysis in Rhino: A User-Friendly Guide

The introduction of the "Daylight Factor Analysis in Rhino: A User-Friendly Guide" tool represents a significant step forward in architectural design practices. By providing free and easy access to daylight analysis, it empowers designers to assess and optimize their designs efficiently, ultimately leading to improved design performance. Early-stage simulations facilitated by the tool offer valuable insights, enabling designers to make informed decisions that enhance occupant comfort, reduce energy consumption, and contribute to the creation of sustainable buildings.

One of the key advantages of this tool is its integration with widely used software, enabling designers to seamlessly incorporate daylight analysis into their design workflow. The user-friendly interface ensures that designers, regardless of their technical expertise, can easily navigate through the analysis process and interpret the simulation results (Figure 10.). This accessibility fosters a collaborative environment where designers can explore various daylighting strategies, evaluate their impact on the design, and engage in discussions to optimize natural light distribution within their projects.



HUMAN WITH DAYLIGHT FACTOR(DF) ANALYSIS

Select Surface(s) for Context — Reflection Context 0.35 — Surface Type 6- 'SHADING' — (3 Geomeries Selected!)

MULLIONS (IF APPLICABLE)

Select Surface(s) for Mullions — Reflection Mullions 0.35 — Rad Material Context_Material — (0 Geomeries Selected!)

EXTERIOR & INTERIOR WALLs (IF APPLICABLE)

Select Surface(s) for Extrior Walls — Reflection Walls 0.50 — Rad Material Exterior_Wall — (5 Geomeries Selected!)

SIMULATION PARAMETERS

RADIANCE SETTINGS (DON'T CHANGE IF YOU DON'T NEED TO)

Sky Condition? CLOUDY

Grid Size 3.0

Working Plane Height 0.85

Distance to Border 0.50

RUN!!! ON

BAKE? BAKED!!!

Legend Low Bound 0.0

Legend High Bound 5.00

Legend Color 0

Number of Segments 10

Font Size 1.8

What is the %percentage 20

What is the treshold 2.00

area with >= %2 DF
above working plane at 0.85
min. requiered: 20%
Our Result: 46.6%

Figure 10. Analysis by Daylight Factor Analysis in Rhino: A User-Friendly Guide

The "Daylight Factor Analysis in Rhino: A User-Friendly Guide" tool serves as a catalyst for a more iterative and data-driven design process. By offering instant feedback on the daylighting performance of a design, it helps designers identify areas for improvement and refine their design strategies accordingly. The tool's ability to guide design refinements based on daylight simulation data enables the creation of harmonious spaces that seamlessly integrate with the surrounding environment. By harnessing the benefits of natural light, the tool contributes to the well-being of occupants and enhances the aesthetic appeal of the designed spaces.

Overlaps and Comparisons

When comparing the "Daylight Factor Analysis in Rhino: A User-Friendly Guide" tool with traditional daylight calculation methods, it is important to recognize the historical significance and value of these approaches. Traditional methods, developed over centuries, provided architects with a foundation for understanding the principles of daylighting and its impact on architecture.

One such traditional method is the use of sun charts and sun path diagrams. Architects would utilize these graphical tools to predict the path of the sun throughout the day and year, determining the amount and direction of sunlight that would enter a space. These diagrams allowed architects to consider solar angles, shadows, and the positioning of windows and openings to optimize daylight penetration. Another traditional approach involves the use of physical scale models and physical sky simulators. Architects would create intricate scale models of their designs and employ light sources to simulate natural lighting conditions. By analyzing the model's illuminated areas and shadows, designers could gain insights into the distribution of daylight within the space.

While traditional daylight calculation methods possess historical significance and offer a hands-on approach to daylight analysis, they often require significant time, resources, and expertise. The "Daylight Factor Analysis in Rhino: A User-Friendly Guide" tool complements and enhances these traditional methods by providing an efficient and accessible means of performing accurate daylight simulations. Its integration with computational tools and simplified interface democratizes daylight analysis, making it available to a broader range of architects and designers.

The development of the "Daylight Factor Analysis in Rhino: A User-Friendly Guide" tool marks a significant milestone in the field of daylight analysis. By bridging the gap between architectural design and computational simulation, this tool empowers architects and designers to optimize daylighting strategies, create sustainable buildings, and prioritize occupant well-being. While traditional daylight calculation methods have laid the foundation for our understanding of daylight's role in architecture, this tool enhances accessibility, efficiency, and accuracy in the assessment of design performance.

RESULTS AND DISCUSSIONS

In this chapter, the results and analysis of the conducted case studies will be presented. The outcomes of each project were evaluated based on the research questions, exploring the impact of advanced technological tools on architectural problem-solving, efficiency, and creative exploration. Furthermore, the implications of technology-driven approaches in various aspects of architectural projects, such as parametric modeling for automation, digital fabrication, and environmental analysis and simulations, were examined. By adopting a critical perspective and considering the balance between technology and problem-solving, this discussion aims to provide information on the role of technology in contemporary architectural practice.

Overview of the four case studies

Each project demonstrated the increasing reliance on advanced technological tools, such as robotic arms, parametric modeling, and digital fabrication, while exploring the interplay between technology and problem-solving. The analysis delves into the extent to which technology-driven approaches influenced the problem-solving process, stimulated creative exploration, and maintained a focus on effective problem-solving. Additionally, the integration of technology in construction and assembly, along with the implications of prioritizing technology-driven solutions in environmental analysis and simulations, are examined.

Case Study 1: Enhancing Construction and Assembly through Holographic Technology

The integration of holographic technology facilitated effective communication and visualization, leading to enhanced problem-solving capabilities in construction and assembly. By immersing stakeholders in a virtual representation of the project, holographic technology allowed for real-time feedback and collaborative decision-making. Its interactive nature stimulated creativity and exploration, offering new perspectives in problem-solving approaches. The findings of this case study demonstrate that holographic technology can be a valuable tool for architects to strike a balance between leveraging technology and ensuring it remains a means to effectively address design challenges. The table below for the case study, presenting the research questions and corresponding responses:

Research Questions	**Author's Finding(s)**
How does the increasing reliance on advanced technological tools, such as holographic technology, impact the core principles of problem-solving and the overall efficiency of architectural projects?	Holographic technology significantly impacts the core principles of problem-solving and enhances the efficiency of architectural projects. It revolutionizes communication and visualization, providing an immersive and collaborative platform for effective problem-solving and decision-making. Holographic technology stimulates creative exploration by offering new perspectives and possibilities in design. Its integration streamlines the problem-solving process, allowing architects to address design challenges intuitively and interactively.
To what extent does holographic technology influence the problem-solving process in architectural projects and stimulate creative exploration?	Holographic technology influences the problem-solving process in architectural projects to a significant extent. By providing an immersive and collaborative platform, it facilitates effective communication, visualization, and real-time feedback. Holographic technology stimulates creative exploration by offering new perspectives and possibilities in design, leading to innovative problem-solving approaches.

Table 1. Results of research questions for "Enhancing Construction and Assembly through Holographic Technology"

Case Study 2: Leveraging the Power of Customized Parametric Modeling

Parametric modeling influences the problem-solving process in architectural projects and offers new avenues for exploration. However, there is a need to achieve a better balance by considering essential problem-solving aspects. Architects should avoid overshadowing functional, contextual, and user-centric aspects with technology showcases. Cultivating a critical mindset within architectural education and practice encourages architects to question the excessive reliance on parametric modeling and explore alternative approaches that better align with contextual needs and problem-solving principles. A critical mindset fosters a deeper understanding of the limitations and potentials of digital fabrication techniques, enabling architects to appropriately integrate them into construction and assembly processes. The table below for the case study, presenting the research questions and corresponding responses:

Research Questions	**Author's Finding(s)**
Are architects and designers adequately considering essential problem-solving aspects while demonstrating the capabilities of digital fabrication techniques, or is	Architects and designers need to achieve a better balance in leveraging digital fabrication techniques. While exploring the capabilities of parametric modeling, they should consider essential problem-

there a need to achieve a better balance in their approach?	solving aspects to avoid overshadowing functional, contextual, and user-centric aspects of design.
Can cultivating a critical mindset within architectural education and practice encourage architects to question the excessive reliance on parametric modeling for automation and explore alternative approaches that better align with contextual needs and problem-solving principles?	Cultivating a critical mindset within architectural education and practice encourages architects to question the excessive reliance on parametric modeling and explore alternative approaches that better align with contextual needs and problem-solving principles. It fosters a deeper understanding of the limitations and potentials of digital fabrication techniques, empowering architects to make informed decisions on their appropriate integration in construction and assembly processes.
How can architects develop a deeper understanding of the limitations and potentials of digital fabrication techniques, allowing them to discern when and how to appropriately integrate them in construction and assembly processes?	Architects can develop a deeper understanding of the limitations and potentials of digital fabrication techniques through education, research, and hands-on experience. By exploring the capabilities and drawbacks of these techniques, architects can discern when and how to appropriately integrate them in construction and assembly processes based on the

	specific project requirements and problem-solving principles.

Table 2. Results of research questions for “*Leveraging the Power of Customized Parametric Modeling*”

Case Study 3: From Complexity to Simplicity: Robotic Fabrication's Influence

Robotic fabrication techniques offer significant benefits in construction and assembly processes. Architects must strike a balance between leveraging technology and ensuring it serves as a means to effectively address design challenges without overshadowing the problem-solving process. By maintaining a strong focus on problem-solving, architects can integrate robotic fabrication techniques to streamline construction, enhance efficiency, and uphold the functional, contextual, and user-centric aspects of the design. The table below for the case study, presenting the research questions and corresponding responses:

Research Questions	**Author’s Finding(s)**

How can architects strike a balance between leveraging technology, such as digital fabrication, in construction and assembly while ensuring it remains a means to effectively address design challenges rather than overshadowing the problem-solving process?	Architects can strike a balance by maintaining a strong focus on problem-solving. Technology, such as robotic fabrication, should serve as a means to effectively address design challenges without overshadowing the problem-solving process. Architects should prioritize the functional, contextual, and user-centric aspects of the design while leveraging technology to streamline construction, enhance efficiency, and maintain design integrity.

Table 3. Results of research questions for "*From Complexity to Simplicity: Robotic Fabrication's Influence*"

Case Study 4: A User-Friendly Daylight Simulation Tool

The user-friendly daylight simulation tool exemplifies technology that enhances problem-solving and design outcomes. It avoids the excessive use of parametric modeling for automation, prioritizing functional, contextual, and user-centric aspects over showcasing technology. Implementing strategies and frameworks to evaluate the appropriateness and necessity of environmental analysis and simulations ensures they serve as tools for effective problem-solving rather than superficial displays of data visualization. Integrating construction and assembly, parametric modeling, digital fabrication, and environmental analysis and simulations should maintain a strong problem-solving focus, utilizing technology as a necessity rather than solely for showcasing purposes. The table below for the case study, presenting the research questions and corresponding responses:

Research Questions	**Author’s Finding(s)**
Are there examples of architectural projects where the excessive use of parametric modeling for automation has compromised the holistic problem-solving process, resulting in design outcomes that prioritize the showcase of technology over functional, contextual, and user-centric aspects?	Yes, there are examples where the excessive use of parametric modeling for automation has compromised the holistic problem-solving process. In some cases, design outcomes have prioritized the showcase of technology over functional, contextual, and user-centric aspects, leading to suboptimal solutions.
What strategies or frameworks can be implemented to evaluate the appropriateness and necessity of environmental analysis and simulations, ensuring they serve as tools for effective problem-solving rather than mere superficial displays of data visualization?	Strategies and frameworks can be implemented to evaluate the appropriateness and necessity of environmental analysis and simulations. Architects can establish clear objectives, define performance metrics, and integrate feedback loops for iterative refinement. This ensures that environmental analysis and simulations serve as tools for effective problem-

	solving, providing meaningful insights rather than superficial data visualization.
How can the integration of construction and assembly, parametric modeling for automation, digital fabrication, and environmental analysis and simulations be approached to maintain a strong focus on problem-solving, ensuring that technology is utilized as a necessity rather than solely for showcasing purposes?	The integration of construction and assembly, parametric modeling for automation, digital fabrication, and environmental analysis and simulations should be approached with a strong focus on problem-solving. Architects should prioritize the functional, contextual, and user-centric aspects of design and use technology as a means to address design challenges effectively. This ensures that technology is utilized as a necessity rather than solely for showcasing purposes.

Table 4. Results of research questions for "*A User-Friendly Daylight Simulation Tool*"

The case studies presented demonstrate the profound impact of technology on the problem-solving process in architectural projects. Holographic technology offers an immersive and collaborative platform, revolutionizing communication and visualization. Parametric modeling opens up new avenues for exploration, but architects must strike a better balance to prioritize essential problem-solving aspects. Robotic fabrication techniques streamline construction processes while maintaining a focus on problem-solving. The user-friendly daylight simulation tool showcases the appropriate integration of technology to enhance design outcomes. Overall, by adopting a critical mindset, architects can navigate the complexities of technology, discern its limitations and potentials, and leverage it as a means to effectively address design challenges. Through a strong problem-solving focus and thoughtful integration of technology, architects can create designs that harmonize functionality, contextuality, and user-centricity, ultimately shaping the built environment in innovative and sustainable ways.

Implications and Results

The findings from the conducted case studies in this study have significant implications for the field of architecture and design. By integrating advanced technological tools, such as holographic technology, customized parametric modeling, robotic fabrication techniques, and user-friendly simulation tools, architects can revolutionize the problem-solving process and shape the built environment in innovative and sustainable ways.

Case Study 1: Enhancing Construction and Assembly through Holographic Technology

The use of holographic technology in construction and assembly processes offers transformative potential. It enables stakeholders to have a virtual representation of the project, facilitating enhanced communication, visualization, and real-time feedback. This immersive and collaborative platform fosters creativity, exploration, and innovative problem-solving approaches. The implications of these findings are significant, as they demonstrate how holographic technology can redefine traditional construction practices, improve coordination, reduce errors, and enhance overall project efficiency.

Case Study 2: Leveraging the Power of Customized Parametric Modeling

Customized parametric modeling provides opportunities for automation and exploration in architectural design. However, it is crucial to maintain a critical mindset and strike a balance between technology-driven solutions and fundamental problem-solving aspects. The findings emphasize the importance of integrating parametric modeling judiciously, considering contextual needs and problem-solving principles. Architects can leverage the power of parametric modeling to optimize design outcomes, enhance efficiency, and uphold functional, contextual, and user-centric aspects of projects. These results highlight the significance of maintaining a problem-solving focus while harnessing the potential of technology.

Case Study 3: Streamlining Construction and Assembly through Robotic Fabrication

The integration of robotic fabrication techniques in architectural practice streamlines construction and assembly processes, offering precision, efficiency, and cost-effectiveness. Architects must maintain a problem-solving focus while leveraging technology, ensuring it serves as a means to address design challenges effectively. By integrating robotic fabrication techniques with a strong problem-solving approach, architects can optimize construction processes, enhance efficiency, and uphold the functional, contextual, and user-centric aspects of the design. These results demonstrate how technology can transform the construction industry and shape the built environment in more sustainable and innovative ways.

Case Study 4: User-Friendly Daylight Simulation for Optimal Design Performance

User-friendly daylight simulation tools provide designers with instant feedback on daylighting performance, enabling them to optimize natural light distribution within their projects. The integration of such tools facilitates an iterative and data-driven design process, leading to harmonious spaces that seamlessly integrate with the surrounding environment. By harnessing the benefits of natural light, the user-friendly daylight simulation tool contributes to occupant well-being and enhances the aesthetic appeal of the designed spaces. These results emphasize the importance of incorporating technology as a tool to enhance design outcomes and create environments that promote occupant comfort and sustainability.

In summary, the findings from the case studies have significant implications for architecture and design. The integration of advanced technological tools offers new possibilities for problem-solving, efficiency, and creative exploration. Architects can leverage these tools to redefine traditional practices, optimize design outcomes, streamline construction processes, and enhance the user experience. By maintaining a problem-solving focus and thoughtfully integrating technology, architects can shape the built environment in innovative and sustainable ways.

Limitations and direction for future research

While the conducted case studies have provided valuable insights into the integration of technology in architecture and design, it is important to acknowledge the limitations of this research. The number of case studies included in this study was relatively limited, which may impact the generalizability of the findings. It is essential to consider this study as a perspective rather than a conclusive research effort, providing a foundation for future research, particularly within the scope of PhD studies.

One of the primary limitations of this research is the small sample size of case studies. Although the selected case studies offered diverse perspectives and addressed different aspects of technology integration, a larger number of case studies would have provided a more comprehensive understanding of the implications and significance of these technologies across a broader range of architectural projects. It is crucial to recognize that the results obtained from the conducted case studies may not fully represent the complexities and variations present in the broader architectural context.

Furthermore, due to the limited number of case studies, it was challenging to establish definitive and statistically significant findings. The qualitative nature of the data gathered from the case studies restricts the ability to generalize the results to a larger population. While the findings offer valuable insights and demonstrate the potential of integrating technology in architecture, further research involving a larger number of case studies would be required to validate and strengthen these findings.

In light of these limitations, this research should be regarded as a starting point for future investigations. The identified case studies and their findings lay the groundwork for further exploration and in-depth examination within the context of PhD studies. Future research should aim to expand the number of case studies, encompassing a wider range of architectural projects with diverse contexts, scales, and design challenges. This will enable a more comprehensive analysis of the implications and significance of technology integration in architecture and design.

Additionally, future research should also incorporate quantitative methods and data analysis techniques to complement the qualitative insights obtained from the case studies. By employing a mixed-methods approach, researchers can gather both qualitative and quantitative data, providing a more robust and comprehensive understanding of the impact of technology on architectural outcomes.

While this research has shed light on the integration of technology in architecture and design through a limited number of case studies, it is important to acknowledge the limitations of this study. The small sample size and qualitative nature of the data restrict the generalizability of the findings. However, these limitations present opportunities for future research, particularly within the scope of PhD studies, to further explore the implications and significance of technology integration in architecture. By expanding the number of case studies, employing quantitative methods, and addressing a wider range of architectural projects, researchers can enhance our understanding of the role of technology in shaping the built environment.

CONCLUSION

The results and analysis of the conducted case studies will be presented in this chapter. The outcomes of each project were evaluated based on the research questions, exploring the impact of advanced technological tools on architectural problem-solving, efficiency, and creative exploration. Furthermore, the implications of technology-driven approaches in various aspects of architectural projects, such as parametric modeling for automation, digital fabrication, and environmental analysis and simulations, were examined. By adopting a critical perspective and considering the balance between technology and problem-solving, this discussion aims to provide information on the role of technology in contemporary architectural practice.

Summary of the Study

In conclusion, this study has explored the integration of technology in architecture and design, with a particular emphasis on problem-solving and the design process. By examining four key areas of technology integration, namely Construction & Assembly, Parametric Modelling for Automation, Digital Fabrication, and Environmental Analysis & Simulations, this research has shed light on how technology can enhance problem-solving capabilities and streamline the design process in architecture.

Through the analysis of case studies, the study has showcased the transformative potential of technology in addressing design challenges and facilitating innovative solutions. The utilization of holographic technology has revolutionized the construction and assembly processes, enabling architects to visualize and resolve complex spatial issues in real-time. Customized parametric modeling has empowered architects to automate information modeling, facilitating rapid iterations and design optimization. Robotic fabrication has simplified the fabrication and assembly of architectural elements, enhancing precision and efficiency. Additionally, user-friendly daylight simulation tools have enabled architects to incorporate environmental considerations into their designs, promoting sustainability and occupant well-being.

By leveraging technology, architects can approach design problems in a more systematic and efficient manner. Technology tools offer advanced computational capabilities, data analysis, and simulation capabilities that allow architects to explore multiple design iterations, evaluate performance metrics, and make informed decisions. This enhances the problem-solving process, enabling architects to address complex design challenges, optimize functional requirements, and respond to contextual factors.

The significance of this research lies in its contribution to the understanding of how technology can facilitate problem-solving and improve the design process in architecture. By showcasing the practical applications of technology in addressing design challenges, this study provides valuable insights for architects, researchers, and stakeholders. It emphasizes the importance of integrating technology as a means to enhance creativity, efficiency, and sustainability in architectural design.

However, it is important to acknowledge the limitations of this study. The research was limited in terms of the number of case studies analyzed, which may restrict the generalizability of the findings. Additionally, the qualitative nature of the research calls for further investigation with quantitative analysis to validate and expand upon the results. This study serves as a starting point for future research, which could delve deeper into the integration of technology in problem-solving and the design process in architecture.

The integration of technology in architecture offers immense potential for advancing problem-solving capabilities and streamlining the design process. By leveraging computational design tools, digital fabrication techniques, and advanced simulation methods, architects can address complex challenges, optimize design solutions, and create innovative and sustainable built environments. The ongoing exploration and refinement of technology integration will enable architects to meet the evolving needs of society and push the boundaries of architectural design.

Possible Contributions to the field

This scope of work holds the potential for significant contributions to the field of architecture by highlighting the importance of using technology as a catalyst for problem-solving and design processes. By examining case studies that showcase the potential of technology in addressing specific design challenges, this study aims to create awareness and inspire architects and designers to harness the power of technology to enhance problem-solving approaches in their work.

The case studies presented in this research demonstrate how technology can be leveraged to overcome design obstacles and foster innovative solutions. For instance, the integration of holographic technology in the construction and assembly process enables architects to visualize and resolve spatial issues in real-time, promoting efficient and accurate design outcomes. By showcasing this application, the research seeks to inspire architects to explore holography's potential as a problem-solving tool within their own projects.

Similarly, the study emphasizes the impact of customized parametric modeling in automating information modeling, allowing architects to generate and evaluate multiple design iterations rapidly. This capability not only streamlines the design process but also empowers architects to explore and optimize design solutions based on specific problem-solving criteria. The case studies presented in this research exemplify how parametric modeling can be effectively employed to address complex design challenges, offering a glimpse into its potential to enhance problem-solving capabilities.

Furthermore, the research sheds light on the transformative influence of robotic fabrication on the fabrication and assembly of architectural elements. By harnessing advanced robotic technologies, architects can achieve heightened levels of precision and efficiency, resulting in improved problem-solving outcomes during the construction process. The case studies provided in this research serve as compelling examples of how robotic fabrication can be utilized to overcome challenges and streamline fabrication and assembly processes, ultimately enhancing problem-solving efficiency.

By showcasing these case studies, the research seeks to shift the focus from a mere display of technological prowess to a problem-solving approach in the utilization of technology. It underscores the significance of using technology as a means to address design challenges and optimize design solutions in a purposeful and targeted manner. The research urges architects to consider the problem-solving potential of technology tools and techniques and to integrate them thoughtfully into their design processes.

The potential significant contributions of this research lie in its ability to generate awareness and provide insights into the effective use of technology for problem-solving in architecture. By showcasing case studies that exemplify the potential of technology in addressing specific design challenges, the research inspires architects to approach technology as a powerful problem-solving tool rather than a mere novelty. This shift in perspective has the potential to enhance the efficiency, creativity, and sustainability of architectural design, ultimately benefiting the entire field.

This research has the potential for significant contributions to the field of architecture by promoting the understanding and utilization of technology as a means of problem-solving. Through the presented case studies, architects and designers are encouraged to explore the problem-solving potential of technology tools and techniques, elevating their ability to address complex design challenges and create innovative and sustainable built environments. By fostering a problem-solving mindset in the use of technology, this research has the potential to drive substantial advancements and positive change in the field of architecture.

Recommendation for future Research

Considering the findings and contributions of this research, several recommendations can be made for future studies that aim to further explore the potential of technology as a problem-solving tool in architecture and design.

Firstly, it is recommended that future research focuses on creating case studies that incorporate cross-uses of the topics explored in this study. By combining different technological approaches such as holographic technology, parametric modeling, digital fabrication, and environmental analysis, architects can explore the synergies and benefits that arise from the integration of multiple technologies. This cross-use approach has the potential to unlock new avenues for problem-solving and design optimization, enabling architects to tackle complex challenges from a multidimensional perspective.

Additionally, future research could benefit from actively involving practitioners, students, and teachers in the deployment and evaluation of technology as a problem-solving tool. Engaging these stakeholders and gathering their insights and experiences can provide valuable real-world perspectives and practical knowledge. By incorporating the wisdom and reflections of those actively working in the field, this research can be reinforced as a milestone study and serve as a guide for students and practitioners alike. Their expertise can shed light on the practical implications, challenges, and opportunities of using technology as a problem-solving tool, further enriching the understanding and application of technology in architectural practice.

Furthermore, future research could explore the potential of integrating technology into architectural education. By incorporating technology-driven problem-solving approaches into the curriculum, students can develop a strong foundation in using technology as a tool for addressing design challenges. This integration can help foster an awareness of the problem-solving capabilities of technology early on, enabling future architects to embrace and leverage technological advancements effectively. Research could focus on identifying the most effective pedagogical strategies and tools for teaching and learning technology-driven problem-solving methodologies, ensuring that students are well-equipped to harness technology's potential in their future practice.

Lastly, future studies could delve into the long-term impacts and sustainability aspects of technology-driven problem-solving approaches in architecture. Investigating the environmental, social, and economic implications of incorporating technology into the design process can provide valuable insights into creating sustainable and resilient built environments. By analyzing the life-cycle impacts of technology use, identifying potential pitfalls, and proposing strategies for mitigating negative effects, researchers can guide architects and designers towards responsible and ethical application of technology in problem-solving.

Future research in this field should focus on creating case studies with cross-uses of technology, involving practitioners, students, and teachers in the deployment and evaluation of technology as a problem-solving tool, integrating technology into architectural education, and exploring the long-term sustainability aspects of technology-driven approaches. By following these recommendations, researchers can build upon the foundation laid by this study and further advance the understanding, application, and impact of technology in architecture and design.

Concluding Remarks

This research focuses on the potential and significance of technology as a problem-solving tool in the field of architecture and design. By examining case studies that exemplify the integration of technology in various aspects of the design process, we have uncovered valuable insights and contributions.

