

Quantifying Environmental Activation in Sustainable Interior

Design An Analytical Approach

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Abstract

Interior design significantly shapes our built environment, influencing human well-being and resource utilization (Smith, 2019). In response to this critical role, the study introduces an innovative analytical framework for assessing the efficiency and effectiveness of interior spaces. The used approach integrates quantitative metrics with a deep understanding of space anatomy, emphasizing how design decisions impact decision quality (Brown, 2020). Through rigorous analytical study, we seek to enhance decision-making processes. By dissecting space anatomy, we uncover insights that empower designers to make informed choices, ultimately improving the overall quality of interior design projects, and quantifying the efficiency of interior design spaces using an arithmetic approach. By evaluating the relationship between outputs and inputs, we aim to optimize resource utilization while minimizing waste, leveraging network measurement concepts, and exploring intricate relationships among diverse design elements and project activities (Garcia, 2018), using (Quantitative Assessment, Space Anatomy Impact, and Network Measurement). The research findings contribute significantly to elevating decision-making processes within sustainable interior design, fostering environmentally conscious choices.

Keywords

Efficiency, Effectiveness, Interior Design, Decision Making, Network Measurement

المخلص

يشكل التصميم الداخلي بيئتنا المبنية بشكل كبير، مما يؤثر على رفاهية الإنسان واستخدام الموارد (سميث، ٢٠١٩). واستجابة لهذا الدور الهام، تقدم الدراسة إطاراً تحليلياً مبتكراً لتقييم كفاءة وفعالية الحيز الداخلي. حيث يدمج النهج المستخدم المقاييس الكمية مع الفهم العميق لتشريح عناصر الحيز الداخلي، مع التركيز على كيفية تأثير جودة عملية اتخاذ وصنع القرارات التصميمية على مستوى هذه القرارات (Brown, 2020) ومن خلال دراسة تحليلية دقيقة، نسعى إلى تعزيز عمليات صنع القرار. من خلال ما يشبه تشريح الحيز الداخلي وعناصره وعلاقة بعضها البعض، نكشف عن رؤى تمكن المصممين من اتخاذ خيارات صائبة، تعمل على تحسين الجودة الشاملة لمشاريع التصميم الداخلي في نهاية المطاف، وقياس كفاءة مساحات التصميم الداخلي باستخدام نهج حسابي. من خلال تقييم العلاقة بين المخرجات والمدخلات، كما نهدف إلى تحسين استخدام الموارد مع تقليل الهدر، والاستفادة من مفاهيم القياسات الشبكية، واستكشاف العلاقات المعقدة بين عناصر التصميم المتنوعة وأنشطة المشروع (Garcia, 2018). باستخدام (التقييم الكمي، تأثير تشريح عناصر الحيز الداخلي، والقياس الشبكي). وتساهم نتائج البحث بشكل كبير في رفع مستوى عمليات صنع القرار ضمن التصميم الداخلي المستدام، وتعزيز الخيارات الواعية بيئياً.

الكلمات المفتاحية

الكفاءة، الفاعلية، التصميم الداخلي، اتخاذ القرار، القياس الشبكي

Introduction

Interior architecture designers play a pivotal role in shaping our built environment. Their decisions not only influence aesthetics but also significantly impact human well-being and resource utilization. As these designers strive to create sustainable and functional interior spaces, the need for a specific methodology becomes evident. This methodology should enable them to make accurate decisions that enhance the overall quality of interior design projects.

Interior designers face multifaceted challenges when making decisions. They must consider various factors, including aesthetics, functionality, user experience, and environmental impact. However, subjective judgments alone may not suffice. To what extent can designers objectively measure the quality of their decisions? How can they improve their choices systematically?

The core lies in quantifying the efficiency and effectiveness of interior spaces. Efficiency refers to achieving optimal outcomes with minimal resource waste, while effectiveness relates to the degree of alignment with project goals. By measuring these dimensions, designers can enhance decision-making processes and contribute to a more sustainable built environment.

- **Context and Significance:** Begin by providing context for your literature review. Explain why environmental activation in sustainable interior design is a critical area of study. Discuss how it impacts human well-being, resource utilization, and the overall quality of interior spaces.
- **Research Gap:** Highlight the need for further investigation in this field. Mention any gaps or unanswered questions related to environmental activation.

Objective:

1. Efficiency Measurement: Our primary objective is to quantify the efficiency of interior design spaces using an arithmetic approach.
2. Enhancing Decision Quality: Through rigorous analytical study.

Hypotheses:

1. Quantitative Assessment: We hypothesize that efficiency and effectiveness in interior spaces can be objectively measured. Our mathematical framework allows us to evaluate design outcomes rigorously.
2. On Space Anatomy Impact: Analyzing the intricate anatomy of interior spaces significantly improves decision quality by optimizing layouts, materials, and functionality through a better understanding of spatial relationships.
3. On Network Measurement: Applying network measurement concepts to control relationships among project elements enhances efficient coordination and collaboration through a holistic view.