The findings of this research highlight that technology, when strategically applied, can significantly enhance the problem-solving capabilities of architects and designers. Through holographic technology, architects can visualize and communicate design ideas with enhanced clarity and spatial understanding, facilitating more effective problem-solving and decision-making. Customized parametric modeling enables automation and optimization, streamlining the design process and allowing for efficient exploration of design alternatives. Robotic fabrication techniques offer increased precision, efficiency, and complexity management, empowering architects to materialize their designs with greater accuracy and detail. Furthermore, user-friendly simulation tools enable architects to assess and optimize environmental performance, resulting in more sustainable and user-centric designs.

One of the key contributions of this research is the emphasis on problem-solving in the design process. Rather than solely focusing on the showcase aspect of technology, this study underscores the importance of technology as a means to address design challenges and improve design outcomes. By showcasing case studies that demonstrate the problem-solving potential of technology, this research aims to create awareness and inspire architects and designers to leverage technology as a tool for effective problem-solving.

The significance of this research lies in its potential to revolutionize architectural practice by promoting a problem-solving mindset and harnessing technology's capabilities to address complex design challenges. By incorporating technology-driven methodologies, architects can overcome limitations, enhance creativity, and unlock innovative design solutions. The case studies presented in this research serve as examples, illustrating how technology can be integrated seamlessly into the design process, fostering a holistic and user-centric approach to architecture.

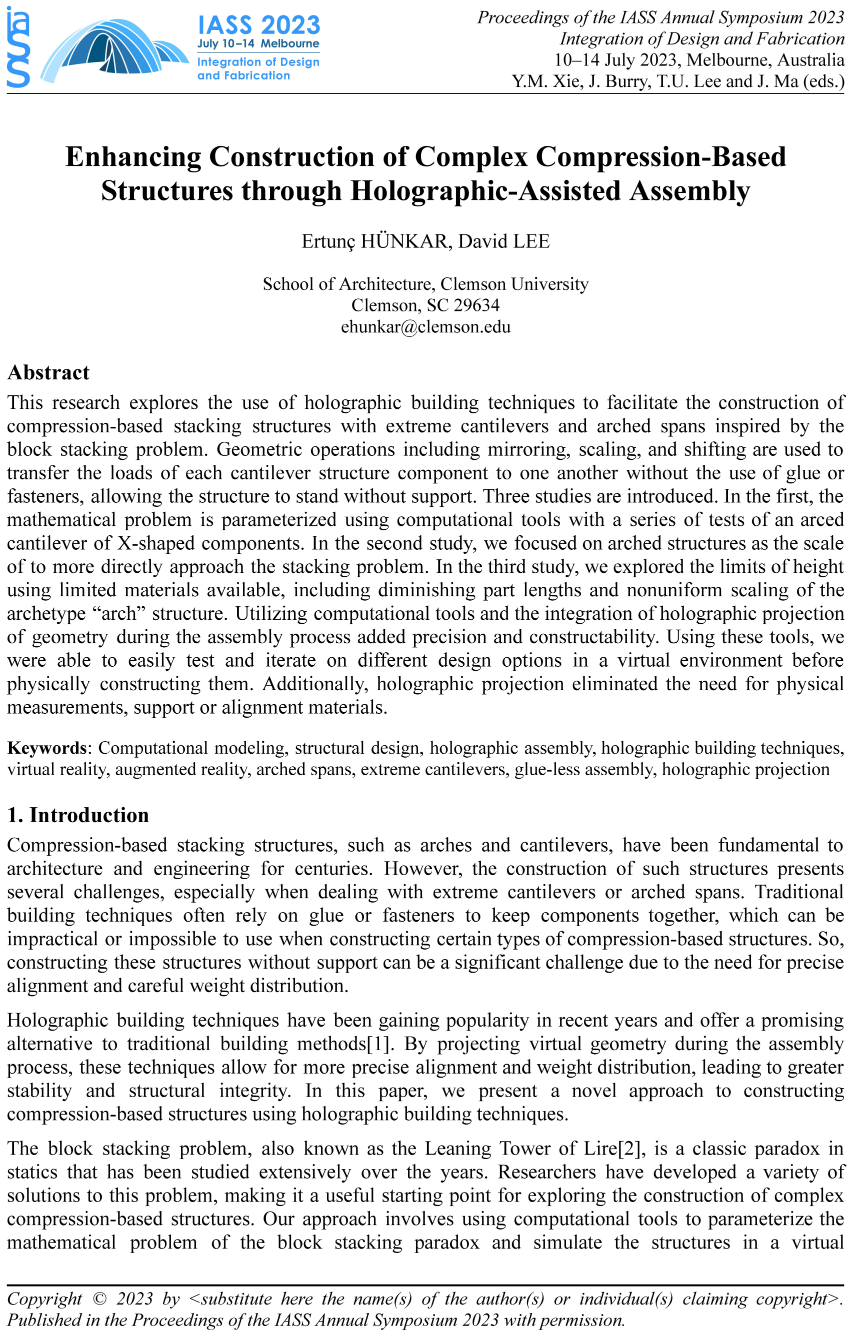
This work has potentially contributed to the field by highlighting the transformative role of technology in problem-solving and design. By advocating for a problem-solving approach and showcasing case studies that demonstrate the potential of technology, this study aims to inspire architects, educators, and practitioners to adopt technology-driven strategies and methods. It is our hope that this research serves as a milestone in the ongoing exploration and integration of technology in architecture, propelling the field forward and empowering architects to create innovative, sustainable, and user-centric built environments.

As technology continues to advance, it is essential to recognize its potential and embrace it as a powerful tool in the architectural practice. By leveraging technology's problem-solving capabilities, architects can navigate the complexities of the built environment and create designs that address societal needs, respond to contextual challenges, and enrich the human experience. The future holds immense opportunities for technology-driven problem-solving in architecture, and it is our collective responsibility to explore, innovate, and shape the built environment in ways that are both visionary and meaningful

APPENDICES

Appendix A

Enhancing Construction of Complex Compression-Based Structures through Holographic-Assisted Assembly



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Enhancing Construction of Complex Compression-Based Structures through Holographic-Assisted Assembly

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Abstract

This research explores the use of holographic building techniques to facilitate the construction of compression-based stacking structures with extreme cantilevers and arched spans inspired by the block stacking problem. Geometric operations including mirroring, scaling, and shifting are used to transfer the loads of each cantilever structure component to one another without the use of glue or fasteners, allowing the structure to stand without support. Three studies are introduced. In the first, the mathematical problem is parameterized using computational tools with a series of tests of an arced cantilever of X-shaped components. In the second study, we focused on arched structures as the scale of to more directly approach the stacking problem. In the third study, we explored the limits of height using limited materials available, including diminishing part lengths and nonuniform scaling of the archetype "arch" structure. Utilizing computational tools and the integration of holographic projection of geometry during the assembly process added precision and constructability. Using these tools, we were able to easily test and iterate on different design options in a virtual environment before physically constructing them. Additionally, holographic projection eliminated the need for physical measurements, support or alignment materials.

Keywords: Computational modeling, structural design, holographic assembly, holographic building techniques, virtual reality, augmented reality, arched spans, extreme cantilevers, glue-less assembly, holographic projection

1. Introduction

Compression-based stacking structures, such as arches and cantilevers, have been fundamental to architecture and engineering for centuries. However, the construction of such structures presents several challenges, especially when dealing with extreme cantilevers or arched spans. Traditional building techniques often rely on glue or fasteners to keep components together, which can be impractical or impossible to use when constructing certain types of compression-based structures. So, constructing these structures without support can be a significant challenge due to the need for precise alignment and careful weight distribution.

Holographic building techniques have been gaining popularity in recent years and offer a promising alternative to traditional building methods[1]. By projecting virtual geometry during the assembly process, these techniques allow for more precise alignment and weight distribution, leading to greater stability and structural integrity. In this paper, we present a novel approach to constructing compression-based structures using holographic building techniques.

The block stacking problem, also known as the Leaning Tower of Lire[2], is a classic paradox in statics that has been studied extensively over the years. Researchers have developed a variety of solutions to this problem, making it a useful starting point for exploring the construction of complex compression-based structures. Our approach involves using computational tools to parameterize the mathematical problem of the block stacking paradox and simulate the structures in a virtual

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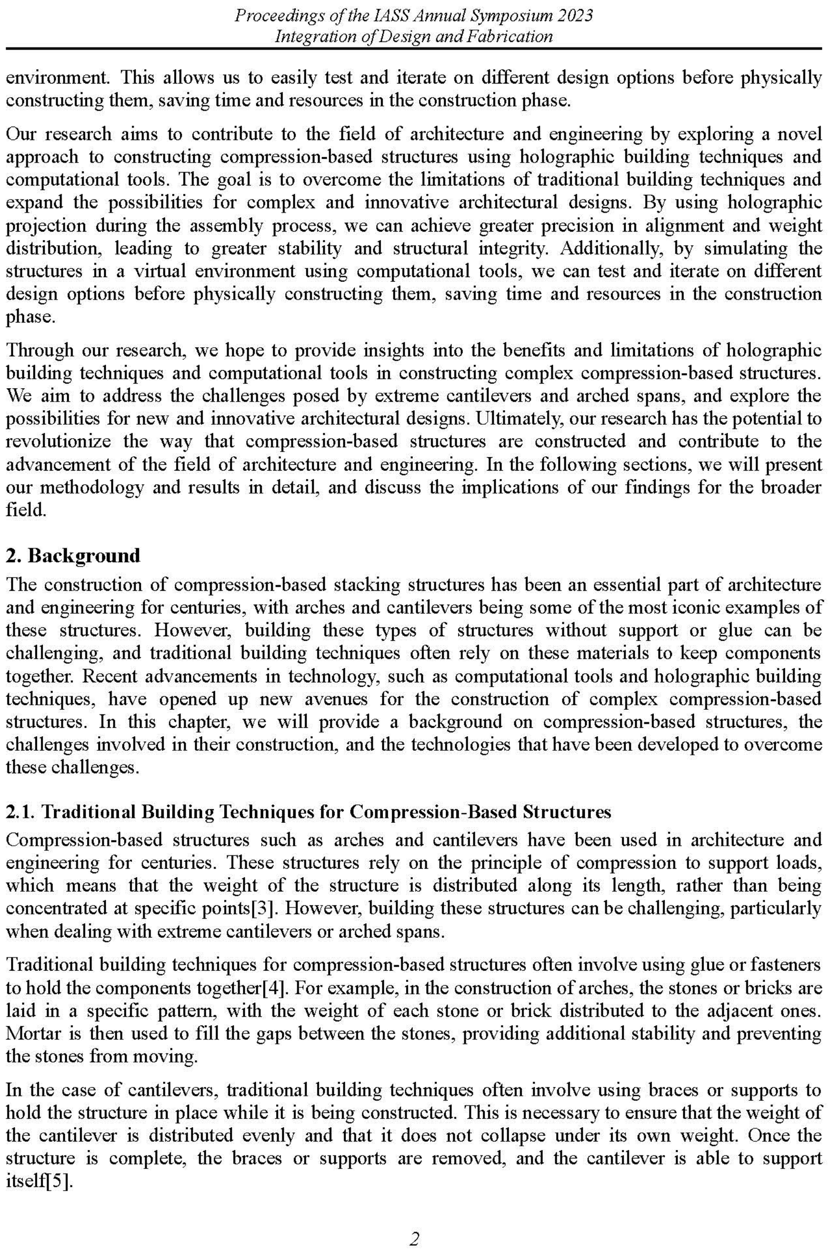
Figure A-1: Publication Page-1



environment. This allows us to easily test and iterate on different design options before physically constructing them, saving time and resources in the construction phase.

Our research aims to contribute to the field of architecture and engineering by exploring a novel approach to constructing compression-based structures using holographic building techniques and computational tools. The goal is to overcome the limitations of traditional building techniques and expand the possibilities for complex and innovative architectural designs. By using holographic projection during the assembly process, we can achieve greater precision in alignment and weight distribution, leading to greater stability and structural integrity. Additionally, by simulating the structures in a virtual environment using computational tools, we can test and iterate on different design options before physically constructing them, saving time and resources in the construction phase.

Through our research, we hope to provide insights into the benefits and limitations of holographic building techniques and computational tools in constructing complex compression-based structures. We aim to address the challenges posed by extreme cantilevers and arched spans, and explore the possibilities for new and innovative architectural designs. Ultimately, our research has the potential to revolutionize the way that compression-based structures are constructed and contribute to the advancement of the field of architecture and engineering. In the following sections, we will present our methodology and results in detail, and discuss the implications of our findings for the broader field.

2. Background

The construction of compression-based stacking structures has been an essential part of architecture and engineering for centuries, with arches and cantilevers being some of the most iconic examples of these structures. However, building these types of structures without support or glue can be challenging, and traditional building techniques often rely on these materials to keep components together. Recent advancements in technology, such as computational tools and holographic building techniques, have opened up new avenues for the construction of complex compression-based structures. In this chapter, we will provide a background on compression-based structures, the challenges involved in their construction, and the technologies that have been developed to overcome these challenges.

2.1. Traditional Building Techniques for Compression-Based Structures

Compression-based structures such as arches and cantilevers have been used in architecture and engineering for centuries. These structures rely on the principle of compression to support loads, which means that the weight of the structure is distributed along its length, rather than being concentrated at specific points[3]. However, building these structures can be challenging, particularly when dealing with extreme cantilevers or arched spans.

Traditional building techniques for compression-based structures often involve using glue or fasteners to hold the components together[4]. For example, in the construction of arches, the stones or bricks are laid in a specific pattern, with the weight of each stone or brick distributed to the adjacent ones. Mortar is then used to fill the gaps between the stones, providing additional stability and preventing the stones from moving.

In the case of cantilevers, traditional building techniques often involve using braces or supports to hold the structure in place while it is being constructed. This is necessary to ensure that the weight of the cantilever is distributed evenly and that it does not collapse under its own weight. Once the structure is complete, the braces or supports are removed, and the cantilever is able to support itself[5].

Figure A-2: Publication Page-2

While these traditional building techniques have been used successfully for many years, they have limitations when it comes to constructing complex compression-based structures. Constructing these structures without support can be a significant challenge due to the need for precise alignment and careful weight distribution.

As a result, new building techniques have emerged in recent years that offer alternative approaches to constructing compression-based structures. One such approach is the use of holographic building techniques, which we will explore in more detail in the following sections.

2.2. Limitations of Traditional Building Techniques for Compression-Based Structures

Despite the long history of compression-based structures, traditional building techniques have several limitations that can make construction difficult, particularly for structures with extreme cantilevers or arched spans. One significant challenge is the need for precise alignment of each component. Even slight deviations from the intended position can lead to structural instability and collapse. This need for precise alignment can be particularly challenging for structures with complex geometries, which can be difficult to measure and align accurately.

Another limitation of traditional techniques is the need for additional support materials, such as scaffolding or bracing. These materials can be costly and time-consuming to install, particularly for large or complex structures. Additionally, the use of these materials can limit the design possibilities, as they can obstruct access to certain areas or limit the range of possible component configurations.

Glue or fasteners are commonly used in traditional building techniques to keep components together. However, the use of these materials can be impractical or impossible for certain types of compression-based structures[6]. Also, traditional building techniques can be limited in their ability to accommodate complex geometries. Structures with complex geometries, such as those with curved or irregular shapes, can be difficult to construct using traditional techniques, particularly when dealing with extreme cantilevers or arched spans. This limitation can limit the range of possible designs and limit the creativity of architects and engineers.

These limitations have led to the development of new and innovative building techniques, such as holographic building techniques, that offer potential solutions to these challenges. Holographic building techniques offer a promising solution to the challenges and limitations of traditional building techniques for compression-based structures. By projecting virtual geometry during the assembly process, holographic techniques allow for more precise alignment and weight distribution, leading to greater stability and structural integrity. This approach also eliminates the need for physical measurements, support, or alignment materials[7].

Overall, holographic building techniques offer a promising solution to the challenges and limitations of traditional building techniques for compression-based structures. By allowing for more precise alignment and weight distribution, holographic techniques can lead to greater stability and structural integrity, making it possible to construct more complex and innovative architectural designs. In the next section, we will present our approach to using holographic building techniques in the construction of compression-based structures with extreme cantilevers and arched spans.

2.3. Holographic Building Techniques as a Solution

Holographic building techniques have emerged as a promising solution to the challenges and limitations of traditional building techniques for compression-based structures. These techniques utilize virtual reality and augmented reality to project holographic images of the structure's geometry during the assembly process[11]. This enables builders to visualize the final structure before its construction, to identify any potential issues, and to test different design options virtually, reducing errors and saving time and resources in the construction phase.

Figure A-3: Publication Page-3

One of the primary advantages of holographic building techniques is the ability to achieve greater precision in alignment and weight distribution, which is crucial for compression-based structures. With traditional building techniques, precise alignment and weight distribution can be difficult to achieve, leading to instability and potential collapse of the structure. Holographic building techniques eliminate the need for manual measurements and alignment, allowing builders to achieve greater accuracy in the assembly process[8].

Furthermore, holographic building techniques can also reduce the use of materials and resources in the construction phase. With traditional building techniques, builders may need to use additional support or alignment materials, adding to the overall cost and complexity of the construction process. Holographic building techniques eliminate the need for additional materials, resulting in more cost-effective and efficient construction.

2.4. Current State of Field

Over the past few years, construction techniques that use holographic technology to project a virtual model of a structure onto the construction site have emerged, providing new opportunities for building compression-based structures. This approach eliminates the need for physical measurement, support, or alignment materials, resulting in a significant reduction in construction time and cost. An instance of such an approach is found in the Hyphae House and the Paperless Worksite[9], where researchers employed augmented reality on smartphones to construct complex structures without using CNC technology. Despite some placement issues with the blocks, the technology exhibited potential as a construction and visualization method.

Another example of this holographic building technique is the Allbrick Feature Wall[10], where researchers worked with All Brick and the University of Tasmania to create a small feature wall using an interactive mixed reality model that displayed the precise location of each brick. By eliminating the need for templates, drawings, or physical measurements, the estimated 2-week build time was significantly reduced to only 6.5 hours of bricklaying. Holographic instructions were developed by sorting bricks by height and showing one course at a time, with further improvement by showing only an outline of the top face of each brick as a virtual boundary during placement. The HoloLens's precision was well within the tolerances of general construction, as confirmed by a lidar scan of the project.

Despite these advances, there are still challenges in the compression-based structures field. Understanding and researching the structures' behavior under different loads and conditions, particularly those with cantilevers or arched spans, is critical.

3. Methodology

In this chapter, we will detail the methodology used to approach the block stacking problem. We begin by describing the parameterization of the mathematical problem using computational tools, which involves the creation of a dynamic parametric model and subsequent physical model to test its accuracy. We will then move on to discuss three specific studies undertaken within this framework, including the arced cantilever of X-shaped components, arched structures, and limits of height using limited materials. Finally, we will examine the utilization of holographic projection of geometry during the assembly process, providing insights into the advantages and limitations of this approach.

3.1. Parameterization of the mathematical problem using computational tools

The block stacking problem is a well-known paradox in statics that has been extensively studied over the years. The objective of this problem is to stack blocks along the edge of a table in a way that keeps the center of gravity of the assembly on or within the non-overhang side of the table.(Figure 1.). In order to use this problem as a design input, we have created a parametric model of the problem using

Figure A-4: Publication Page-4

linear elements.

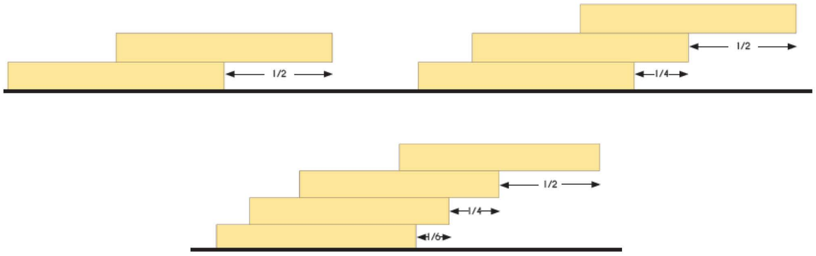


Figure 1. Block Stacking Problem Diagram

This parametric model allows us to explore the relationship between the number of elements and the cantilever distance in a dynamic and interactive way. We have color-coded the model to indicate the cantilever distance, with red indicating the maximum distance and green indicating the minimum distance. This dynamic model has provided us with valuable insights into the behavior of the system and has helped us to identify potential design improvements.

With the information gleaned from the dynamic model, we proceeded to build a physical model of the block stacking problem (Figure 2.). The physical model consists of 4.5-inch long wooden pieces stacked in a manner similar to the parametric model. However, the vertical distance between the wooden pieces in the physical model is greater than 4.5 inches to accommodate supporting pieces.

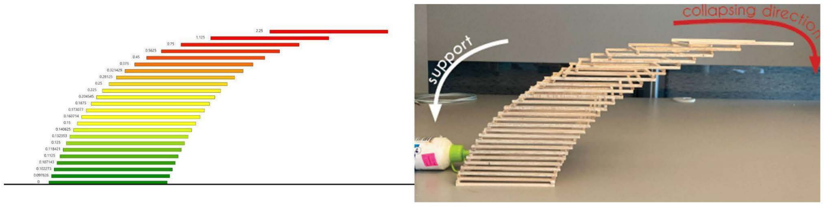


Figure 2. First Iteration Parametric Model & Physical Model

In our initial attempt to build the physical model, we found that it collapsed without any support. This led us to come up with a new iteration of the design. We decided to reduce the length of the wooden pieces as we stacked them higher, as this would provide us with a stronger chance of achieving a self-supporting structure. Thanks to the parametric nature of our model, it was relatively easy to come up with these types of variations and explore their impact on the system.

Since the parametric model is created with parameters, it was easy to come up with variations to improve the physical model. For instance, by reducing the length of the material from 4.5 inches to 2.7 inches, we were able to create a physical model that stands on its own, step by step (Figure 3.). This process allowed us to fine-tune the physical model until we achieved the desired outcome. In contrast to the physical model, the digital model required the addition of supporting lateral wood pieces in every space, due to the lack of lateral stability in the stacking direction. This was necessary to prevent the pieces from falling over immediately, as the digital model only tested the stacking direction from

Figure A-5: Publication Page-5

bottom to top. Thus, this modification added an extra level of complexity to the models, and the entire process of creating both the physical models took approximately 1.5 working days, due to the precision required in the small shifting distances.

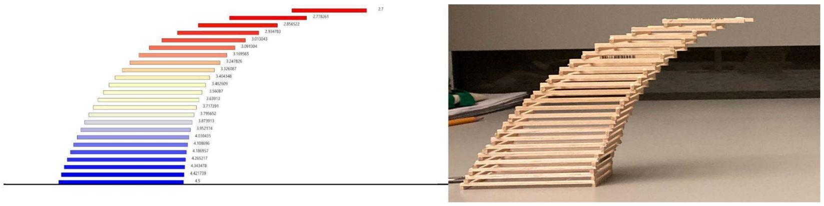


Figure 3. First Iteration Parametric Model & Physical Model

In summary, we utilized a parametric model to analyze the block stacking problem, which enabled us to visualize the problem dynamically and generate insights that helped us create a self-supporting physical model. Through this process, we were able to gain a deeper understanding of the block stacking problem and develop an effective solution.

3.2. Three studies: arced cantilever of X-shaped components, arched structures, and limits of height using limited materials

After conducting experiments with physical models, we decided to prototype different variations of the stacking strategy. Our first prototype aimed to construct an arched cantilever surface with X-shaped stacking components for a portion of the entire structure (Figure 4.). The X shape allowed us to change the stacking angle to construct the portion of the surface more precisely. However, the prototype resulted in a collapsed structure. The angled components created a shear force that shifted the center of gravity, causing the structure to collapse. From this experiment, we learned two important things. First, X-shaped components with different angles can lead to a shift in the center of gravity, resulting in structural collapse. Second, there was no support for the cantilever as it grew with less and less support underneath. These outcomes helped us improve the structural capabilities of our next prototypes.

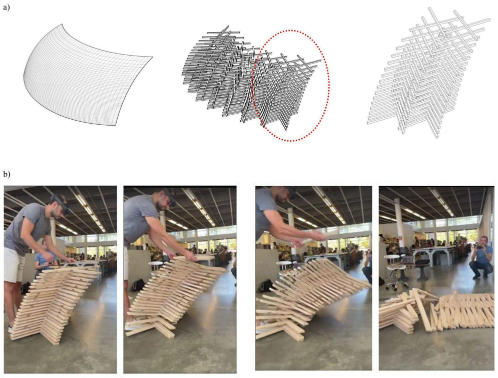


Figure A-6: Publication Page-6

Figure 4. (a) Cantilever Surface and its portion with X shaped Components, (b) Collapsed prototype

Learning from the first prototype, our second prototype utilized 90 degree rotating stacking components from our physical models. We started by decreasing the total height of the prototype, allowing us to use more wood pieces in opposite directions to support the initial cantilevering piece. We started with a stool-scale stacking, creating a stool by stacking pieces on top of each other. To enhance the stool's structural capacity, we had two units that were similar to each other except for one being mirrored and shrunken down in its width to create an interlocking connection with the initial unit. Following the same idea, we created a bench using a similar procedure, designed to have its initial unit interlocked with the supporting unit of the bench. This enabled us to create both pieces in a way that they support each other (stool to bench). When weight is applied to these furniture pieces, the stacking system locks itself in place, similar to a compression-based structure (Figure 5.).

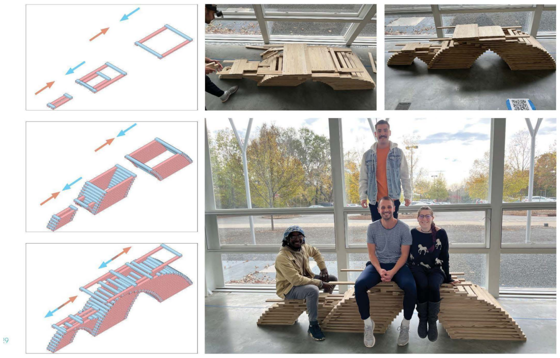


Figure 5. Stool and bench formation

The success of this prototype encouraged us to proceed with a larger installation. However, we had two important constraints to consider: the number of wood pieces and the length of wood pieces. While we had a parametric model that generated new lengths, we decided to use the wood pieces that were available in our inventory. We sorted the wood pieces from long to short, from the ground up, using a parametric model that took into account the available wood pieces. By doing so, we aimed to use different lengths to create structural stability where the installation touched the ground (Figure 6.).

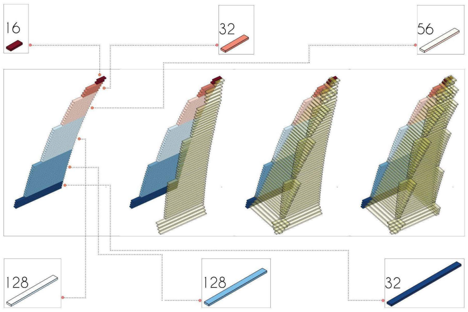


Figure A-7: Publication Page-7

Figure 6. Material Inventory and Distribution

Unlike the second prototype, both units supported the initial unit, created as the same and then shifted to create an interlocking connection. In the end, we successfully built the installation with the available material we had (Figure 7.). The installation demonstrated the potential of the stacking strategy to create a stable structure, even with limited materials. It also highlighted the importance of considering the availability and characteristics of the materials when designing a structure, as well as the need for careful planning and execution to ensure the structural stability of the final product.

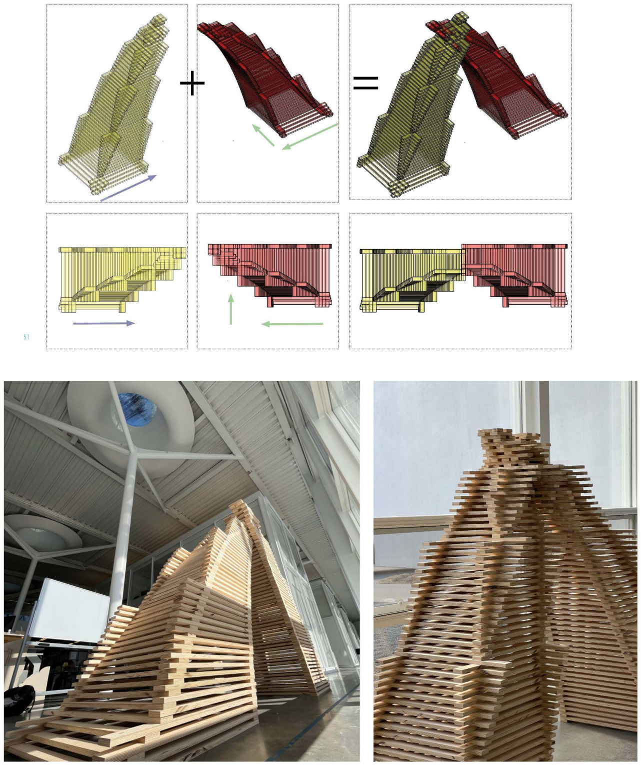


Figure 7. Installation Formation & Finished Prototype

3.3. Utilization of holographic projection of geometry during the assembly process

For all three prototypes that the researchers attempted to build, holographic projection techniques were used to project the computational model onto the site location. This allowed the researchers to perform construction without relying on physical measurements or 2D drawings, which was particularly

Figure A-8: Publication Page-8

important for wood stacking due to the small distance on each stacking layer. A straightforward construction technique was followed. First, the model was prepared as a parametric model and visualized with an Augmented Reality headset. This preparation required time to set up the most efficient adjustments. The researchers started by color-coding each wood piece based on its height, but this created too many colors to follow. They decided to go with only two colors for the stacking, with level 0 in orange and level 1 in blue. This alternating color rule was followed to put the wood pieces. The parameters were set up in a way that this sequence could be controlled by an external phone that had 'Fologram' and/or HoloLens. All this setup was done in grasshopper.

Secondly, a QR code was generated to align the digital model to the physical construction site. The researchers taped the printed QR code on the area where they wanted to build so that they could restart the device and start again where they left off if they encountered technical issues such as running out of battery, losing the model, or HoloLens stopped working, etc. This setup was fundamental for each of the three prototypes, although there were some differences and additions in different phases.

For instance, while prototyping the arced surface geometry with X-shaped components, the researchers used a gravity simulation to detect where the structure would collapse before building the whole portion of it. Kangaroo was used in grasshopper to perform the simulation, which had promising results (Figure 8.).

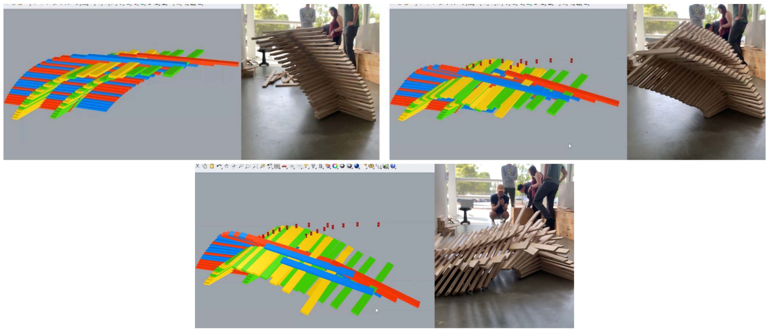


Figure 8. Gravity Simulation that shows the collapse digitally

However, the inefficiency in terms of the time it took to run (over an hour) made the researchers decide not to stick to the simulation. In this prototype, holographic projection was used in a shaded view (Figure 9.).

Figure A-9: Publication Page-9

Figure 9. Shaded holographic projection

But the shaded view created problems in that the researchers could not track the real wood piece when they had HoloLens due to the projection type. Therefore, they switched the projection method from shading to wireframe, which worked better because they could easily align the edges of the wood pieces on the wireframe view. It also avoided any freezing due to heavier geometries that were generated by shaded views. So for the second "Arched structures and their performance" and third "Height limitations of limited materials in block stacking" prototypes, wireframe projection was used (Figure 10.)

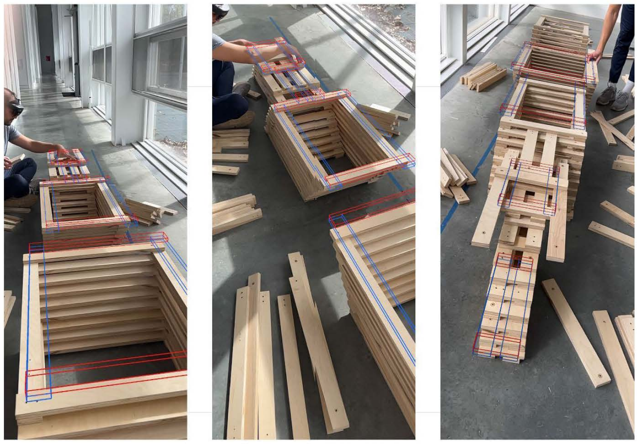


Figure 10. Shaded holographic projection

Holographic projection was used for the construction of all these experiments due to the dynamics of the project that the researchers were working on. It helped them locate the wood pieces in exact locations, even though they shifted slightly on each layer. This was crucial because this notion of movement on each stacking layer enabled the researchers to create these self-standing structures by controlling the center of gravity. Any error while placing them might cause unexpected collapses during the construction phase, but none were encountered. By using holographic projection, the structural design performed in a way that the researchers reached their goal without using glue, fasteners, or any other connection detail.

4. Results

The implementation of computational tools and holographic projection has resulted in a number of significant benefits for the design and construction process. Perhaps most notably, these techniques have enabled the creation of precise and highly constructable design options. By using these tools, we are able to create highly accurate digital models that can be easily translated into physical structures. This has allowed for an unprecedented level of precision in the design and construction process, greatly reducing the likelihood of errors or inefficiencies.

Also, the use of computational tools and holographic projection has also eliminated the need for physical measurements, support, or alignment materials. This has resulted in significant cost savings and reduced waste, as well as a more streamlined and efficient construction process. With these

Figure A-10: Publication Page-10

techniques, designers and builders can create complex structures with ease, without the need for extensive support or alignment structures.

Overall, the implementation of computational tools and holographic projection has greatly improved the efficiency, accuracy, and sustainability of the design and construction process. With these tools, designers and builders can create highly precise and constructable designs, while also reducing costs and waste. As the technology continues to develop, it is likely that we will see even more innovative and impactful uses of these techniques in the future.

5.Discussion

The field of architecture has been revolutionized by the use of computational design tools that allow architects to explore complex forms that were once impossible to create, thereby expanding the design solution space. However, traditional design annotation methods can be inefficient, especially in construction environments with limited fabrication means and skilled laborers. To address these challenges, the recent use of holographic projection technology in experimental architectural projects has shown promising results. By projecting computationally generated geometries onto the field of vision using wearable devices or smartphones, architects can create an immersive environment for implementers. Interactive holography provides architects with the ability to translate design intentions into intelligent instructions instead of static drawings, offering a significant opportunity to reduce construction complexity and potentially increase precision[11].

Nonetheless, there may be limitations to the size and complexity of structures that can be constructed using holographic projection-based techniques. While the method has shown promise in constructing small-scale prototypes, it may not be feasible for larger or more complex structures such as bridges or skyscrapers. The construction of these types of structures would require more advanced and robust holographic projection systems, as well as extensive testing and validation to ensure that they are safe and reliable. Another limitation is that the current technology may not be accessible or affordable for all builders and architects. The cost of developing and implementing holographic projection-based systems may be prohibitive for smaller firms or individual builders, limiting the potential impact of this technology on the broader construction industry.

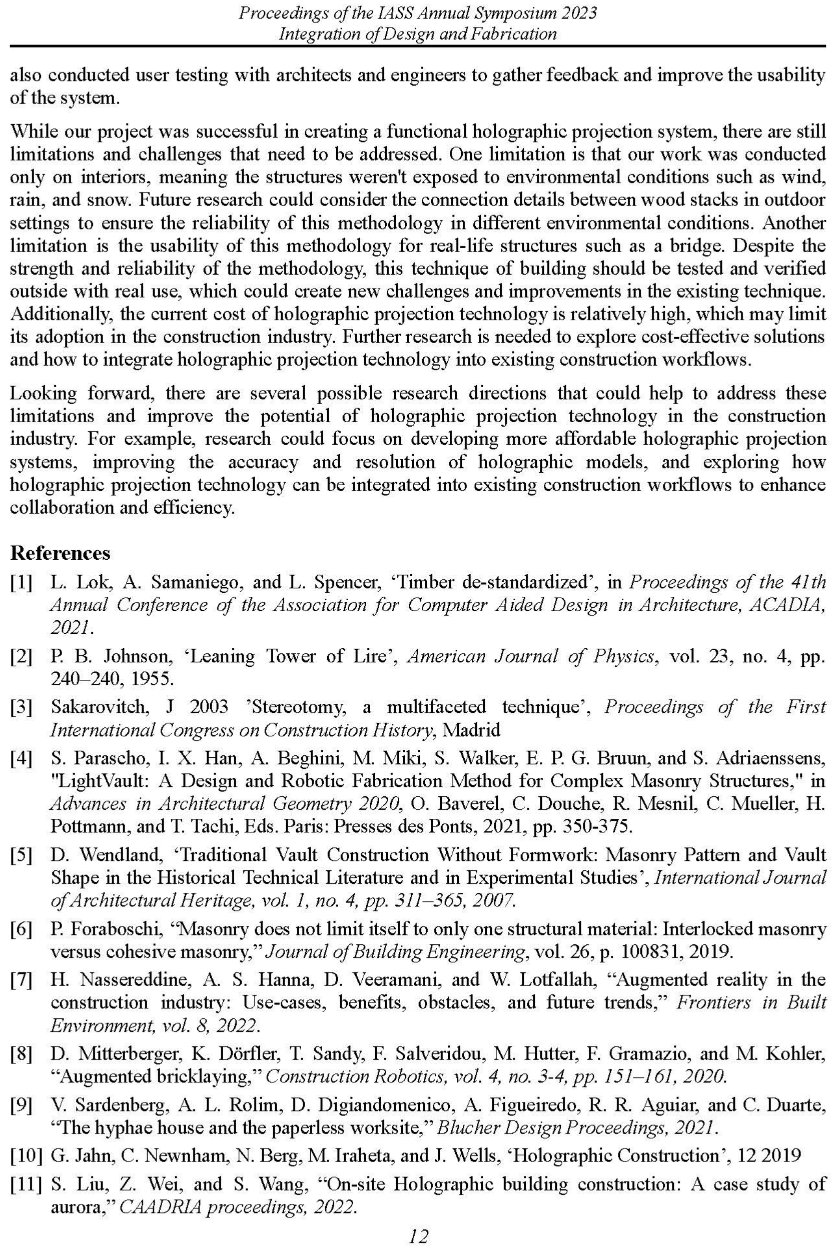
Our work was conducted only on interiors, meaning the structures were not exposed to environmental conditions such as wind, rain, snow, and others. It is crucial to address this limitation in future research by reconsidering the connection details between wood stacks and other materials used in construction. Additionally, the usability of this methodology for real-life structures such as bridges needs to be tested and verified in real-world applications. While holographic-assisted assembly is a promising technology, it requires further development and testing to ensure its effectiveness and reliability in real-world applications.

6.Conclusion

Holographic projection technology has the potential to revolutionize the construction industry by providing a new way of visualizing and planning construction projects. The ability to create 3D holographic models of building designs allows architects, engineers, and builders to better understand the structure of a building before it is constructed, making the construction process more efficient and cost-effective.

Our project aimed to explore the potential of holographic projection technology in the construction industry through the development of a prototype holographic projection system. We used a combination of hardware and software components to create a system capable of projecting 3D holographic models onto a physical space. Our methodology involved testing and refining various components of the system, such as the projector and the software used to create the 3D models. We

Figure A-11: Publication Page-11



also conducted user testing with architects and engineers to gather feedback and improve the usability of the system.

While our project was successful in creating a functional holographic projection system, there are still limitations and challenges that need to be addressed. One limitation is that our work was conducted only on interiors, meaning the structures weren't exposed to environmental conditions such as wind, rain, and snow. Future research could consider the connection details between wood stacks in outdoor settings to ensure the reliability of this methodology in different environmental conditions. Another limitation is the usability of this methodology for real-life structures such as a bridge. Despite the strength and reliability of the methodology, this technique of building should be tested and verified outside with real use, which could create new challenges and improvements in the existing technique. Additionally, the current cost of holographic projection technology is relatively high, which may limit its adoption in the construction industry. Further research is needed to explore cost-effective solutions and how to integrate holographic projection technology into existing construction workflows.

Looking forward, there are several possible research directions that could help to address these limitations and improve the potential of holographic projection technology in the construction industry. For example, research could focus on developing more affordable holographic projection systems, improving the accuracy and resolution of holographic models, and exploring how holographic projection technology can be integrated into existing construction workflows to enhance collaboration and efficiency.

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[10] G. Jahn, C. Newnham, N. Berg, M. Iraheta, and J. Wells, 'Holographic Construction', 12 2019

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Figure A-12: Publication Page-12

Appendix B

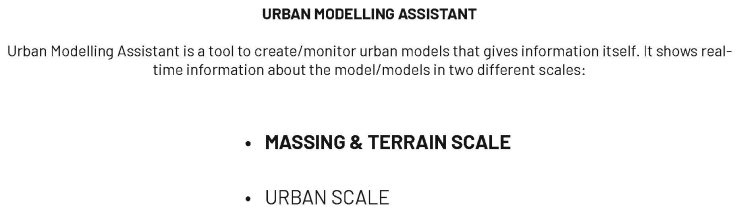
Urban Modeling Assistant

URBAN MODELLING ASSISTANT

Figure B-1: Document Page-1

WHAT IS TOOL ABOUT ?

Figure B-2: Document Page-2

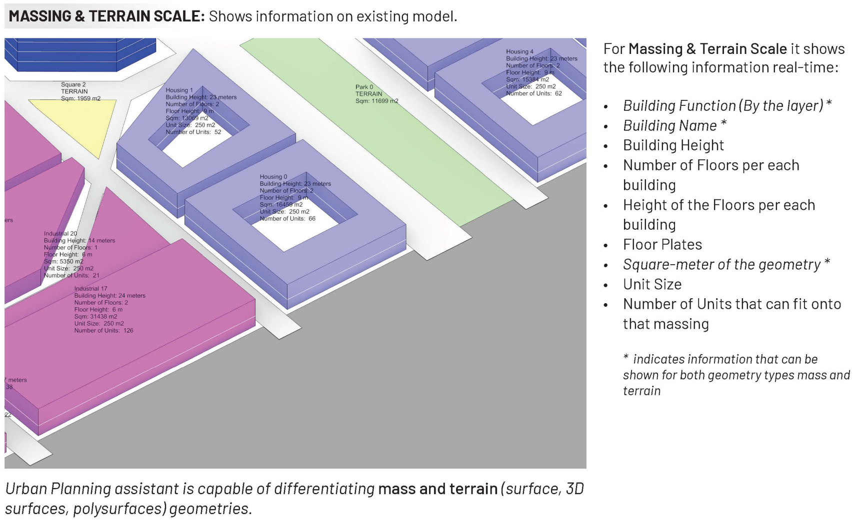


URBAN MODELLING ASSISTANT

Urban Modelling Assistant is a tool to create/monitor urban models that gives information itself. It shows real-time information about the model/models in two different scales:

- **MASSING & TERRAIN SCALE**
- URBAN SCALE

Figure B-3: Document Page-3



MASSING & TERRAIN SCALE: Shows information on existing model.

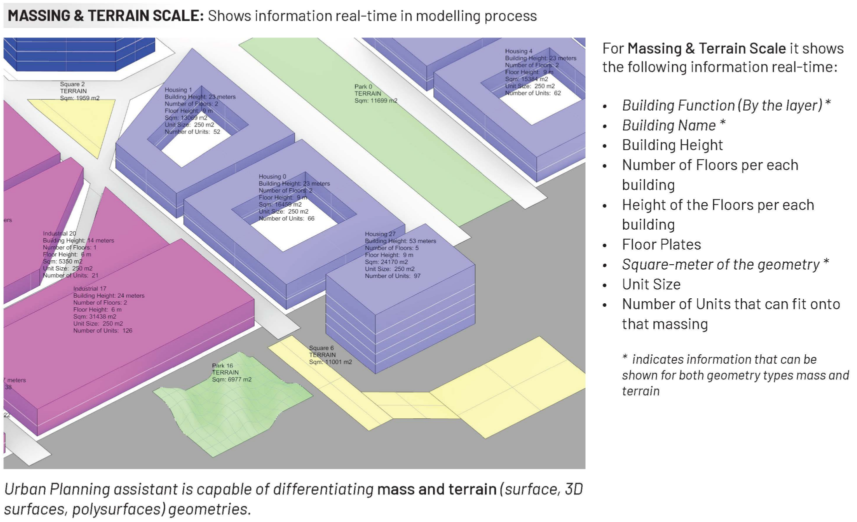
Urban Planning assistant is capable of differentiating **mass and terrain** *(surface, 3D surfaces, polysurfaces) geometries.*

For **Massing & Terrain Scale** it shows the following information real-time:

- *Building Function (By the layer) **
- *Building Name **
- Building Height
- Number of Floors per each building
- Height of the Floors per each building
- Floor Plates
- *Square-meter of the geometry **
- Unit Size
- Number of Units that can fit onto that massing

** indicates information that can be shown for both geometry types mass and terrain*

Figure B-4: Document Page-4



MASSING & TERRAIN SCALE: Shows information real-time in modelling process

Urban Planning assistant is capable of differentiating **mass and terrain** *(surface, 3D surfaces, polysurfaces) geometries.*

For **Massing & Terrain Scale** it shows the following information real-time:

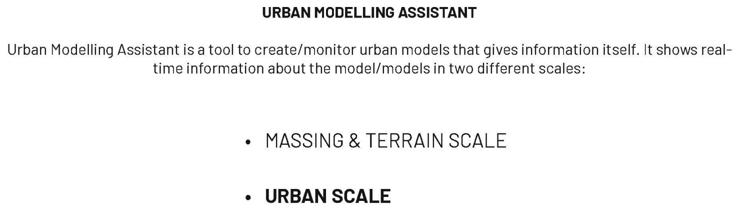
- *Building Function (By the layer) **
- *Building Name **
- Building Height
- Number of Floors per each building
- Height of the Floors per each building
- Floor Plates
- *Square-meter of the geometry **
- Unit Size
- Number of Units that can fit onto that massing

** indicates information that can be shown for both geometry types mass and terrain*

Figure B-5: Document Page-5

WHAT IS TOOL ABOUT ?

Figure B-6: Document Page-6

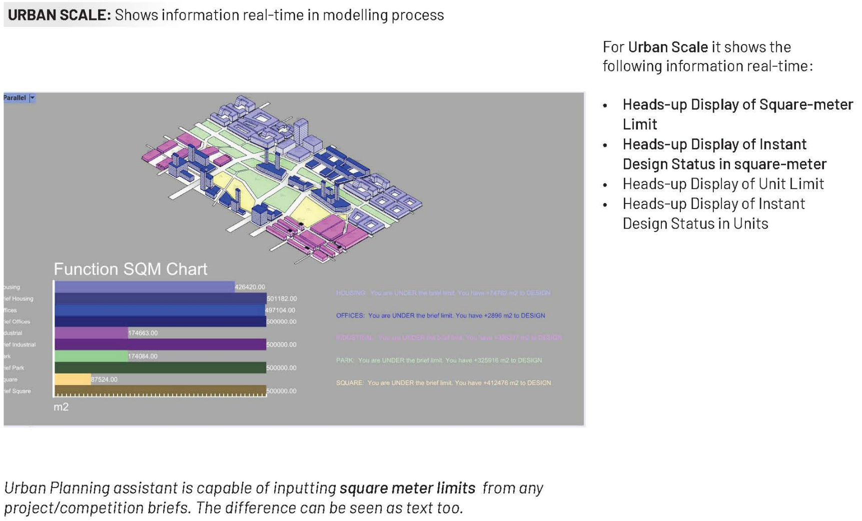


URBAN MODELLING ASSISTANT

Urban Modelling Assistant is a tool to create/monitor urban models that gives information itself. It shows real-time information about the model/models in two different scales:

- MASSING & TERRAIN SCALE
- **URBAN SCALE**

Figure B-7: Document Page 7



URBAN SCALE: Shows information real-time in modelling process

For **Urban Scale** it shows the following information real-time:

- **Heads-up Display of Square-meter Limit**
- **Heads-up Display of Instant Design Status in square-meter**
- Heads-up Display of Unit Limit
- Heads-up Display of Instant Design Status in Units

HOUSING: You are UNDER the brief limit. You have +74762 m2 to DESIGN

OFFICES: You are UNDER the brief limit. You have +2896 m2 to DESIGN

INDUSTRIAL: You are UNDER the brief limit. You have +325337 m2 to DESIGN

PARK: You are UNDER the brief limit. You have +325916 m2 to DESIGN

SQUARE: You are UNDER the brief limit. You have +412476 m2 to DESIGN

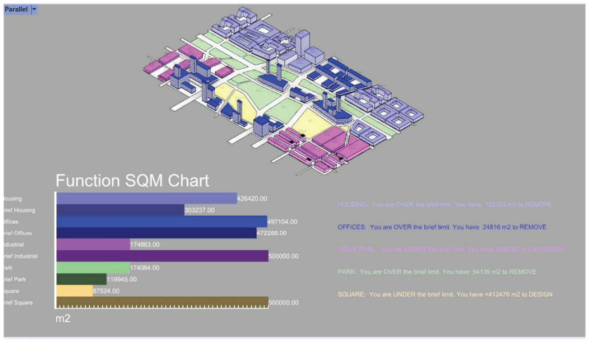
Urban Planning assistant is capable of inputting ***square meter limits*** *from any project/competition briefs. The difference can be seen as text too.*

Figure B-8: Document Page-8

URBAN SCALE: Shows information real-time in modelling process

For **Urban Scale** it shows the following information real-time:

- **Heads-up Display of Square-meter Limit**
- **Heads-up Display of Instant Design Status in square-meter**
- Heads-up Display of Unit Limit
- Heads-up Display of Instant Design Status in Units



HOUSING: You are OVER the brief limit. You have 123183 m2 to REMOVE

OFFICES: You are OVER the brief limit. You have 24816 m2 to REMOVE

INDUSTRIAL: You are UNDER the brief limit. You have +325337 m2 to DESIGN

PARK: You are OVER the brief limit. You have 54139 m2 to REMOVE

SQUARE: You are UNDER the brief limit. You have +412476 m2 to DESIGN

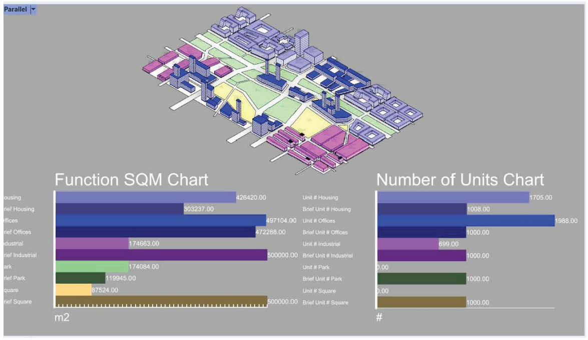
Urban Planning assistant is capable of changing square meter limits from any project/competition briefs. The difference can be seen as text too.

Figure B-9: Document Page-9

URBAN SCALE: Shows information real-time in modelling process

For **Urban Scale** it shows the following information real-time:

- **Heads-up Display of Square-meter Limit**
- **Heads-up Display of Instant Design Status in square-meter**
- **Heads-up Display of Unit Limit**
- **Heads-up Display of Instant Design Status in Units**



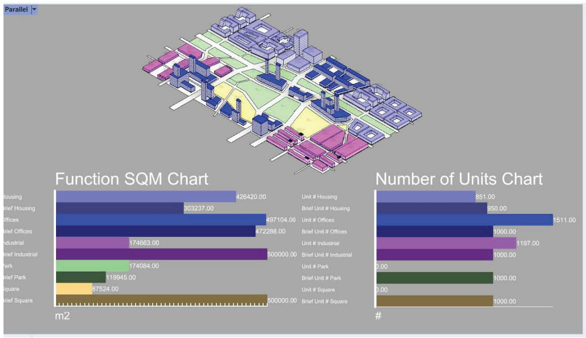
Urban Planning assistant is capable of inputting ***square-meter and unit limits*** *from any project/competition briefs. No units are defined for the "Square" and "Park" functions due to their geometries.*

Figure B-10: Document Page-10

URBAN SCALE: Shows information real-time in modelling process

For **Urban Scale** it shows the following information real-time:

- **Heads-up Display of Square-meter Limit**
- **Heads-up Display of Instant Design Status in square-meter**
- **Heads-up Display of Unit Limit**
- **Heads-up Display of Instant Design Status in Units**



Urban Planning assistant is capable of inputting ***square-meter and unit limits*** *from any project/competition briefs. No units are defined for the "Square" and "Park" functions due to their geometries.*

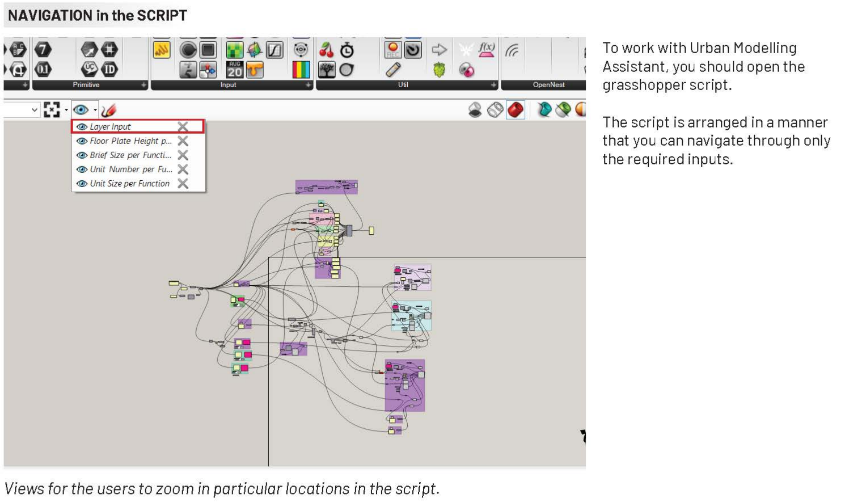
Figure B-11: Document Page 11

HOW IT WORKS ?

Before you start testing please make sure you installed the plug-ins from the folder:

"Urban Modeling Assistant\Install"

Figure B-12: Document Page-12



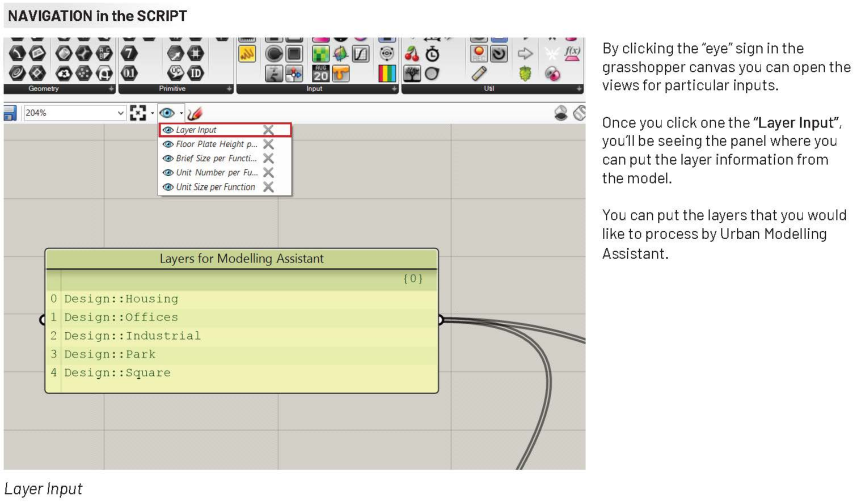
NAVIGATION in the SCRIPT

Views for the users to zoom in particular locations in the script.

To work with Urban Modelling Assistant, you should open the grasshopper script.

The script is arranged in a manner that you can navigate through only the required inputs.

Figure B-13: Document Page-13



NAVIGATION in the SCRIPT

Layers for Modelling Assistant

{0}

```
0 Design::Housing
1 Design::Offices
2 Design::Industrial
3 Design::Park
4 Design::Square
```

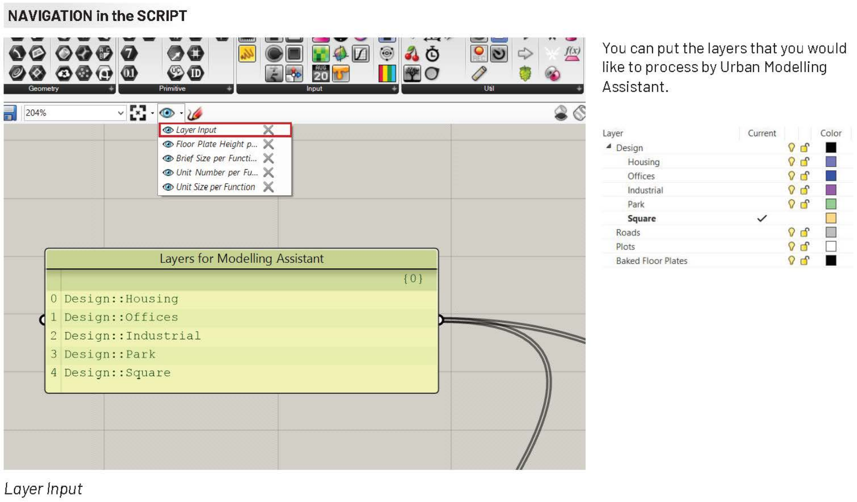
Layer Input

By clicking the "eye" sign in the grasshopper canvas you can open the views for particular inputs.

Once you click one the **"Layer Input"**, you'll be seeing the panel where you can put the layer information from the model.

You can put the layers that you would like to process by Urban Modelling Assistant.

Figure B-14: Document Page-14



NAVIGATION in the SCRIPT

Layers for Modelling Assistant

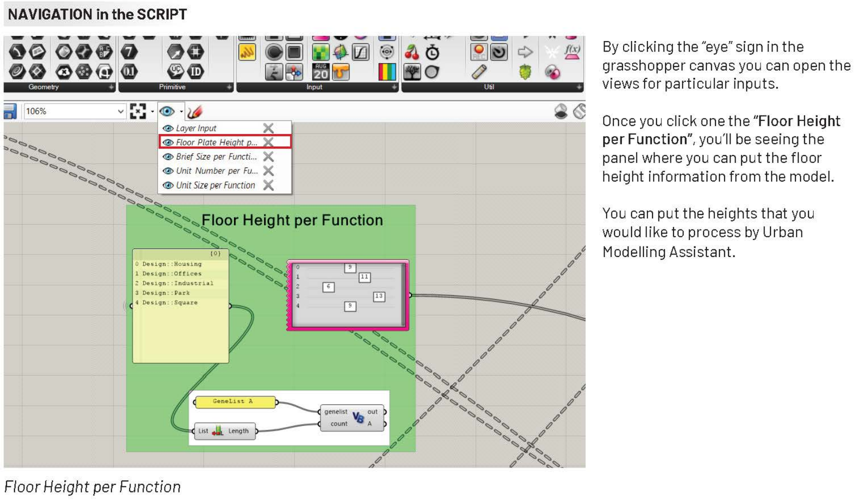
```
{0}
0 Design::Housing
1 Design::Offices
2 Design::Industrial
3 Design::Park
4 Design::Square
```

You can put the layers that you would like to process by Urban Modelling Assistant.

Layer	Current	Color
Design		■
Housing		■
Offices		■
Industrial		■
Park		■
Square	✓	■
Roads		■
Plots		□
Baked Floor Plates		■

Layer Input

Figure B-15: Document Page 15



NAVIGATION in the SCRIPT

```
{0}
0 Design::Housing
1 Design::Offices
2 Design::Industrial
3 Design::Park
4 Design::Square
```

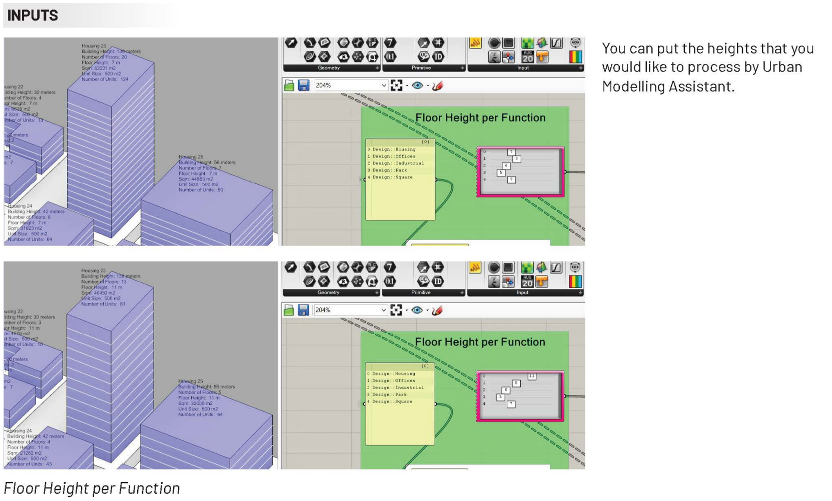
By clicking the "eye" sign in the grasshopper canvas you can open the views for particular inputs.

Once you click one the **"Floor Height per Function"**, you'll be seeing the panel where you can put the floor height information from the model.

You can put the heights that you would like to process by Urban Modelling Assistant.

Floor Height per Function

Figure B-16: Document Page-16

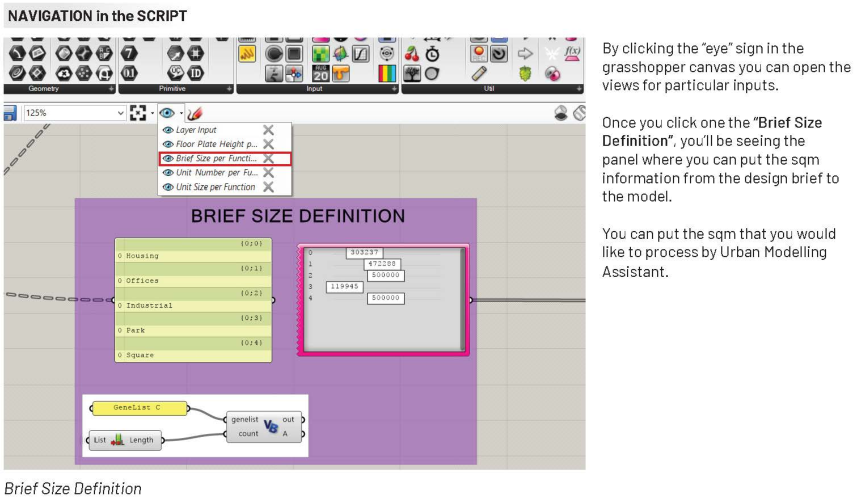


INPUTS

You can put the heights that you would like to process by Urban Modelling Assistant.

Floor Height per Function

Figure B-17: Document Page-17



NAVIGATION in the SCRIPT

By clicking the “eye” sign in the grasshopper canvas you can open the views for particular inputs.

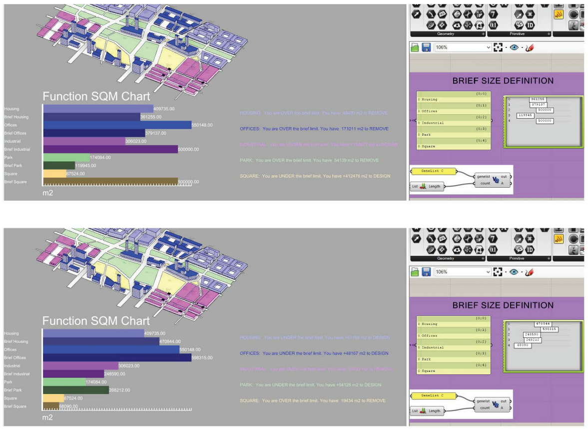
Once you click one the **“Brief Size Definition”**, you’ll be seeing the panel where you can put the sqm information from the design brief to the model.

You can put the sqm that you would like to process by Urban Modelling Assistant.

Brief Size Definition

Figure B-18: Document Page-18

INPUTS

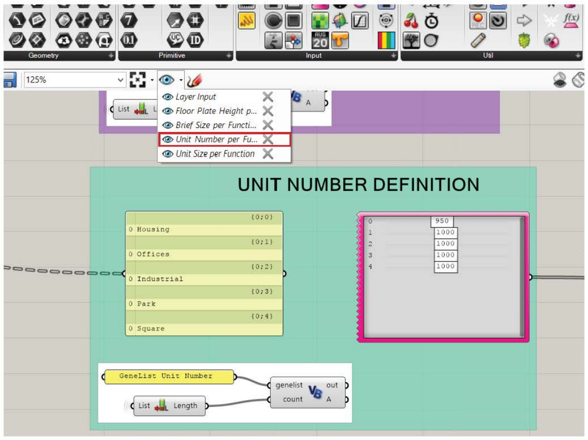


You can put the sqm limit that you would like to process by Urban Modelling Assistant.

Brief Size Definition

Figure B-19: Document Page 19

NAVIGATION in the SCRIPT



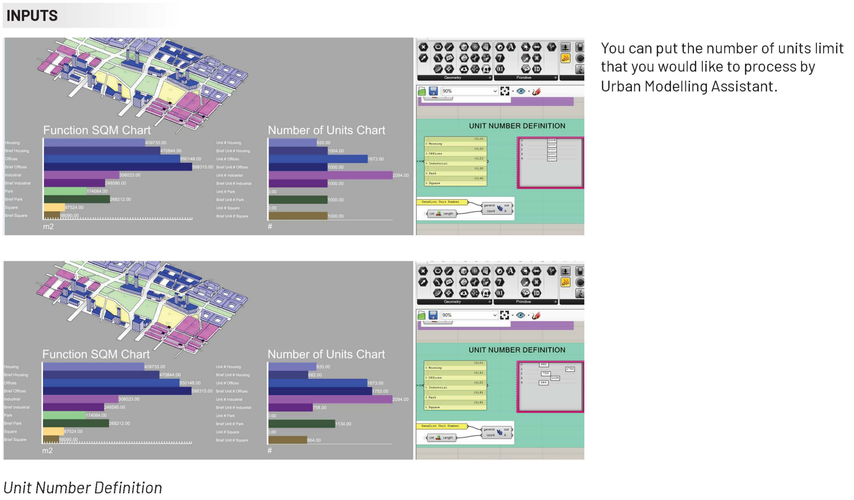
By clicking the "eye" sign in the grasshopper canvas you can open the views for particular inputs.

Once you click one the "**Unit Number Definition**", you'll be seeing the panel where you can put the number of units information from the design brief to the model.

You can put the number of units that you would like to process by Urban Modelling Assistant.

Unit Number Definition

Figure B-20: Document Page-20

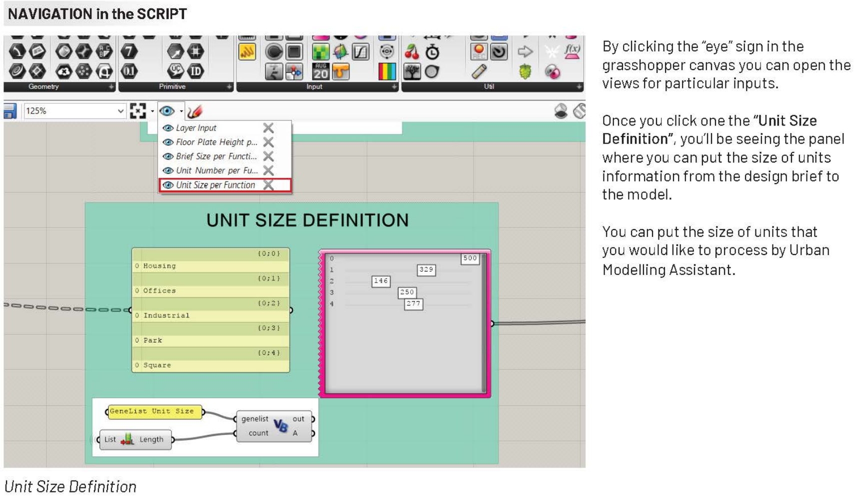


INPUTS

You can put the number of units limit that you would like to process by Urban Modelling Assistant.

Unit Number Definition

Figure B-21: Document Page-21



NAVIGATION in the SCRIPT

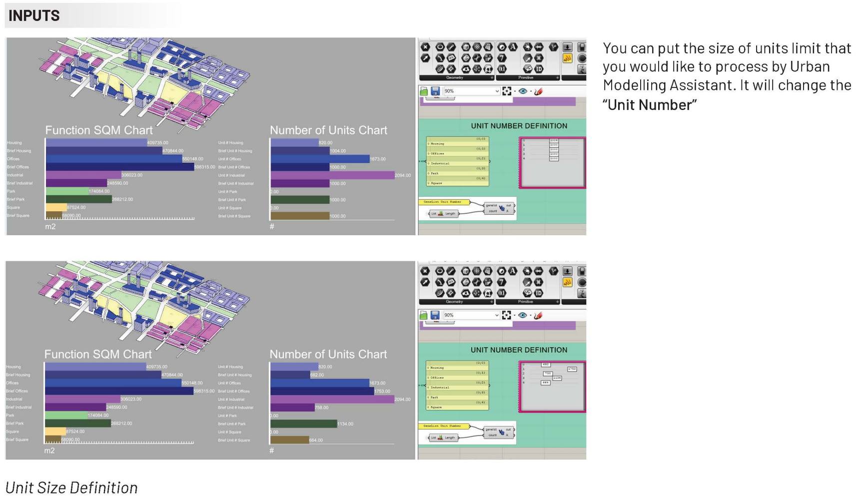
By clicking the "eye" sign in the grasshopper canvas you can open the views for particular inputs.

Once you click one the "**Unit Size Definition**", you'll be seeing the panel where you can put the size of units information from the design brief to the model.

You can put the size of units that you would like to process by Urban Modelling Assistant.

Unit Size Definition

Figure B-23: Document Page-22

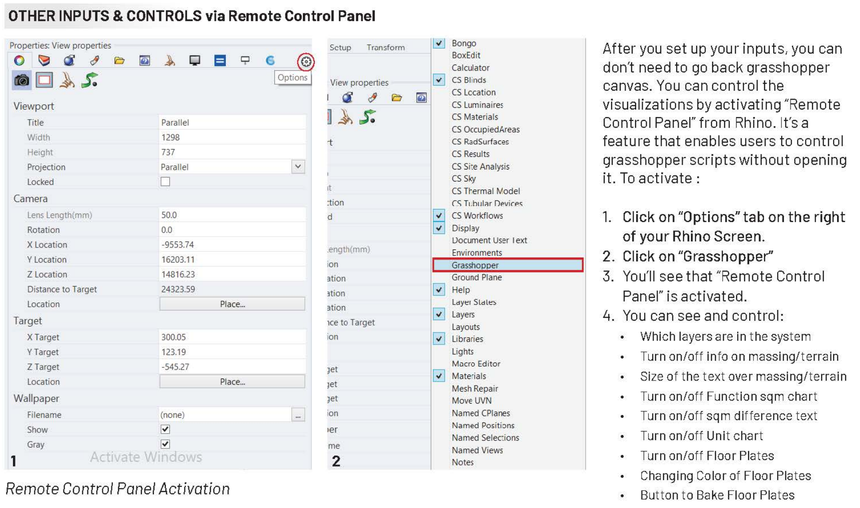


INPUTS

You can put the size of units limit that you would like to process by Urban Modelling Assistant. It will change the "Unit Number"

Unit Size Definition

Figure B-23: Document Page 23



OTHER INPUTS & CONTROLS via Remote Control Panel

Properties: View properties

Viewport

Title	Parallel
Width	1298
Height	737
Projection	Parallel
Locked	☐

Camera

Lens Length(mm)	50.0
Rotation	0.0
X Location	-9553.74
Y Location	16203.11
Z Location	14816.23
Distance to Target	24323.59
Location	Place...

Target

X Target	300.05
Y Target	123.19
Z Target	-545.27
Location	Place...

Wallpaper

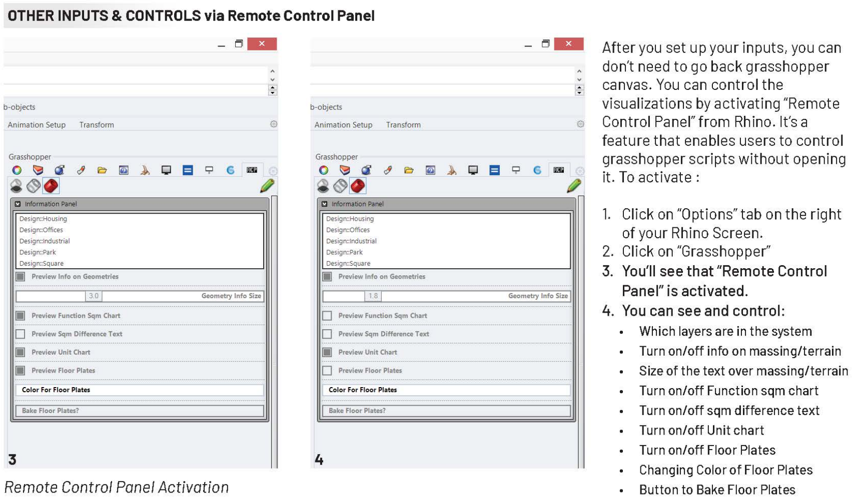
Filename	(none)
Show	☑
Gray	☑

After you set up your inputs, you can don't need to go back grasshopper canvas. You can control the visualizations by activating "Remote Control Panel" from Rhino. It's a feature that enables users to control grasshopper scripts without opening it. To activate :

1. Click on "Options" tab on the right of your Rhino Screen.
2. Click on "Grasshopper"
3. You'll see that "Remote Control Panel" is activated.
4. You can see and control:
    - Which layers are in the system
    - Turn on/off info on massing/terrain
    - Size of the text over massing/terrain
    - Turn on/off Function sqm chart
    - Turn on/off sqm difference text
    - Turn on/off Unit chart
    - Turn on/off Floor Plates
    - Changing Color of Floor Plates
    - Button to Bake Floor Plates

Remote Control Panel Activation

Figure B-24: Document Page-24



OTHER INPUTS & CONTROLS via Remote Control Panel

Remote Control Panel Activation

After you set up your inputs, you can don't need to go back grasshopper canvas. You can control the visualizations by activating "Remote Control Panel" from Rhino. It's a feature that enables users to control grasshopper scripts without opening it. To activate :

1. Click on "Options" tab on the right of your Rhino Screen.
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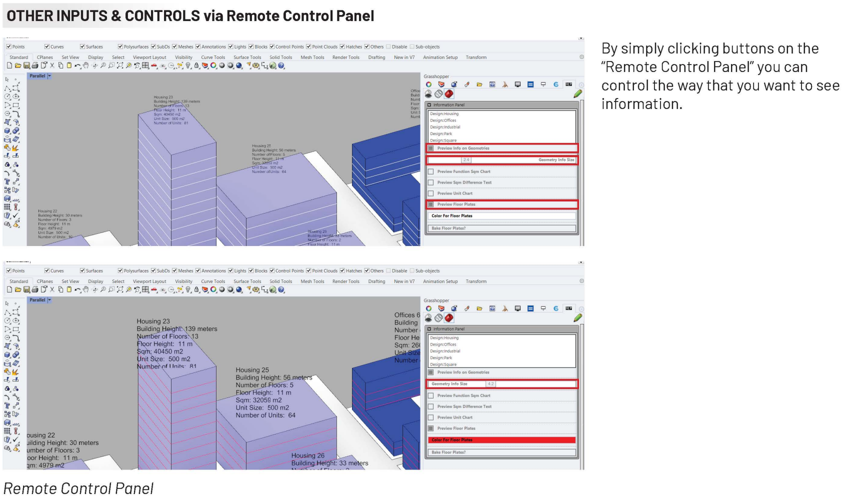
4. **You can see and control:**
    - Which layers are in the system
    - Turn on/off info on massing/terrain
    - Size of the text over massing/terrain
    - Turn on/off Function sqm chart
    - Turn on/off sqm difference text
    - Turn on/off Unit chart
    - Turn on/off Floor Plates
    - Changing Color of Floor Plates
    - Button to Bake Floor Plates

Figure B-25: Document Page-25



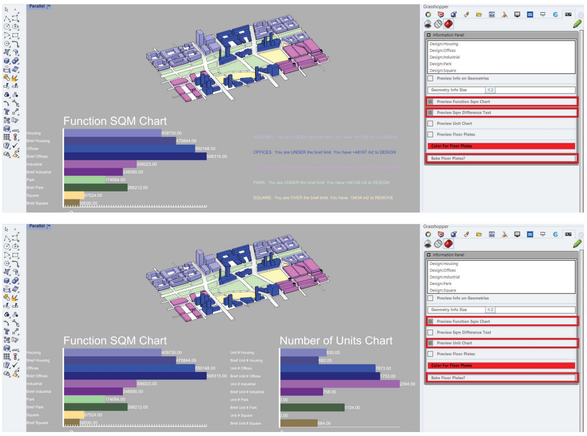
OTHER INPUTS & CONTROLS via Remote Control Panel

Remote Control Panel

By simply clicking buttons on the "Remote Control Panel" you can control the way that you want to see information.

Figure B-26: Document Page-26

OTHER INPUTS & CONTROLS via Remote Control Panel



Design::Housing
Design::Offices
Design::Industrial
Design::Park
Design::Square

☐ Preview Info on Geometries
Geometry Info Size 4.2
☑ Preview Function Sqm Chart
☑ Preview Sqm Difference Text
☐ Preview Unit Chart
☐ Preview Floor Plates
Color For Floor Plates
Bake Floor Plates?

Design::Housing
Design::Offices
Design::Industrial
Design::Park
Design::Square

☐ Preview Info on Geometries
Geometry Info Size 4.2
☑ Preview Function Sqm Chart
☐ Preview Sqm Difference Text
☑ Preview Unit Chart
☐ Preview Floor Plates
Color For Floor Plates
Bake Floor Plates?

By simply clicking buttons on the "Remote Control Panel" you can control the way that you want to see information.

Remote Control Panel

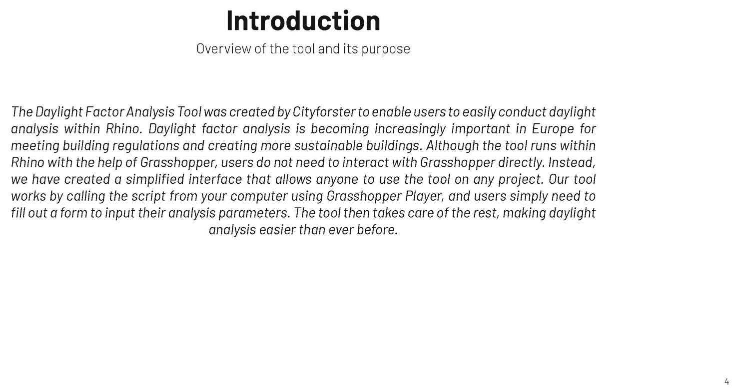
Figure B-27: Document Page 27

Appendix C

Daylight Factor Analysis in Daily Practice: A User-Friendly Guide

Daylight Factor Analysis in Rhino: A User-Friendly Guide

Figure C-1: Document Page-1

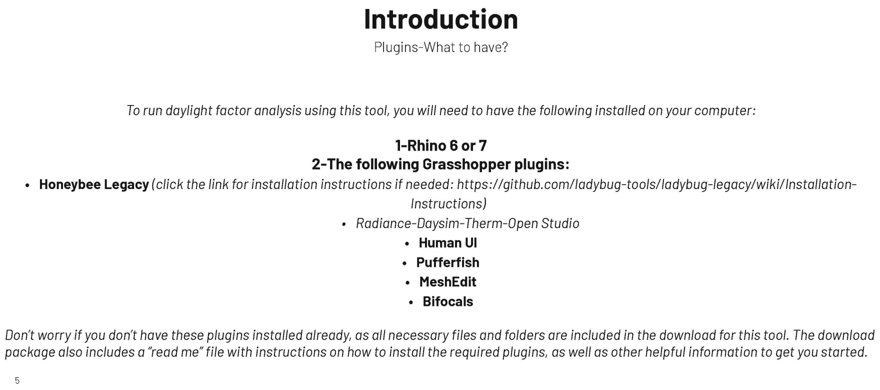


Introduction

Overview of the tool and its purpose

The Daylight Factor Analysis Tool was created by Cityforster to enable users to easily conduct daylight analysis within Rhino. Daylight factor analysis is becoming increasingly important in Europe for meeting building regulations and creating more sustainable buildings. Although the tool runs within Rhino with the help of Grasshopper, users do not need to interact with Grasshopper directly. Instead, we have created a simplified interface that allows anyone to use the tool on any project. Our tool works by calling the script from your computer using Grasshopper Player, and users simply need to fill out a form to input their analysis parameters. The tool then takes care of the rest, making daylight analysis easier than ever before.

Figure C-2: Document Page-2



Introduction

Plugins-What to have?

To run daylight factor analysis using this tool, you will need to have the following installed on your computer:

1-Rhino 6 or 7
2-The following Grasshopper plugins:

- **Honeybee Legacy** *(click the link for installation instructions if needed: https://github.com/ladybug-tools/ladybug-legacy/wiki/Installation-Instructions)*
- *Radiance-Daysim-Therm-Open Studio*
- **Human UI**
- **Pufferfish**
- **MeshEdit**
- **Bifocals**

Don't worry if you don't have these plugins installed already, as all necessary files and folders are included in the download for this tool. The download package also includes a "read me" file with instructions on how to install the required plugins, as well as other helpful information to get you started.

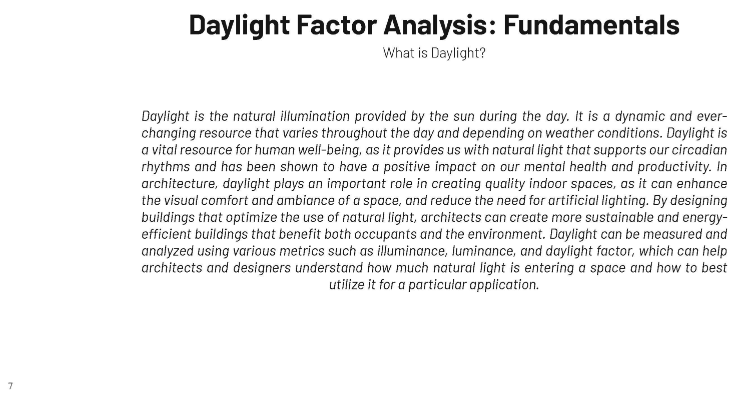
5

Figure C-3: Document Page-3

The Chapel of Notre Dame du Haut, Le Corbusier

6

Figure C-4: Document Page-4

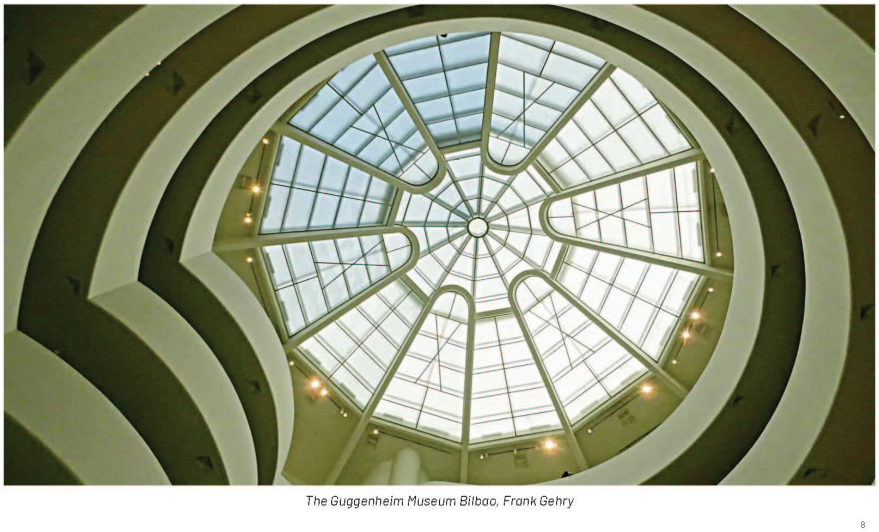


Daylight Factor Analysis: Fundamentals

What is Daylight?

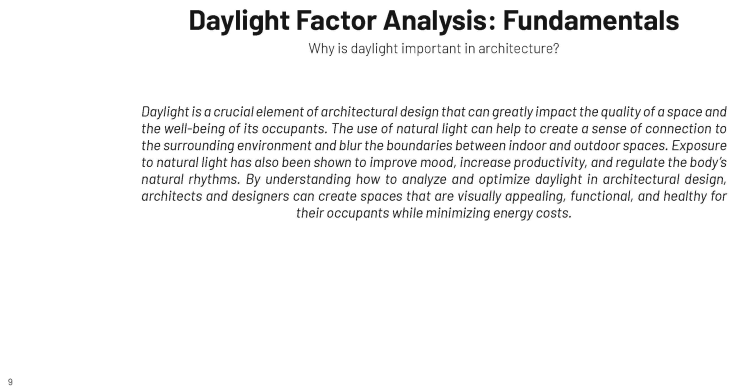
Daylight is the natural illumination provided by the sun during the day. It is a dynamic and ever-changing resource that varies throughout the day and depending on weather conditions. Daylight is a vital resource for human well-being, as it provides us with natural light that supports our circadian rhythms and has been shown to have a positive impact on our mental health and productivity. In architecture, daylight plays an important role in creating quality indoor spaces, as it can enhance the visual comfort and ambiance of a space, and reduce the need for artificial lighting. By designing buildings that optimize the use of natural light, architects can create more sustainable and energy-efficient buildings that benefit both occupants and the environment. Daylight can be measured and analyzed using various metrics such as illuminance, luminance, and daylight factor, which can help architects and designers understand how much natural light is entering a space and how to best utilize it for a particular application.

Figure C-5: Document Page-5



The Guggenheim Museum Bilbao, Frank Gehry

Figure C-6: Document Page-6



Daylight Factor Analysis: Fundamentals

Why is daylight important in architecture?

Daylight is a crucial element of architectural design that can greatly impact the quality of a space and the well-being of its occupants. The use of natural light can help to create a sense of connection to the surrounding environment and blur the boundaries between indoor and outdoor spaces. Exposure to natural light has also been shown to improve mood, increase productivity, and regulate the body's natural rhythms. By understanding how to analyze and optimize daylight in architectural design, architects and designers can create spaces that are visually appealing, functional, and healthy for their occupants while minimizing energy costs.

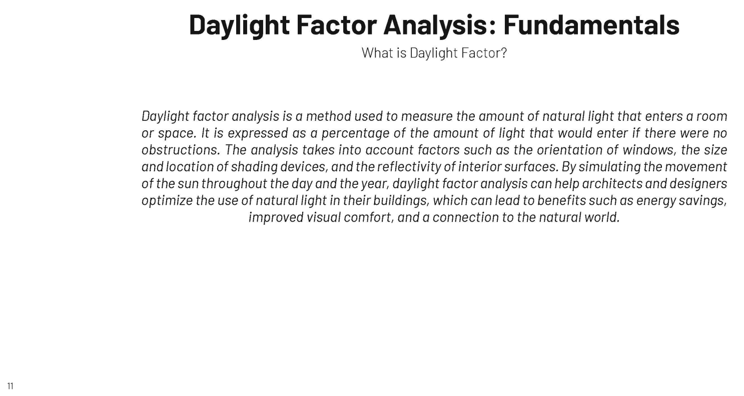
9

Figure C-7: Document Page-7

Maison air et lumière, Nomade

10

Figure C-8: Document Page-8



Daylight Factor Analysis: Fundamentals

What is Daylight Factor?

Daylight factor analysis is a method used to measure the amount of natural light that enters a room or space. It is expressed as a percentage of the amount of light that would enter if there were no obstructions. The analysis takes into account factors such as the orientation of windows, the size and location of shading devices, and the reflectivity of interior surfaces. By simulating the movement of the sun throughout the day and the year, daylight factor analysis can help architects and designers optimize the use of natural light in their buildings, which can lead to benefits such as energy savings, improved visual comfort, and a connection to the natural world.

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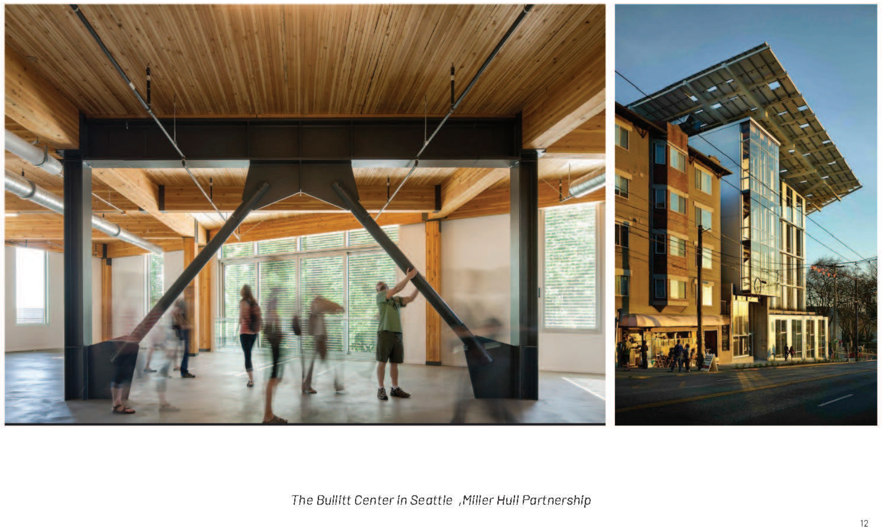
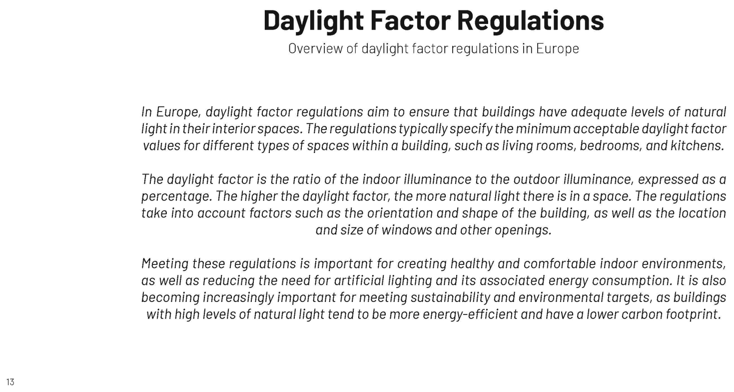
Figure C-9: Document Page-9



The Bullitt Center in Seattle ,Miller Hull Partnership

12

Figure C-10: Document Page-10



Daylight Factor Regulations

Overview of daylight factor regulations in Europe

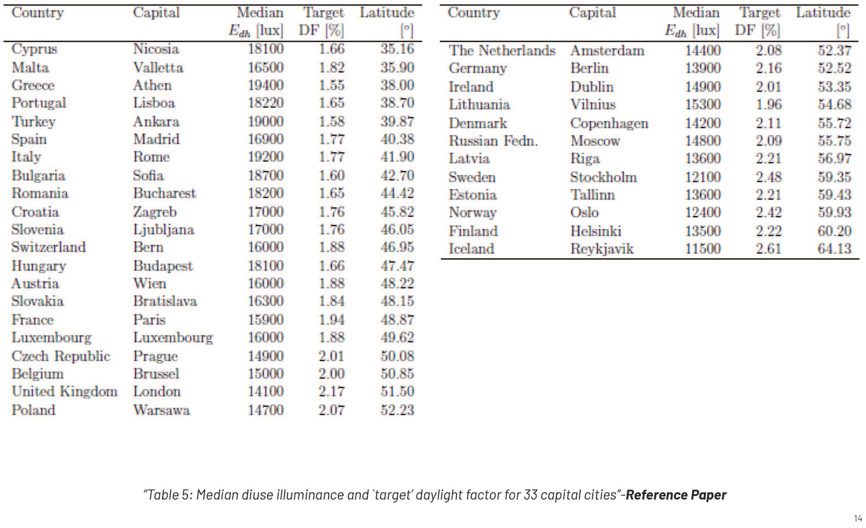
In Europe, daylight factor regulations aim to ensure that buildings have adequate levels of natural light in their interior spaces. The regulations typically specify the minimum acceptable daylight factor values for different types of spaces within a building, such as living rooms, bedrooms, and kitchens.

The daylight factor is the ratio of the indoor illuminance to the outdoor illuminance, expressed as a percentage. The higher the daylight factor, the more natural light there is in a space. The regulations take into account factors such as the orientation and shape of the building, as well as the location and size of windows and other openings.

Meeting these regulations is important for creating healthy and comfortable indoor environments, as well as reducing the need for artificial lighting and its associated energy consumption. It is also becoming increasingly important for meeting sustainability and environmental targets, as buildings with high levels of natural light tend to be more energy-efficient and have a lower carbon footprint.

13

Figure C-11: Document Page-11

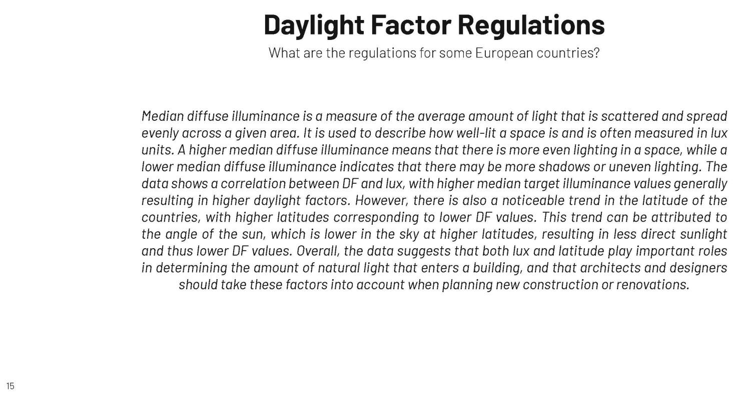


Country	Capital	Median E_{dh} [lux]	Target DF [%]	Latitude [°]
Cyprus	Nicosia	18100	1.66	35.16
Malta	Valletta	16500	1.82	35.90
Greece	Athen	19400	1.55	38.00
Portugal	Lisboa	18220	1.65	38.70
Turkey	Ankara	19000	1.58	39.87
Spain	Madrid	16900	1.77	40.38
Italy	Rome	19200	1.77	41.90
Bulgaria	Sofia	18700	1.60	42.70
Romania	Bucharest	18200	1.65	44.42
Croatia	Zagreb	17000	1.76	45.82
Slovenia	Ljubljana	17000	1.76	46.05
Switzerland	Bern	16000	1.88	46.95
Hungary	Budapest	18100	1.66	47.47
Austria	Wien	16000	1.88	48.22
Slovakia	Bratislava	16300	1.84	48.15
France	Paris	15900	1.94	48.87
Luxembourg	Luxembourg	16000	1.88	49.62
Czech Republic	Prague	14900	2.01	50.08
Belgium	Brussel	15000	2.00	50.85
United Kingdom	London	14100	2.17	51.50
Poland	Warsawa	14700	2.07	52.23
The Netherlands	Amsterdam	14400	2.08	52.37
Germany	Berlin	13900	2.16	52.52
Ireland	Dublin	14900	2.01	53.35
Lithuania	Vilnius	15300	1.96	54.68
Denmark	Copenhagen	14200	2.11	55.72
Russian Fedn.	Moscow	14800	2.09	55.75
Latvia	Riga	13600	2.21	56.97
Sweden	Stockholm	12100	2.48	59.35
Estonia	Tallinn	13600	2.21	59.43
Norway	Oslo	12400	2.42	59.93
Finland	Helsinki	13500	2.22	60.20
Iceland	Reykjavik	11500	2.61	64.13

"Table 5: Median diuse illuminance and `target' daylight factor for 33 capital cities"- ***Reference Paper***

14

Figure C-12: Document Page-12

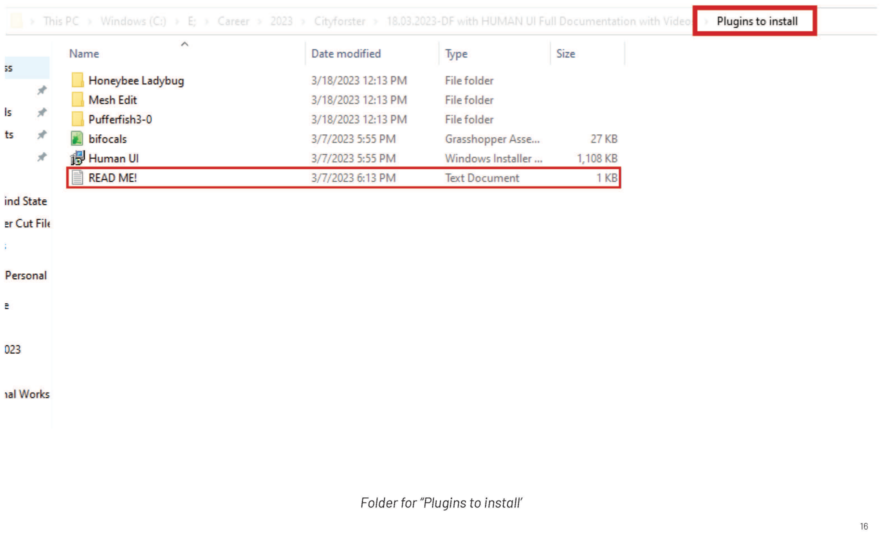


Daylight Factor Regulations

What are the regulations for some European countries?

Median diffuse illuminance is a measure of the average amount of light that is scattered and spread evenly across a given area. It is used to describe how well-lit a space is and is often measured in lux units. A higher median diffuse illuminance means that there is more even lighting in a space, while a lower median diffuse illuminance indicates that there may be more shadows or uneven lighting. The data shows a correlation between DF and lux, with higher median target illuminance values generally resulting in higher daylight factors. However, there is also a noticeable trend in the latitude of the countries, with higher latitudes corresponding to lower DF values. This trend can be attributed to the angle of the sun, which is lower in the sky at higher latitudes, resulting in less direct sunlight and thus lower DF values. Overall, the data suggests that both lux and latitude play important roles in determining the amount of natural light that enters a building, and that architects and designers should take these factors into account when planning new construction or renovations.

Figure C-13: Document Page-13



This PC > Windows (C:) > E; > Career > 2023 > Cityforster > 18.03.2023-DF with HUMAN UI Full Documentation with Video > Plugins to install

Name	Date modified	Type	Size
Honeybee Ladybug	3/18/2023 12:13 PM	File folder	
Mesh Edit	3/18/2023 12:13 PM	File folder	
Pufferfish3-0	3/18/2023 12:13 PM	File folder	
bifocals	3/7/2023 5:55 PM	Grasshopper Asse...	27 KB
Human UI	3/7/2023 5:55 PM	Windows Installer ...	1,108 KB
READ ME!	3/7/2023 6:13 PM	Text Document	1 KB

Folder for "Plugins to install'

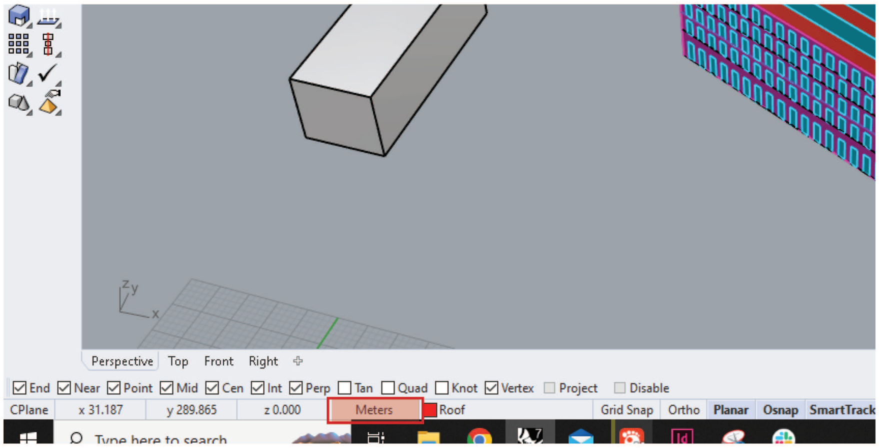
Figure C-14: Document Page-14

Using the Tool

How to install the tool?

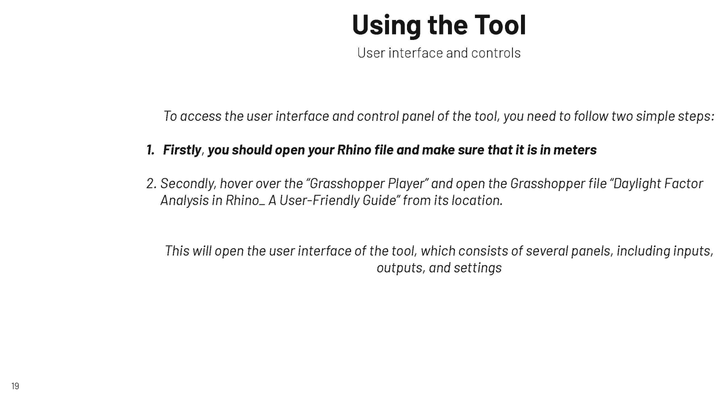
To install the tool, navigate to the containing folder of "Plugins to install" and proceed to install all the plugins. If you need guidance on how to install the plugins, simply refer to the "READ ME!" file for instructions.

Figure C-15: Document Page-15



Rhino File in ***METERs***

Figure C-16: Document Page-16



Using the Tool

User interface and controls

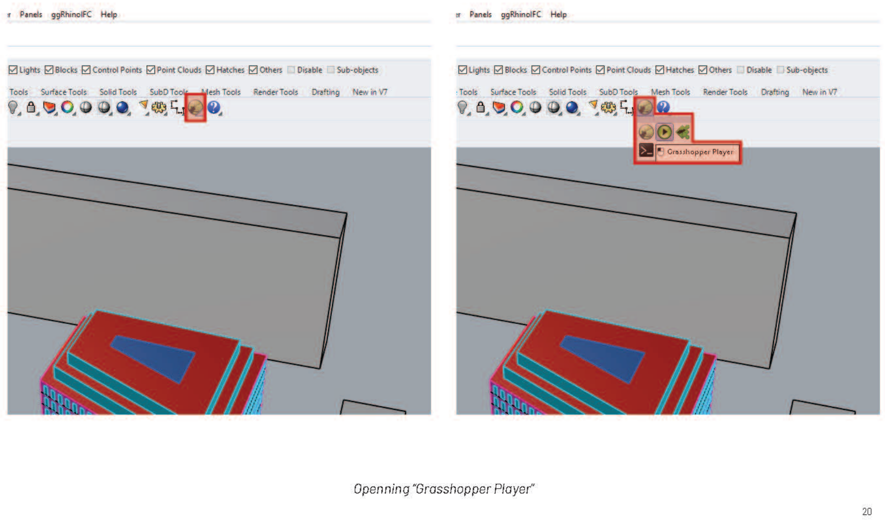
To access the user interface and control panel of the tool, you need to follow two simple steps:

1. ***Firstly**, **you should open your Rhino file and make sure that it is in meters***
2. *Secondly, hover over the "Grasshopper Player" and open the Grasshopper file "Daylight Factor Analysis in Rhino_ A User-Friendly Guide" from its location.*

This will open the user interface of the tool, which consists of several panels, including inputs, outputs, and settings

19

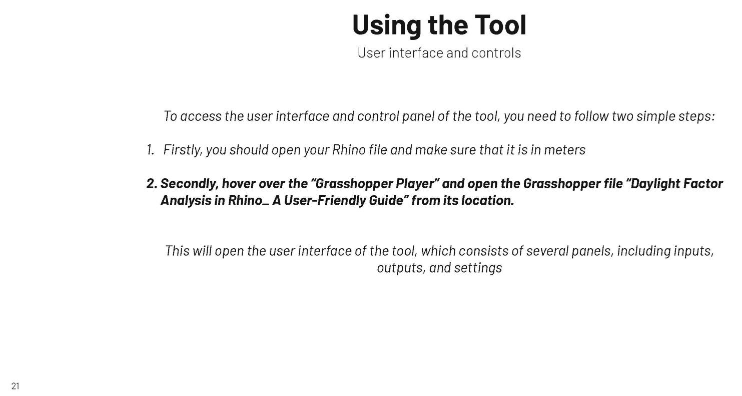
Figure C-17: Document Page-17



Openning "Grasshopper Player"

20

Figure C-18: Document Page-18



Using the Tool

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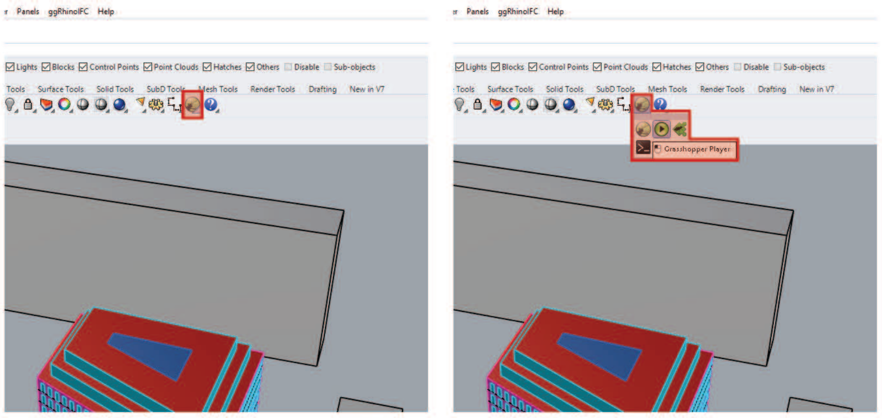
21

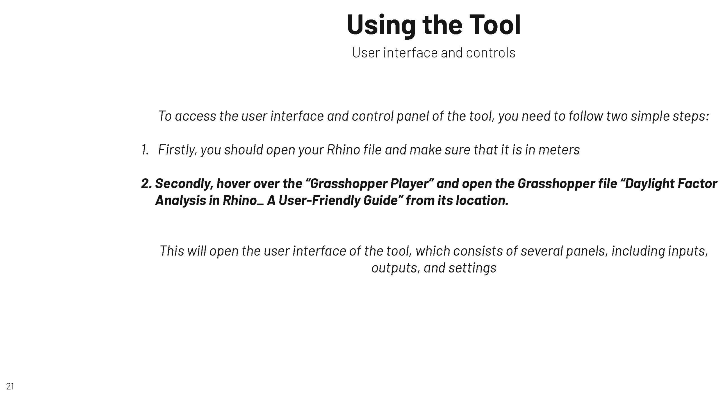
Figure C-19: Document Page-19



Openning "Grasshopper Player"

20

Figure C-20: Document Page-20



Using the Tool

User interface and controls

To access the user interface and control panel of the tool, you need to follow two simple steps:

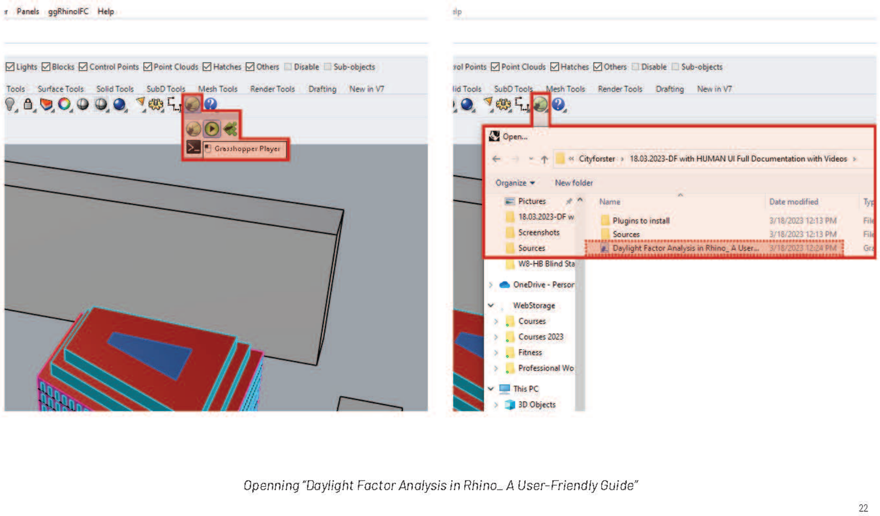
1. *Firstly, you should open your Rhino file and make sure that it is in meters*

2. Secondly, hover over the "Grasshopper Player" and open the Grasshopper file "Daylight Factor Analysis in Rhino_ A User-Friendly Guide" from its location.

This will open the user interface of the tool, which consists of several panels, including inputs, outputs, and settings

21

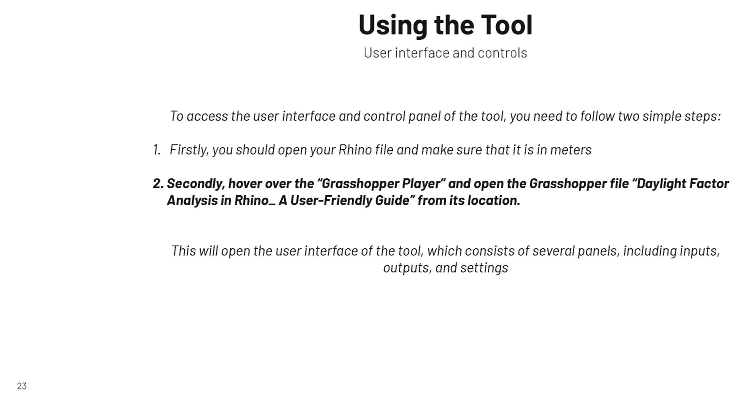
Figure C-21: Document Page-21



Openning "Daylight Factor Analysis in Rhino_ A User-Friendly Guide"

22

Figure C-22: Document Page-22



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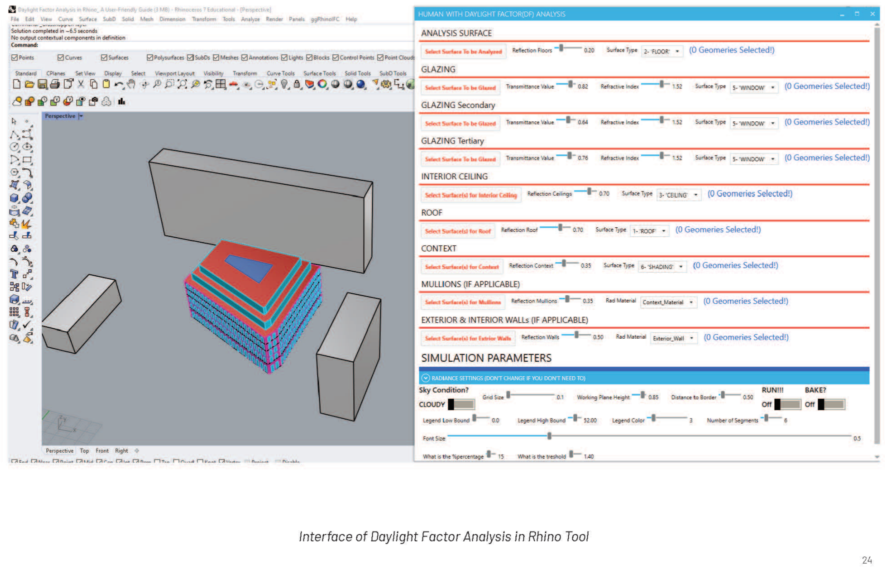
23

Figure C-23: Document Page-23



HUMAN WITH DAYLIGHT FACTOR(DF) ANALYSIS

ANALYSIS SURFACE

Select Surface To be Analyzed — Reflection Floors 0.20 — Surface Type 2- 'FLOOR' — (0 Geomeries Selected!)

GLAZING

Select Surface To be Glazed — Transmittance Value 0.82 — Refractive Index 1.52 — Surface Type 5- 'WINDOW' — (0 Geomeries Selected!)

GLAZING Secondary

Select Surface To be Glazed — Transmittance Value 0.64 — Refractive Index 1.52 — Surface Type 5- 'WINDOW' — (0 Geomeries Selected!)

GLAZING Tertiary

Select Surface To be Glazed — Transmittance Value 0.76 — Refractive Index 1.52 — Surface Type 5- 'WINDOW' — (0 Geomeries Selected!)

INTERIOR CEILING

Select Surface(s) for Interior Ceiling — Reflection Ceilings 0.70 — Surface Type 3- 'CEILING' — (0 Geomeries Selected!)

ROOF

Select Surface(s) for Roof — Reflection Roof 0.70 — Surface Type 1- 'ROOF' — (0 Geomeries Selected!)

CONTEXT

Select Surface(s) for Context — Reflection Context 0.35 — Surface Type 6- 'SHADING' — (0 Geomeries Selected!)

MULLIONS (IF APPLICABLE)

Select Surface(s) for Mullions — Reflection Mullions 0.35 — Rad Material Context_Material — (0 Geomeries Selected!)

EXTERIOR & INTERIOR WALLs (IF APPLICABLE)

Select Surface(s) for Extrior Walls — Reflection Walls 0.50 — Rad Material Exterior_Wall — (0 Geomeries Selected!)

SIMULATION PARAMETERS

RADIANCE SETTINGS (DON'T CHANGE IF YOU DON'T NEED TO)

Sky Condition? CLOUDY

Grid Size 0.1

Working Plane Height 0.85

Distance to Border 0.50

RUN!!! Off

BAKE? Off

Legend Low Bound 0.0

Legend High Bound 52.00

Legend Color 3

Number of Segments 6

Font Size 0.5

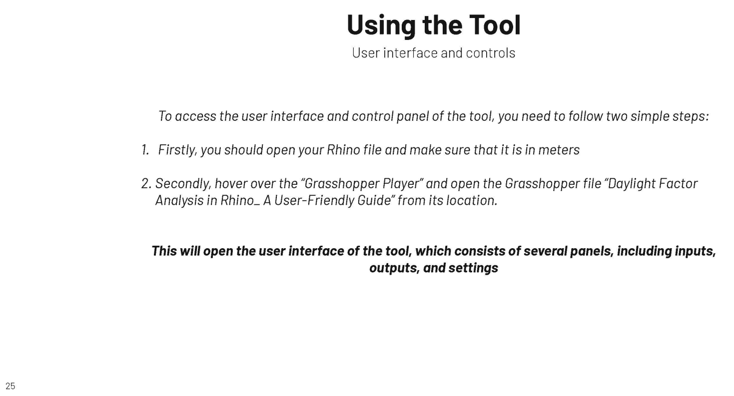
What is the %percentage 15

What is the treshold 1.40

Interface of Daylight Factor Analysis in Rhino Tool

24

Figure C-24: Document Page-24



Using the Tool

User interface and controls

To access the user interface and control panel of the tool, you need to follow two simple steps:

1. *Firstly, you should open your Rhino file and make sure that it is in meters*
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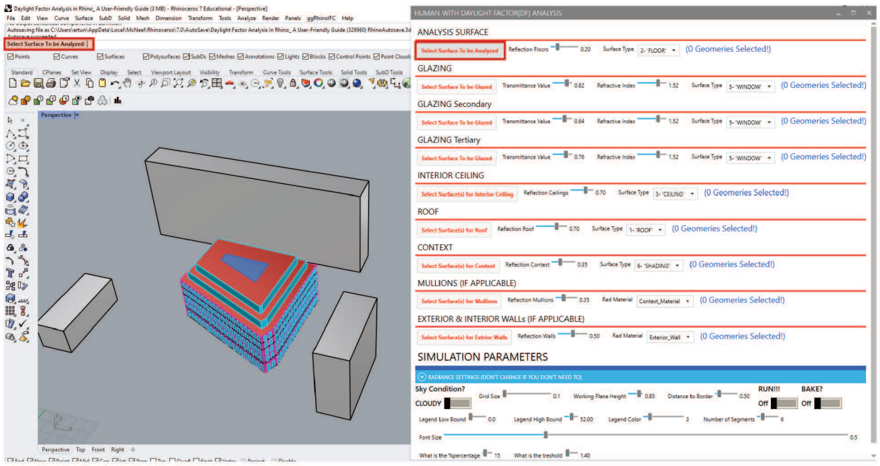
This will open the user interface of the tool, which consists of several panels, including inputs, outputs, and settings

25

Figure C-25: Document Page-25



HUMAN WITH DAYLIGHT FACTOR(DF) ANALYSIS

ANALYSIS SURFACE

Select Surface To be Analyzed | Reflection Floors 0.20 | Surface Type 2- 'FLOOR' | (0 Geomeries Selected!)

GLAZING

Select Surface To be Glazed | Transmittance Value 0.82 | Refractive Index 1.52 | Surface Type 5- 'WINDOW' | (0 Geomeries Selected!)

GLAZING Secondary

Select Surface To be Glazed | Transmittance Value 0.64 | Refractive Index 1.52 | Surface Type 5- 'WINDOW' | (0 Geomeries Selected!)

GLAZING Tertiary

Select Surface To be Glazed | Transmittance Value 0.76 | Refractive Index 1.52 | Surface Type 5- 'WINDOW' | (0 Geomeries Selected!)

INTERIOR CEILING

Select Surface(s) for Interior Ceiling | Reflection Ceilings 0.70 | Surface Type 3- 'CEILING' | (0 Geomeries Selected!)

ROOF

Select Surface(s) for Roof | Reflection Roof 0.70 | Surface Type 1- 'ROOF' | (0 Geomeries Selected!)

CONTEXT

Select Surface(s) for Context | Reflection Context 0.35 | Surface Type 6- 'SHADING' | (0 Geomeries Selected!)

MULLIONS (IF APPLICABLE)

Select Surface(s) for Mullions | Reflection Mullions 0.35 | Rad Material Context_Material | (0 Geomeries Selected!)

EXTERIOR & INTERIOR WALLs (IF APPLICABLE)

Select Surface(s) for Extrior Walls | Reflection Walls 0.50 | Rad Material Exterior_Wall | (0 Geomeries Selected!)

SIMULATION PARAMETERS

RADIANCE SETTINGS (DON'T CHANGE IF YOU DON'T NEED TO)

Sky Condition? CLOUDY | Grid Size 0.1 | Working Plane Height 0.85 | Distance to Border 0.50 | RUN!!! Off | BAKE? Off

Legend Low Bound 0.0 | Legend High Bound 52.00 | Legend Color 3 | Number of Segments 6

Font Size 0.5

What is the %percentage 15 | What is the treshold 1.40

Surface Selection

26

Figure C-26: Document Page-26

Using the Tool

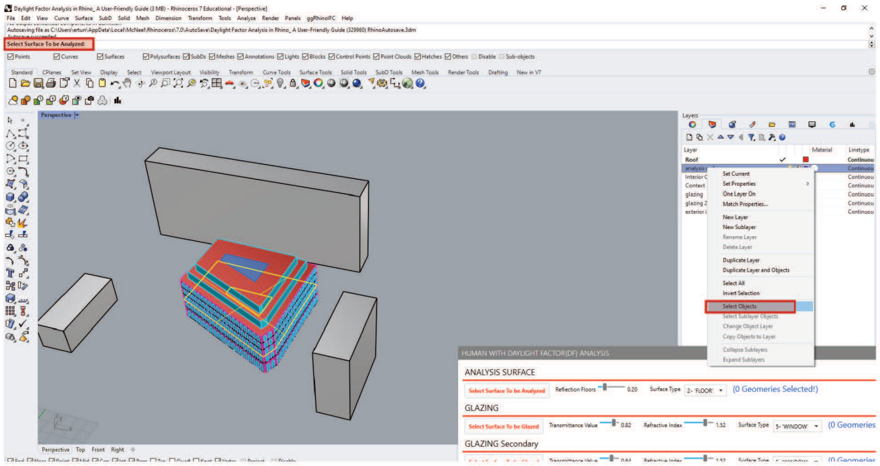
Step-by-step guide to running a daylight analysis using the tool

To input building components, follow these steps:

1. ***Click on the "Select Surface To be Analyzed" button, and select the geometry from your Rhino model.***
2. *Select the percentage of the material reflection.*
3. *Change the surface type from the dropdown menu.*
4. *Check how many geometries you have selected.*

27

Figure C-27: Document Page-27



HUMAN WITH DAYLIGHT FACTOR(DF) ANALYSIS

ANALYSIS SURFACE

Select Surface To be Analyzed | Reflection Floors 0.20 | Surface Type 2- 'FLOOR' | (0 Geomeries Selected!)

GLAZING

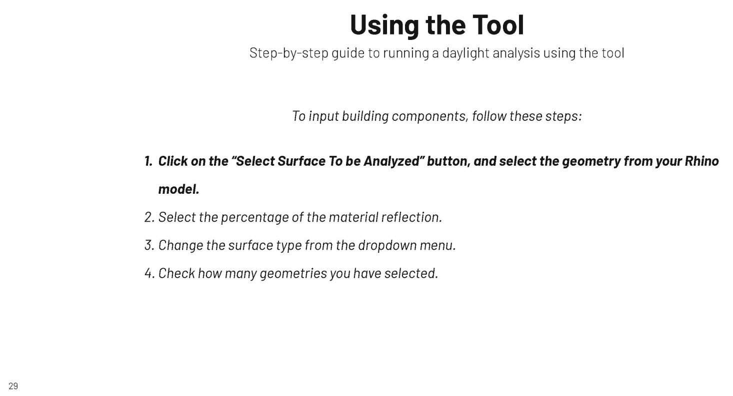
Select Surface To be Glazed | Transmittance Value 0.82 | Refractive Index 1.52 | Surface Type 5- 'WINDOW' | (0 Geomeries

GLAZING Secondary

Surface Selection

28

Figure C-28: Document Page-28



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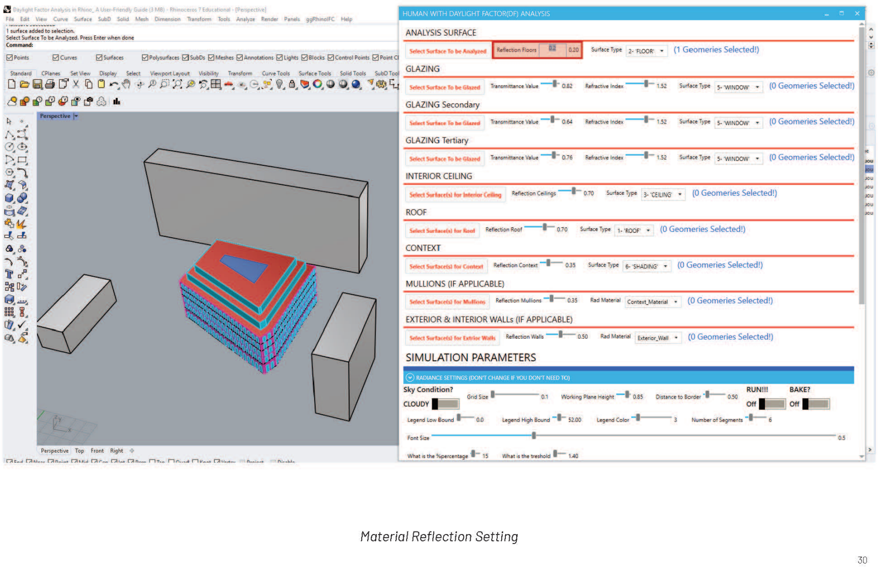
To input building components, follow these steps:

1. ***Click on the "Select Surface To be Analyzed" button, and select the geometry from your Rhino model.***
2. *Select the percentage of the material reflection.*
3. *Change the surface type from the dropdown menu.*
4. *Check how many geometries you have selected.*

29

Figure C-29: Document Page-29



```
1 surface added to selection.
Select Surface To be Analyzed. Press Enter when done
Command:
```

HUMAN WITH DAYLIGHT FACTOR(DF) ANALYSIS

ANALYSIS SURFACE

Select Surface To be Analyzed — Reflection Floors 0.20 — Surface Type 2- 'FLOOR' — (1 Geomeries Selected!)

GLAZING

Select Surface To be Glazed — Transmittance Value 0.82 — Refractive Index 1.52 — Surface Type 5- 'WINDOW' — (0 Geomeries Selected!)

GLAZING Secondary

Select Surface To be Glazed — Transmittance Value 0.64 — Refractive Index 1.52 — Surface Type 5- 'WINDOW' — (0 Geomeries Selected!)

GLAZING Tertiary

Select Surface To be Glazed — Transmittance Value 0.76 — Refractive Index 1.52 — Surface Type 5- 'WINDOW' — (0 Geomeries Selected!)

INTERIOR CEILING

Select Surface(s) for Interior Ceiling — Reflection Ceilings 0.70 — Surface Type 3- 'CEILING' — (0 Geomeries Selected!)

ROOF

Select Surface(s) for Roof — Reflection Roof 0.70 — Surface Type 1- 'ROOF' — (0 Geomeries Selected!)

CONTEXT

Select Surface(s) for Context — Reflection Context 0.35 — Surface Type 6- 'SHADING' — (0 Geomeries Selected!)

MULLIONS (IF APPLICABLE)

Select Surface(s) for Mullions — Reflection Mullions 0.35 — Rad Material Context_Material — (0 Geomeries Selected!)

EXTERIOR & INTERIOR WALLs (IF APPLICABLE)

Select Surface(s) for Extrior Walls — Reflection Walls 0.50 — Rad Material Exterior_Wall — (0 Geomeries Selected!)

SIMULATION PARAMETERS

RADIANCE SETTINGS (DON'T CHANGE IF YOU DON'T NEED TO)

Sky Condition? CLOUDY — Grid Size 0.1 — Working Plane Height 0.85 — Distance to Border 0.50 — RUN!!! Off — BAKE? Off

Legend Low Bound 0.0 — Legend High Bound 52.00 — Legend Color 3 — Number of Segments 6

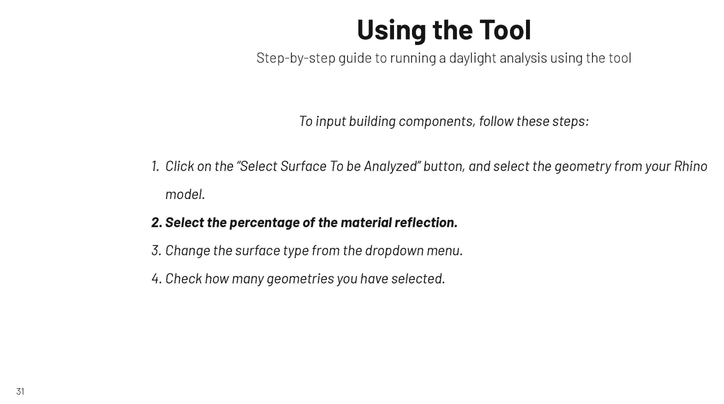
Font Size 0.5

What is the %percentage 15 — What is the treshold 1.40

Material Reflection Setting

30

Figure C-30: Document Page-30



Using the Tool

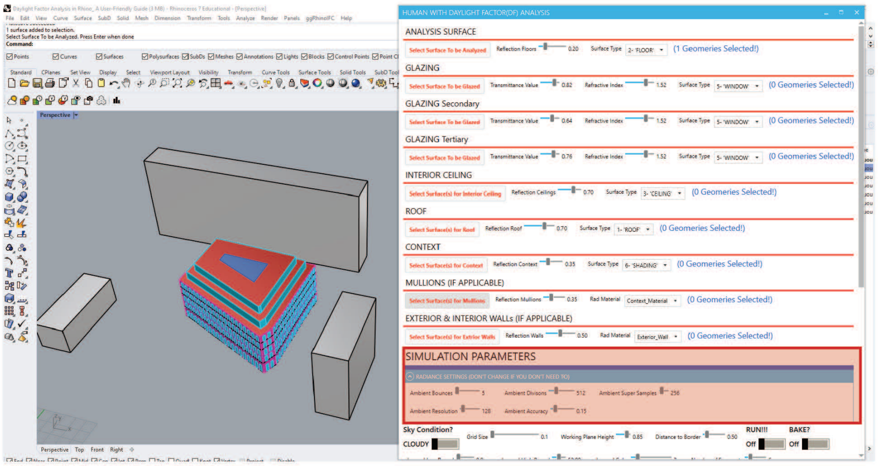
Step-by-step guide to running a daylight analysis using the tool

To input building components, follow these steps:

1. *Click on the "Select Surface To be Analyzed" button, and select the geometry from your Rhino model.*
2. ***Select the percentage of the material reflection.***
3. *Change the surface type from the dropdown menu.*
4. *Check how many geometries you have selected.*

31

Figure C-31: Document Page-31



1 surface added to selection.
Select Surface To be Analyzed. Press Enter when done
Command:

HUMAN WITH DAYLIGHT FACTOR(DF) ANALYSIS

ANALYSIS SURFACE
Select Surface To be Analyzed — Reflection Floors 0.20 — Surface Type 2- 'FLOOR' — (1 Geomeries Selected!)

GLAZING
Select Surface To be Glazed — Transmittance Value 0.82 — Refractive Index 1.52 — Surface Type 5- 'WINDOW' — (0 Geomeries Selected!)

GLAZING Secondary
Select Surface To be Glazed — Transmittance Value 0.64 — Refractive Index 1.52 — Surface Type 5- 'WINDOW' — (0 Geomeries Selected!)

GLAZING Tertiary
Select Surface To be Glazed — Transmittance Value 0.76 — Refractive Index 1.52 — Surface Type 5- 'WINDOW' — (0 Geomeries Selected!)

INTERIOR CEILING
Select Surface(s) for Interior Ceiling — Reflection Ceilings 0.70 — Surface Type 3- 'CEILING' — (0 Geomeries Selected!)

ROOF
Select Surface(s) for Roof — Reflection Roof 0.70 — Surface Type 1- 'ROOF' — (0 Geomeries Selected!)

CONTEXT
Select Surface(s) for Context — Reflection Context 0.35 — Surface Type 6- 'SHADING' — (0 Geomeries Selected!)

MULLIONS (IF APPLICABLE)
Select Surface(s) for Mullions — Reflection Mullions 0.35 — Rad Material Context_Material — (0 Geomeries Selected!)

EXTERIOR & INTERIOR WALLs (IF APPLICABLE)
Select Surface(s) for Extrior Walls — Reflection Walls 0.50 — Rad Material Exterior_Wall — (0 Geomeries Selected!)

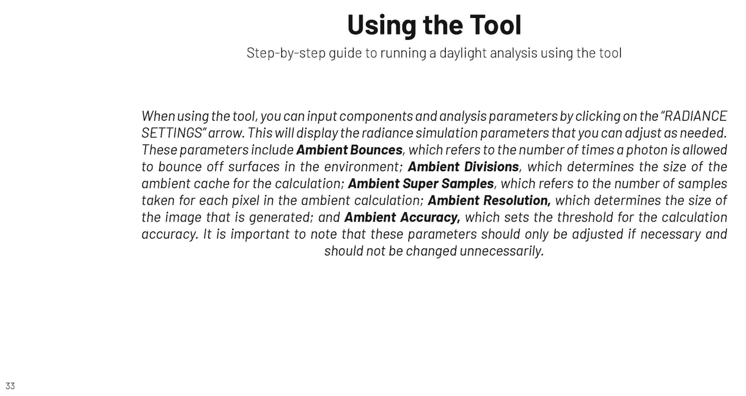
SIMULATION PARAMETERS
RADIANCE SETTINGS (DON'T CHANGE IF YOU DON'T NEED TO)
Ambient Bounces 5 — Ambient Divisons 512 — Ambient Super Samples 256
Ambient Resolution 128 — Ambient Accuracy 0.15

Sky Condition? CLOUDY — Grid Size 0.1 — Working Plane Height 0.85 — Distance to Border 0.50 — RUN!!! Off — BAKE? Off

Accessing the "RADIANCE SETTINGS"

32

Figure C-32: Document Page-32



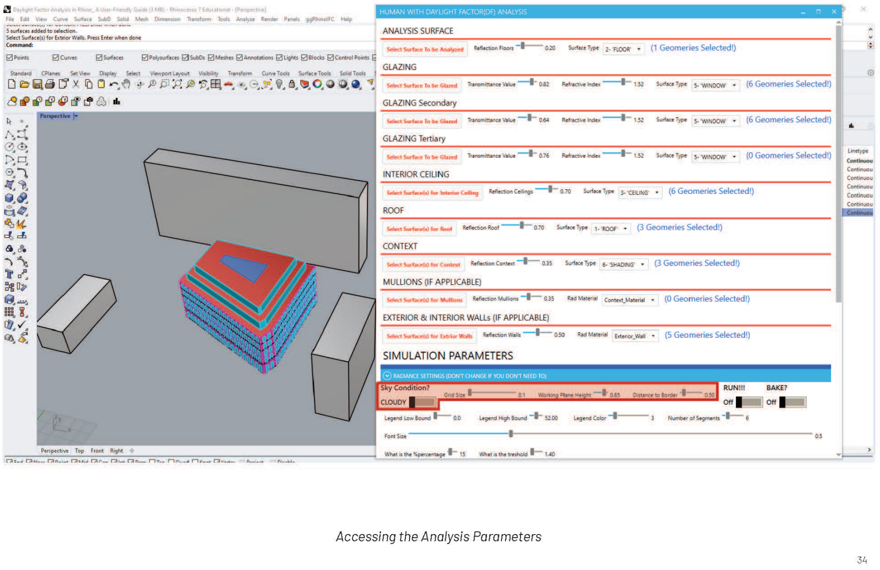
Using the Tool

Step-by-step guide to running a daylight analysis using the tool

*When using the tool, you can input components and analysis parameters by clicking on the "RADIANCE SETTINGS" arrow. This will display the radiance simulation parameters that you can adjust as needed. These parameters include **Ambient Bounces**, which refers to the number of times a photon is allowed to bounce off surfaces in the environment; **Ambient Divisions**, which determines the size of the ambient cache for the calculation; **Ambient Super Samples**, which refers to the number of samples taken for each pixel in the ambient calculation; **Ambient Resolution**, which determines the size of the image that is generated; and **Ambient Accuracy**, which sets the threshold for the calculation accuracy. It is important to note that these parameters should only be adjusted if necessary and should not be changed unnecessarily.*

33

Figure C-33: Document Page-33



HUMAN WITH DAYLIGHT FACTOR(DF) ANALYSIS

ANALYSIS SURFACE

Select Surface To be Analyzed | Reflection Floors 0.20 | Surface Type 2- 'FLOOR' | (1 Geomeries Selected!)

GLAZING

Select Surface To be Glazed | Transmittance Value 0.82 | Refractive Index 1.52 | Surface Type 5- 'WINDOW' | (6 Geomeries Selected!)

GLAZING Secondary

Select Surface To be Glazed | Transmittance Value 0.64 | Refractive Index 1.52 | Surface Type 5- 'WINDOW' | (6 Geomeries Selected!)

GLAZING Tertiary

Select Surface To be Glazed | Transmittance Value 0.76 | Refractive Index 1.52 | Surface Type 5- 'WINDOW' | (0 Geomeries Selected!)

INTERIOR CEILING

Select Surface(s) for Interior Ceiling | Reflection Ceilings 0.70 | Surface Type 3- 'CEILING' | (6 Geomeries Selected!)

ROOF

Select Surface(s) for Roof | Reflection Roof 0.70 | Surface Type 1- 'ROOF' | (3 Geomeries Selected!)

CONTEXT

Select Surface(s) for Context | Reflection Context 0.35 | Surface Type 6- 'SHADING' | (3 Geomeries Selected!)

MULLIONS (IF APPLICABLE)

Select Surface(s) for Mullions | Reflection Mullions 0.35 | Rad Material Context_Material | (0 Geomeries Selected!)

EXTERIOR & INTERIOR WALLs (IF APPLICABLE)

Select Surface(s) for Extrior Walls | Reflection Walls 0.50 | Rad Material Exterior_Wall | (5 Geomeries Selected!)

SIMULATION PARAMETERS

RADIANCE SETTINGS (DON'T CHANGE IF YOU DON'T NEED TO)

Sky Condition? CLOUDY | Grid Size 0.1 | Working Plane Height 0.85 | Distance to Border 0.50 | RUN!!! Off | BAKE? Off

Legend Low Bound 0.0 | Legend High Bound 52.00 | Legend Color 3 | Number of Segments 6

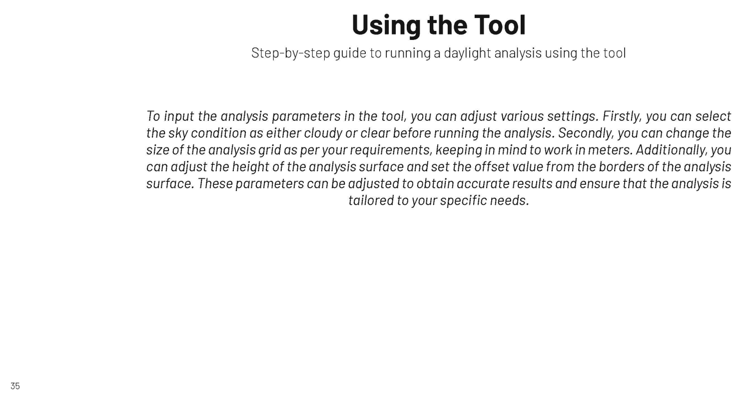
Font Size 0.5

What is the %percentage 15 | What is the treshold 1.40

Accessing the Analysis Parameters

34

Figure C-34: Document Page-34



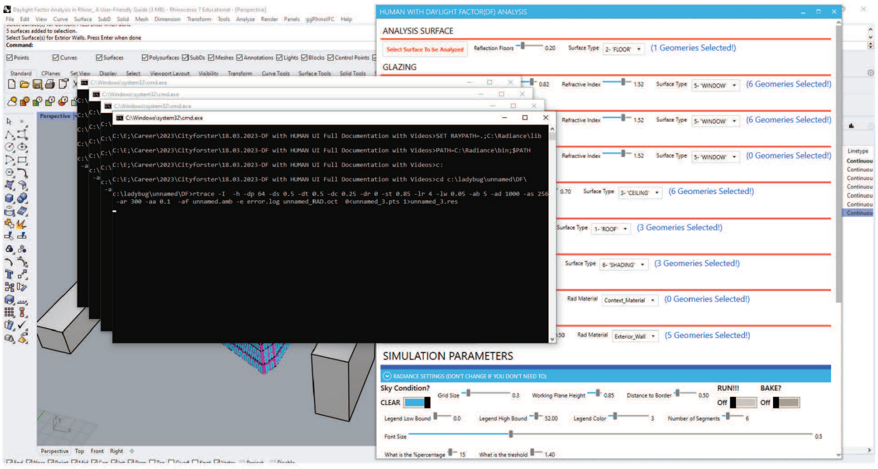
Using the Tool

Step-by-step guide to running a daylight analysis using the tool

To input the analysis parameters in the tool, you can adjust various settings. Firstly, you can select the sky condition as either cloudy or clear before running the analysis. Secondly, you can change the size of the analysis grid as per your requirements, keeping in mind to work in meters. Additionally, you can adjust the height of the analysis surface and set the offset value from the borders of the analysis surface. These parameters can be adjusted to obtain accurate results and ensure that the analysis is tailored to your specific needs.

35

Figure C-35: Document Page-35



```
C:\E;\Career\2023\Cityforster\18.03.2023-DF with HUMAN UI Full Documentation with Videos>SET RAYPATH=.;C:\Radiance\lib

C:\E;\Career\2023\Cityforster\18.03.2023-DF with HUMAN UI Full Documentation with Videos>PATH=C:\Radiance\bin;$PATH

C:\E;\Career\2023\Cityforster\18.03.2023-DF with HUMAN UI Full Documentation with Videos>c:

C:\E;\Career\2023\Cityforster\18.03.2023-DF with HUMAN UI Full Documentation with Videos>cd c:\ladybug\unnamed\DF\

c:\ladybug\unnamed\DF>rtrace -I  -h -dp 64 -ds 0.5 -dt 0.5 -dc 0.25 -dr 0 -st 0.85 -lr 4 -lw 0.05 -ab 5 -ad 1000 -as 256
 -ar 300 -aa 0.1  -af unnamed.amb -e error.log unnamed_RAD.oct  0<unnamed_3.pts 1>unnamed_3.res
```

HUMAN WITH DAYLIGHT FACTOR(DF) ANALYSIS

ANALYSIS SURFACE

Reflection Floors 0.20 Surface Type 2- 'FLOOR' (1 Geomeries Selected!)

GLAZING

0.82 Refractive Index 1.52 Surface Type 5- 'WINDOW' (6 Geomeries Selected!)

Refractive Index 1.52 Surface Type 5- 'WINDOW' (6 Geomeries Selected!)

Refractive Index 1.52 Surface Type 5- 'WINDOW' (0 Geomeries Selected!)

0.70 Surface Type 3- 'CEILING' (6 Geomeries Selected!)

Surface Type 1- 'ROOF' (3 Geomeries Selected!)

Surface Type 6- 'SHADING' (3 Geomeries Selected!)

Rad Material Context_Material (0 Geomeries Selected!)

Rad Material Exterior_Wall (5 Geomeries Selected!)

SIMULATION PARAMETERS

RADIANCE SETTINGS (DON'T CHANGE IF YOU DON'T NEED TO)

Sky Condition? CLEAR

Grid Size 0.3

Working Plane Height 0.85

Distance to Border 0.50

RUN!!! Off

BAKE? Off

Legend Low Bound 0.0

Legend High Bound 52.00

Legend Color 3

Number of Segments 6

Font Size 0.5

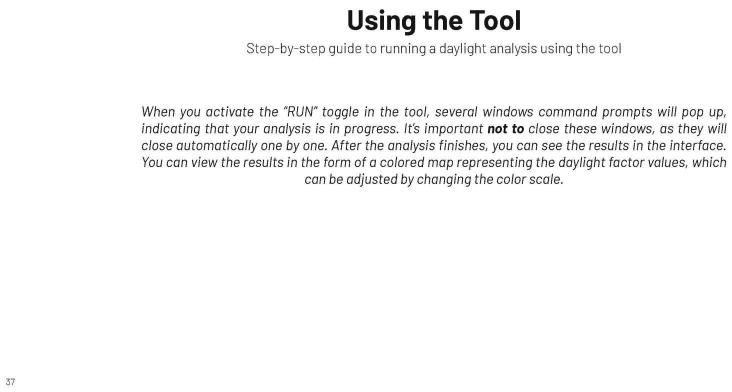
What is the %percentage 15

What is the treshold 1.40

Running the Analysis

36

Figure C-36: Document Page-36



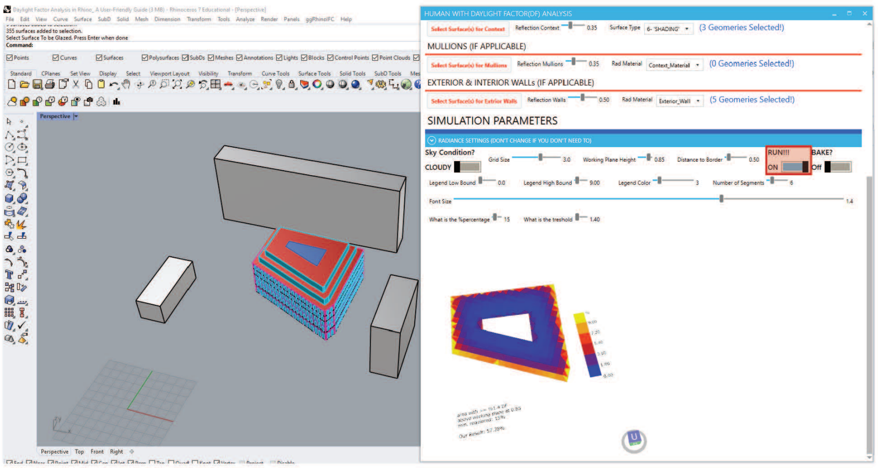
Using the Tool

Step-by-step guide to running a daylight analysis using the tool

*When you activate the "RUN" toggle in the tool, several windows command prompts will pop up, indicating that your analysis is in progress. It's important **not to** close these windows, as they will close automatically one by one. After the analysis finishes, you can see the results in the interface. You can view the results in the form of a colored map representing the daylight factor values, which can be adjusted by changing the color scale.*

37

Figure C-37: Document Page-37



Daylight Factor Analysis in Rhino_ A User-Friendly Guide (3 MB) - Rhinoceros 7 Educational - [Perspective]

```
355 surfaces added to selection.
Select Surface To be Glazed. Press Enter when done
Command:
```

HUMAN WITH DAYLIGHT FACTOR(DF) ANALYSIS

Reflection Context 0.35; Surface Type 6- 'SHADING' (3 Geomeries Selected!)

MULLIONS (IF APPLICABLE)

Reflection Mullions 0.35; Rad Material Context_Material (0 Geomeries Selected!)

EXTERIOR & INTERIOR WALLs (IF APPLICABLE)

Reflection Walls 0.50; Rad Material Exterior_Wall (5 Geomeries Selected!)

SIMULATION PARAMETERS

RADIANCE SETTINGS (DON'T CHANGE IF YOU DON'T NEED TO)

Sky Condition? CLOUDY

Grid Size 3.0; Working Plane Height 0.85; Distance to Border 0.50; RUN!!! ON; BAKE? Off

Legend Low Bound 0.0; Legend High Bound 9.00; Legend Color 3; Number of Segments 6

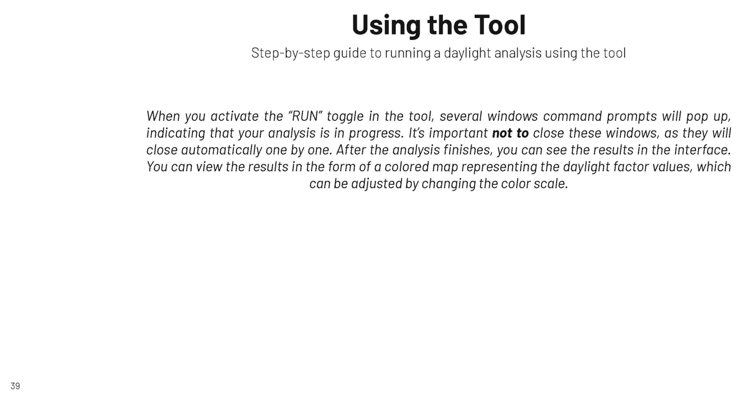
Font Size 1.4

What is the %percentage 15; What is the treshold 1.40

Visualizing the Results

38

Figure C-38: Document Page-38



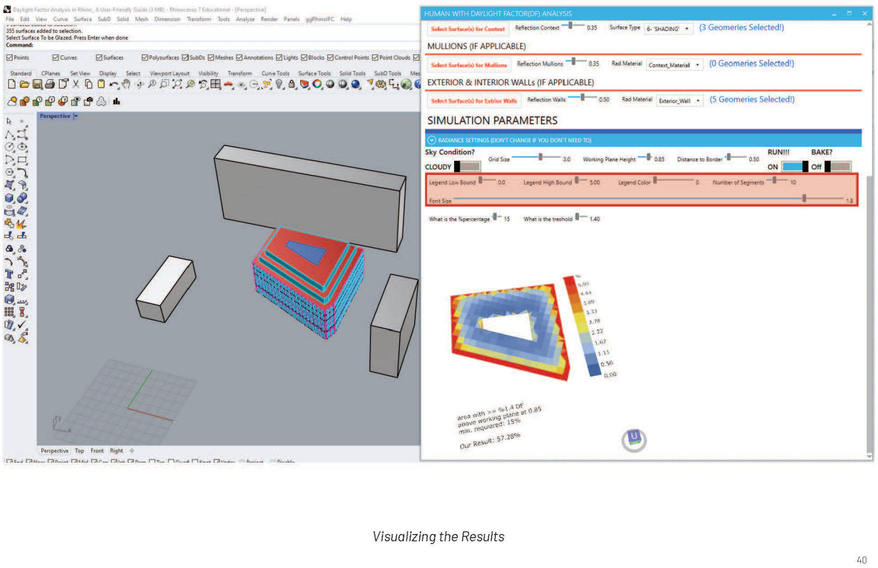
Using the Tool

Step-by-step guide to running a daylight analysis using the tool

*When you activate the "RUN" toggle in the tool, several windows command prompts will pop up, indicating that your analysis is in progress. It's important **not to** close these windows, as they will close automatically one by one. After the analysis finishes, you can see the results in the interface. You can view the results in the form of a colored map representing the daylight factor values, which can be adjusted by changing the color scale.*

39

Figure C-39: Document Page-39



355 surfaces added to selection.
Select Surface To be Glazed. Press Enter when done
Command:

HUMAN WITH DAYLIGHT FACTOR(DF) ANALYSIS

Select Surface(s) for Context — Reflection Context 0.35 — Surface Type 6- 'SHADING' — (3 Geomeries Selected!)

MULLIONS (IF APPLICABLE)

Select Surface(s) for Mullions — Reflection Mullions 0.35 — Rad Material Context_Material — (0 Geomeries Selected!)

EXTERIOR & INTERIOR WALLs (IF APPLICABLE)

Select Surface(s) for Extrior Walls — Reflection Walls 0.50 — Rad Material Exterior_Wall — (5 Geomeries Selected!)

SIMULATION PARAMETERS

RADIANCE SETTINGS (DON'T CHANGE IF YOU DON'T NEED TO)

Sky Condition? CLOUDY — Grid Size 3.0 — Working Plane Height 0.85 — Distance to Border 0.50 — RUN!!! ON — BAKE? Off

Legend Low Bound 0.0 — Legend High Bound 5.00 — Legend Color 0 — Number of Segments 10

Font Size 1.8

What is the %percentage 15 — What is the treshold 1.40

area with >= %1.4 DF
above working plane at 0.85
min. requiered: 15%

Our Result: 57.28%

Visualizing the Results

40

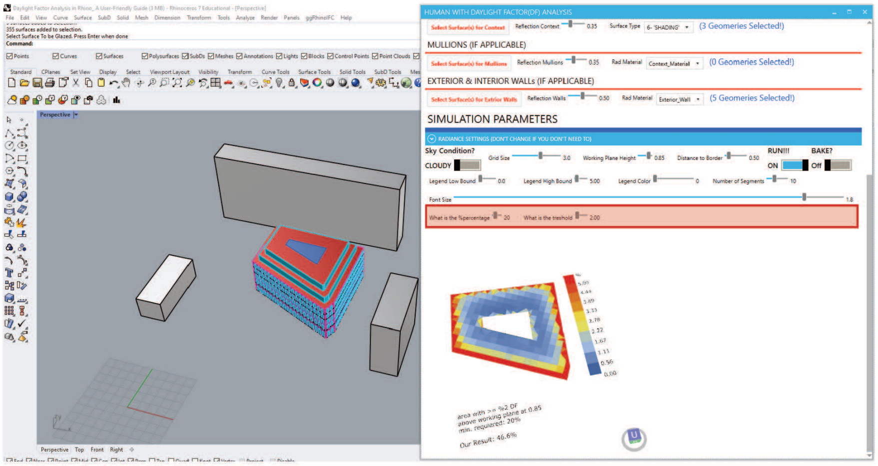
Figure C-40: Document Page-40

Using the Tool

Step-by-step guide to running a daylight analysis using the tool

Once you've set up the analysis parameters and components, you can run the analysis to obtain results. While the analysis is running, you will see a small screen on the interface of the tool, which allows you to zoom in and out or pan around the results. Once the analysis is complete, you can adjust the legend minimum and maximum values, choose different colors for the legend, and change the text size as needed to make the results more readable. This can help you gain a better understanding of the daylight factor and illuminance distribution in your space.

Figure C-41: Document Page-41



355 surfaces added to selection.
Select Surface To be Glazed. Press Enter when done
Command:

HUMAN WITH DAYLIGHT FACTOR(DF) ANALYSIS

Select Surface(s) for Context — Reflection Context 0.35 — Surface Type 6- 'SHADING' — (3 Geomeries Selected!)

MULLIONS (IF APPLICABLE)

Select Surface(s) for Mullions — Reflection Mullions 0.35 — Rad Material Context_Material — (0 Geomeries Selected!)

EXTERIOR & INTERIOR WALLs (IF APPLICABLE)

Select Surface(s) for Extrior Walls — Reflection Walls 0.50 — Rad Material Exterior_Wall — (5 Geomeries Selected!)

SIMULATION PARAMETERS

RADIANCE SETTINGS (DON'T CHANGE IF YOU DON'T NEED TO)

Sky Condition? CLOUDY — Grid Size 3.0 — Working Plane Height 0.85 — Distance to Border 0.50 — RUN!!! ON — BAKE? Off

Legend Low Bound 0.0 — Legend High Bound 5.00 — Legend Color 0 — Number of Segments 10

Font Size 1.8

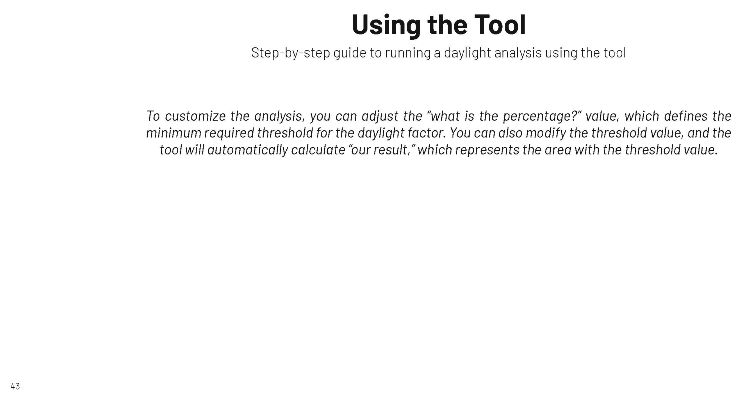
What is the %percentage 20 — What is the treshold 2.00

area with >= %2 DF
above working plane at 0.85
min. requiered: 20%

Our Result: 46.6%

Visualizing & Altering the Results

Figure C-42: Document Page-42



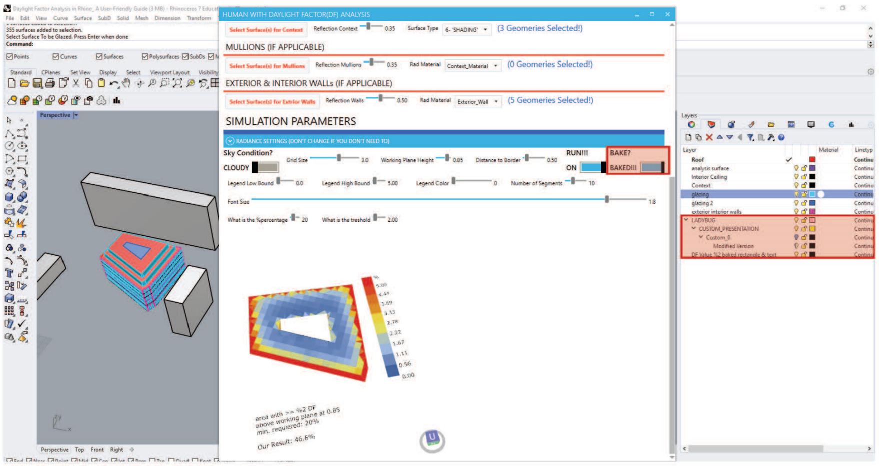
Using the Tool

Step-by-step guide to running a daylight analysis using the tool

To customize the analysis, you can adjust the "what is the percentage?" value, which defines the minimum required threshold for the daylight factor. You can also modify the threshold value, and the tool will automatically calculate "our result," which represents the area with the threshold value.

43

Figure C-43: Document Page-43



Reflection Context 0.35 Surface Type 6- 'SHADING' (3 Geomeries Selected!)

MULLIONS (IF APPLICABLE)

Reflection Mullions 0.35 Rad Material Context_Material (0 Geomeries Selected!)

EXTERIOR & INTERIOR WALLs (IF APPLICABLE)

Reflection Walls 0.50 Rad Material Exterior_Wall (5 Geomeries Selected!)

SIMULATION PARAMETERS

RADIANCE SETTINGS (DON'T CHANGE IF YOU DON'T NEED TO)

Sky Condition? CLOUDY

Grid Size 3.0

Working Plane Height 0.85

Distance to Border 0.50

RUN!!! ON

BAKE? BAKED!!!

Legend Low Bound 0.0

Legend High Bound 5.00

Legend Color 0

Number of Segments 10

Font Size 1.8

What is the %percentage 20

What is the treshold 2.00

area with >= %2 DF
above working plane at 0.85
min. requiered: 20%

Our Result: 46.6%

Visualizing & Altering the Results

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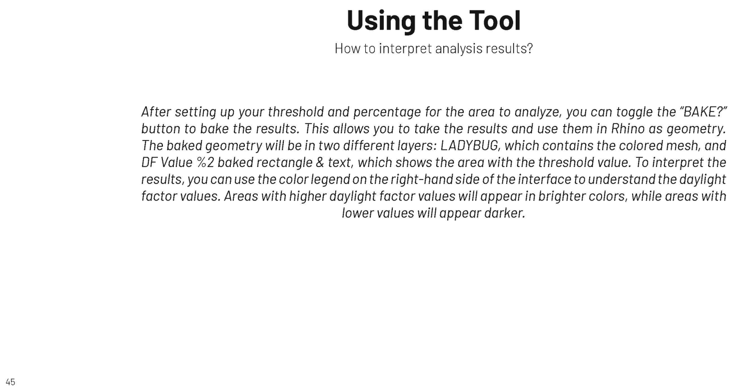
Figure C-44: Document Page-44



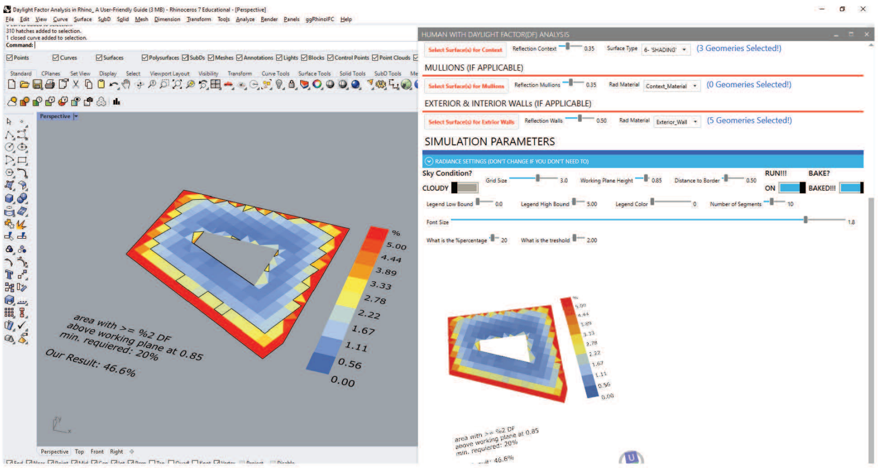
Using the Tool

How to interpret analysis results?

After setting up your threshold and percentage for the area to analyze, you can toggle the "BAKE?" button to bake the results. This allows you to take the results and use them in Rhino as geometry. The baked geometry will be in two different layers: LADYBUG, which contains the colored mesh, and DF Value %2 baked rectangle & text, which shows the area with the threshold value. To interpret the results, you can use the color legend on the right-hand side of the interface to understand the daylight factor values. Areas with higher daylight factor values will appear in brighter colors, while areas with lower values will appear darker.

45

Figure C-45: Document Page-45



310 hatches added to selection.
1 closed curve added to selection.
Command:

area with >= %2 DF
above working plane at 0.85
min. requiered: 20%
Our Result: 46.6%

Reflection Context 0.35 Surface Type 6- 'SHADING' (3 Geomeries Selected!)

MULLIONS (IF APPLICABLE)

Reflection Mullions 0.35 Rad Material Context_Material (0 Geomeries Selected!)

EXTERIOR & INTERIOR WALLs (IF APPLICABLE)

Reflection Walls 0.50 Rad Material Exterior_Wall (5 Geomeries Selected!)

SIMULATION PARAMETERS

Sky Condition? CLOUDY
Grid Size 3.0
Working Plane Height 0.85
Distance to Border 0.50
RUN!!! ON
BAKE? BAKED!!!
Legend Low Bound 0.0
Legend High Bound 5.00
Legend Color 0
Number of Segments 10
Font Size 1.8
What is the %percentage 20
What is the treshold 2.00

Visualizing & Altering the Results

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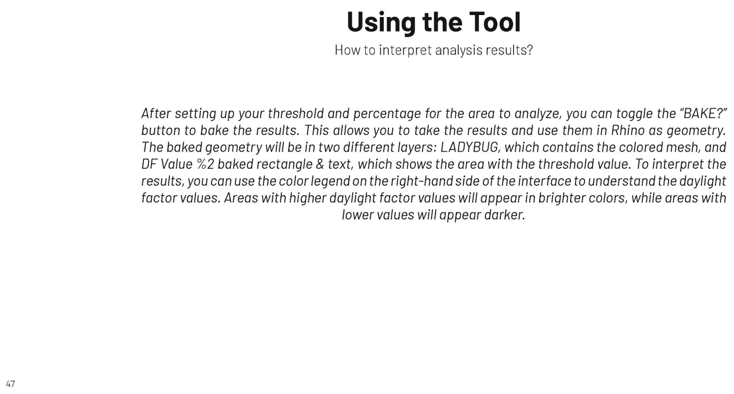
Figure C-46: Document Page-46



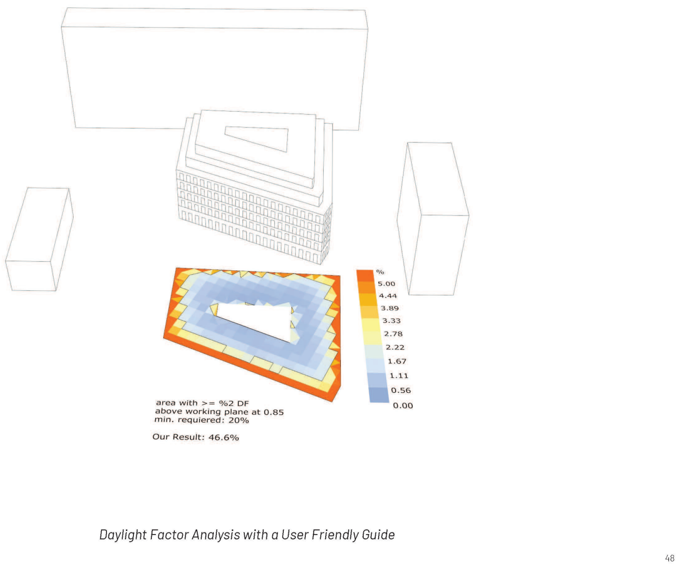
Using the Tool

How to interpret analysis results?

After setting up your threshold and percentage for the area to analyze, you can toggle the "BAKE?" button to bake the results. This allows you to take the results and use them in Rhino as geometry. The baked geometry will be in two different layers: LADYBUG, which contains the colored mesh, and DF Value %2 baked rectangle & text, which shows the area with the threshold value. To interpret the results, you can use the color legend on the right-hand side of the interface to understand the daylight factor values. Areas with higher daylight factor values will appear in brighter colors, while areas with lower values will appear darker.

47

Figure C-47: Document Page-47



area with >= %2 DF
above working plane at 0.85
min. requiered: 20%

Our Result: 46.6%

Daylight Factor Analysis with a User Friendly Guide

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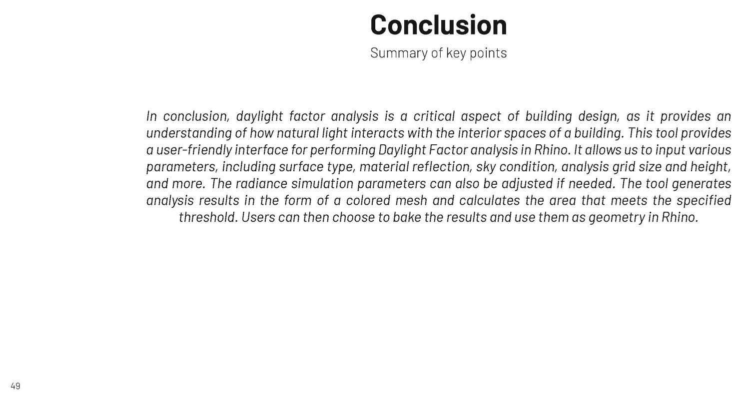
Figure C-48: Document Page-48

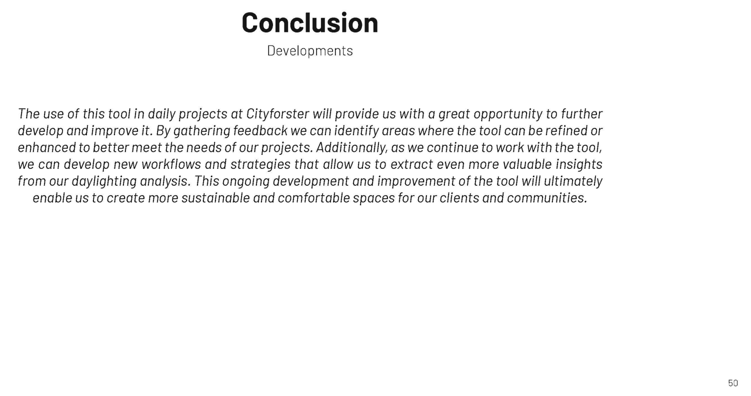


Conclusion

Summary of key points

In conclusion, daylight factor analysis is a critical aspect of building design, as it provides an understanding of how natural light interacts with the interior spaces of a building. This tool provides a user-friendly interface for performing Daylight Factor analysis in Rhino. It allows us to input various parameters, including surface type, material reflection, sky condition, analysis grid size and height, and more. The radiance simulation parameters can also be adjusted if needed. The tool generates analysis results in the form of a colored mesh and calculates the area that meets the specified threshold. Users can then choose to bake the results and use them as geometry in Rhino.

Figure C-49: Document Page-49



Conclusion

Developments

The use of this tool in daily projects at Cityforster will provide us with a great opportunity to further develop and improve it. By gathering feedback we can identify areas where the tool can be refined or enhanced to better meet the needs of our projects. Additionally, as we continue to work with the tool, we can develop new workflows and strategies that allow us to extract even more valuable insights from our daylighting analysis. This ongoing development and improvement of the tool will ultimately enable us to create more sustainable and comfortable spaces for our clients and communities.

Figure C-50 Document Page-50

Appendix D

From Complexity to Simplicity: Robotic Fabrication's Influence on Enhanced Fabrication and Assembly

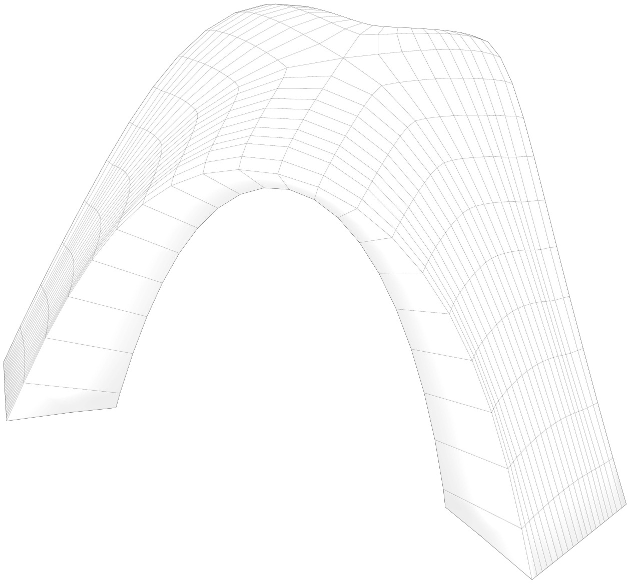


Figure D-1: Macro form

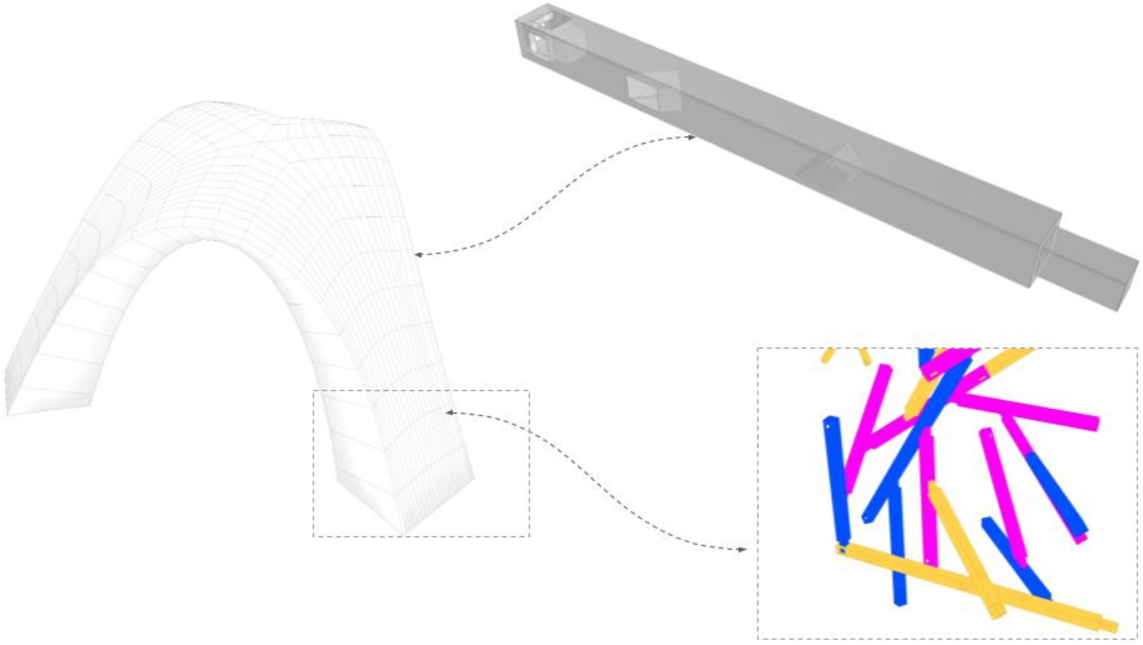


Figure D-2: Partial macro form generated with component-1

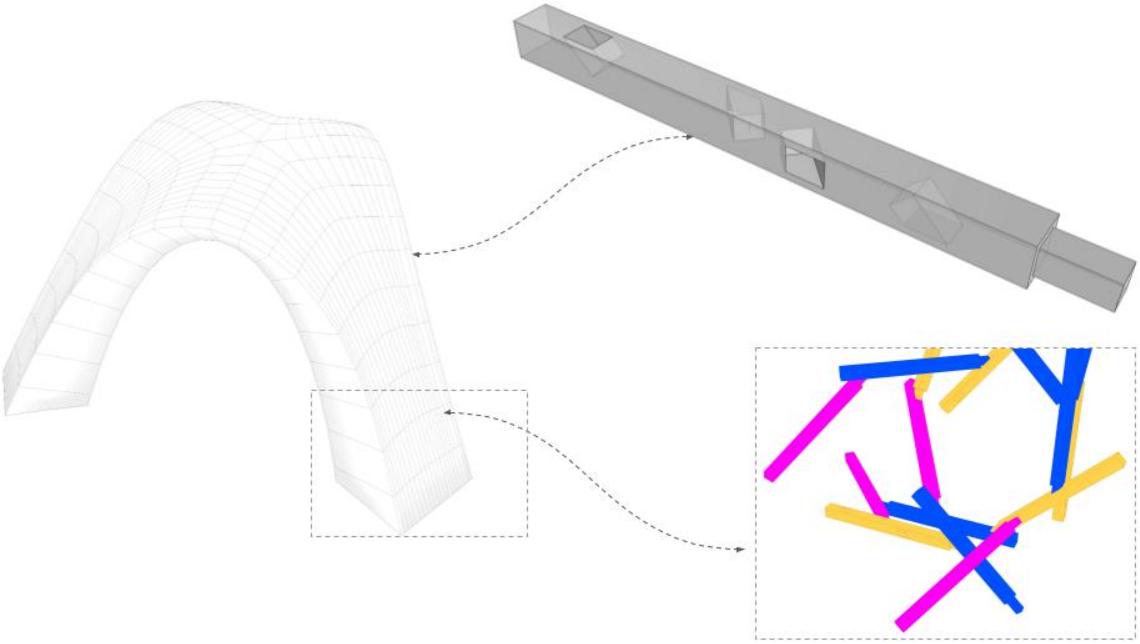


Figure D-3: Partial macro form generated with component-2

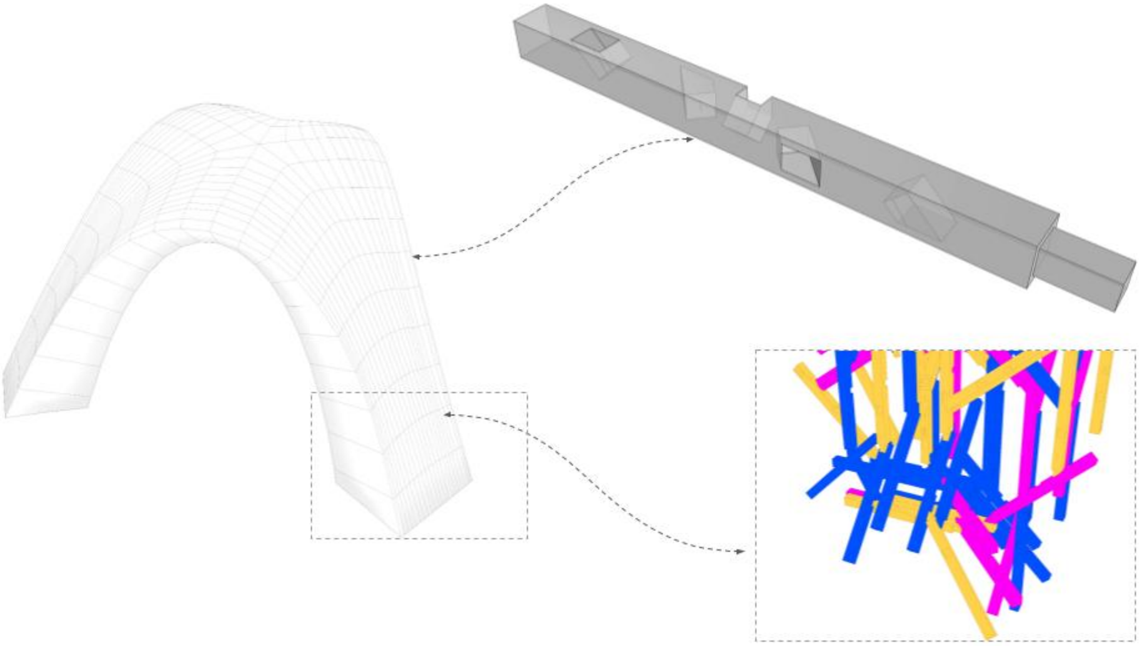


Figure D-4: Partial macro form generated with component-3

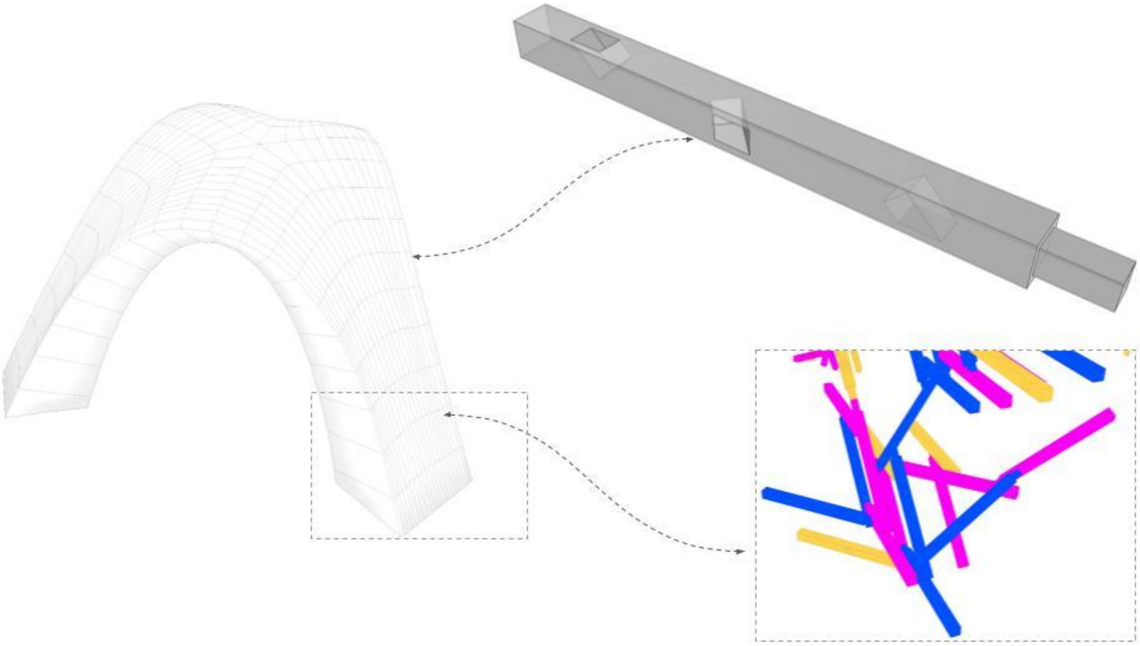


Figure D-7: Partial macro form generated with component-4

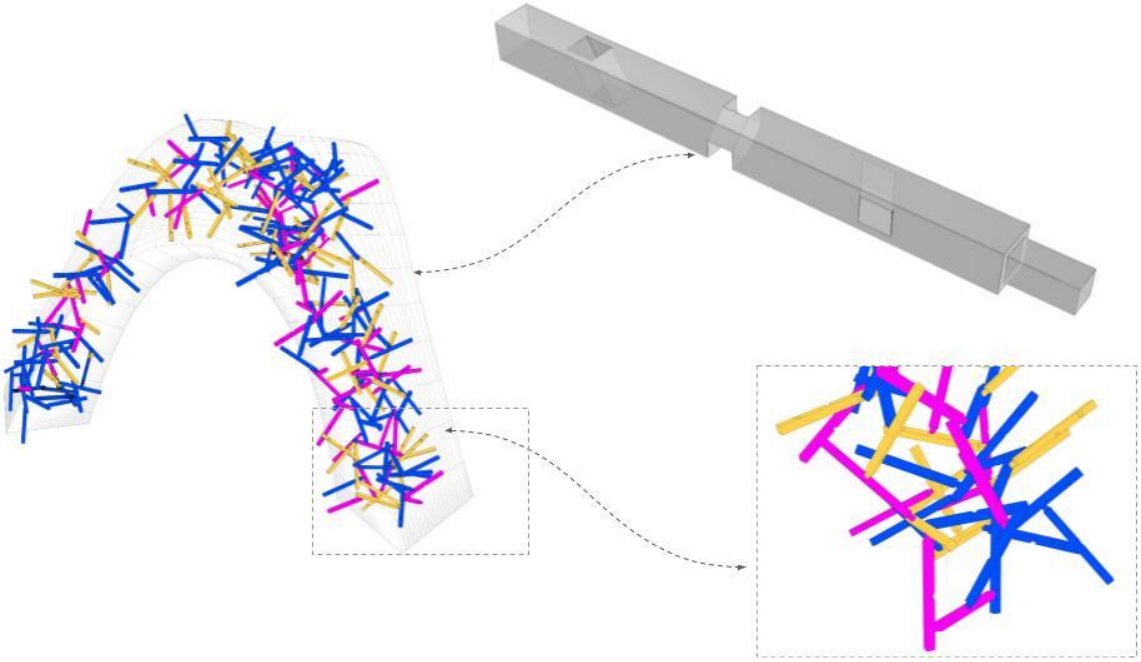


Figure D-8: Macro form generated with component-4

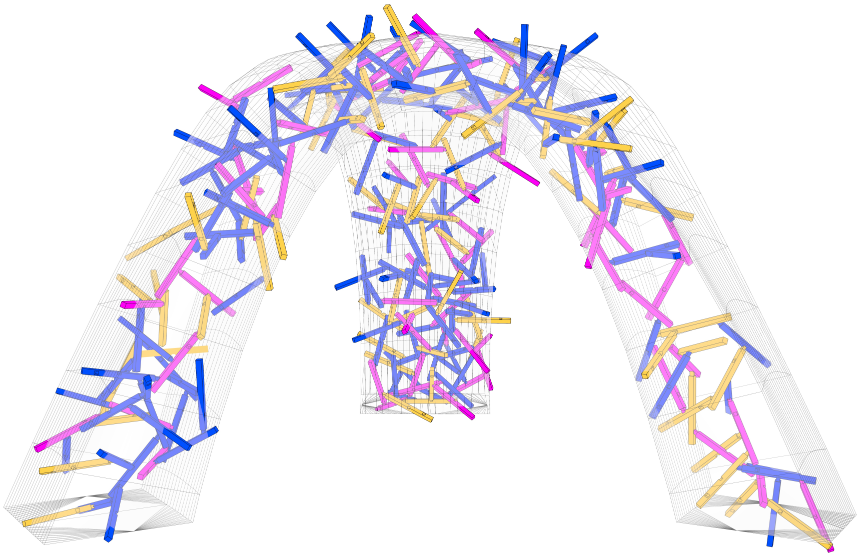


Figure D-9: Macro form generated with component-4

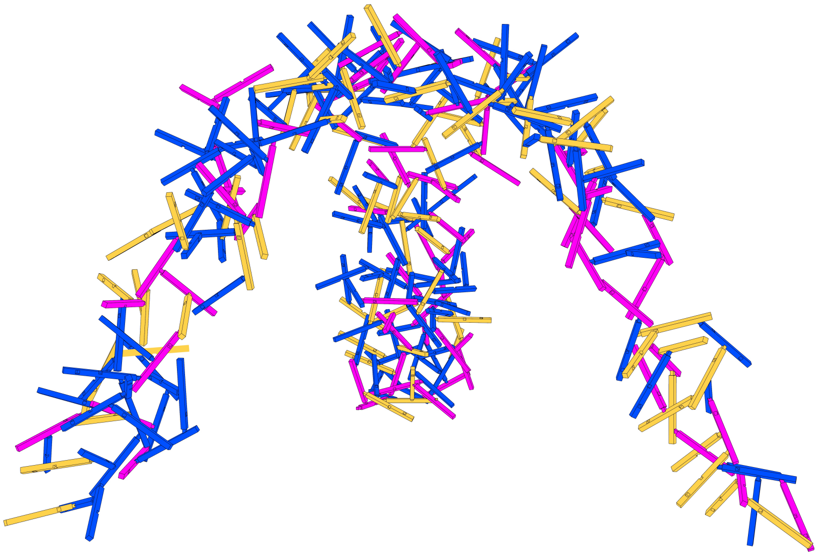


Figure D-10: Macro Form generated with component-4

Figure D-11: Robotic fabrication of component-4

Figure D-12: Prototypes with component-4

Figure D-13: Holographic projection assisted assembly

Figure D-14: Assembly Process

Figure D-15: Assembly process

Figure D-16: Final structure

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