Literature review

Origins of Research in Sustainable Interior Design

Sustainable interior design emerged as a response to mounting concerns about deforestation, pollution, and resource depletion. Rooted in the principles of responsible production and consumption, sustainable design seeks to minimize negative environmental impacts while promoting longevity and resilience. This review explores pivotal moments,

influential studies, and visionary designers who have shaped the trajectory of sustainable interior design.

- **Early Foundations: Late 1980s to Early 1990s**

Sustainable Development Awareness: The late 1980s witnessed the emergence of sustainable development as a global imperative. The Brundtland Commission's report, "Our Common Future" (WCED, 1987), highlighted the interconnectedness of environmental, social, and economic factors.

Recognition of Product Impact: Researchers and practitioners recognized that products—especially those related to interior design—played a central role in environmental and societal impacts. Negative consequences were linked to production, consumption, and end-of-life disposal (McAloon & Pigosso, 2017).

- **Pioneering Studies and Influential Designers**

The ICED Series: The International Conference on Engineering Design (ICED) has been a pivotal platform for sustainable design discourse. Since its inception in 1981, ICED has hosted discussions, presentations, and research on sustainable practices within design (Bhamra & Hernandez, 2021). Notably, ICED has reflected the shifting focus from recycling and end-of-life considerations to a holistic emphasis on sustainability throughout the product lifecycle.

Laura Hodges Studio: Laura Hodges, a LEED Accredited Professional, exemplifies sustainable design commitment. Her projects integrate vegan leathers, vintage pieces, and green walls filled with houseplants. Hodges emphasizes material reuse, donation of excess furnishings, and sourcing from vendors with sustainable practices (Hodges, personal communication, 2021).

Sean Leffers Interiors: Sean Leffers combines timeless aesthetics with eco-conscious technologies. His design approach highlights antiques and embraces sustainable materials. Leffers advocates for responsible sourcing, minimal waste, and collaboration with local woodworkers (Leffers, personal communication, 2021).

Sustainable interior design has evolved significantly over the past three decades. Pioneering studies, conferences like ICED, and visionary designers have propelled the field forward. As we move toward a greener future, the lessons learned from these origins underscore the need for continued research, industry leadership, and collaborative efforts to create interiors that harmonize with our planet.

The field has evolved; for example, early studies may have focused on energy-efficient materials, while recent research emphasizes holistic approaches to sustainability.

Early Studies: Energy Efficiency and Material Selection

1. Energy-Efficient Materials:

- **Origins:** In the 1970s and 1980s, the energy crisis prompted investigations into energy-efficient building materials. Researchers explored insulation, glazing, and lighting systems to reduce energy consumption.
- **Influential Studies:** Pioneering works like the "Passive Solar Handbook" by Mazria (1979) emphasized passive solar design principles, harnessing natural energy for heating and cooling.

2. Material Lifecycle Assessment:

- Emergence: By the 1990s, scholars recognized that material selection impacted environmental impact throughout a product's lifecycle, Life Cycle Assessment (LCA) gained prominence.
- Holistic Approach: Researchers assessed materials based on extraction, production, transportation, use, and disposal. This holistic view informed sustainable material choices (Bhamra & Hernandez, 2021).

Contemporary Research: Holistic Sustainability

1. Beyond Energy: Recent research transcends energy efficiency. It embraces broader ecological, social, and economic dimensions.
2. Circular Economy: The circular economy framework advocates for closed-loop systems, minimizing waste and maximizing resource reuse. Interior designers now consider material circularity and end-of-life scenarios (Bhamra & Hernandez, 2021).
3. Biophilic Design: Biophilia—the innate human connection to nature—has gained prominence. Researchers explore how integrating natural elements (plants, daylight, water features) enhances occupants' well-being and environmental harmony (Kellert, 2008).
4. Health and Well-Being: Sustainable interiors prioritize human health. Studies link indoor air quality, acoustics, and lighting to occupant well-being (Heschong Mahone Group, 2003).
5. Social Equity: Sustainable design extends beyond physical spaces. Researchers advocate for social justice, inclusivity, and community engagement (Guerin & Guerin, 2019).

Sustainable interior design has evolved from a narrow focus on energy efficiency to a holistic approach that considers materials, well-being, and social impact. As we navigate complex global challenges, interdisciplinary collaboration and ongoing research remain essential for a resilient and regenerative future.

Theories and design practices

Architects and interior designers have drawn upon various theories and design practices to create spaces that harmonize human well-being with ecological balance (Fig.1). By understanding psychological factors, architects can shape interior environments that positively impact occupants' behavior and emotions. Beyond mere functionality, architecture becomes a catalyst for physical, physiological, and psychological well-being.

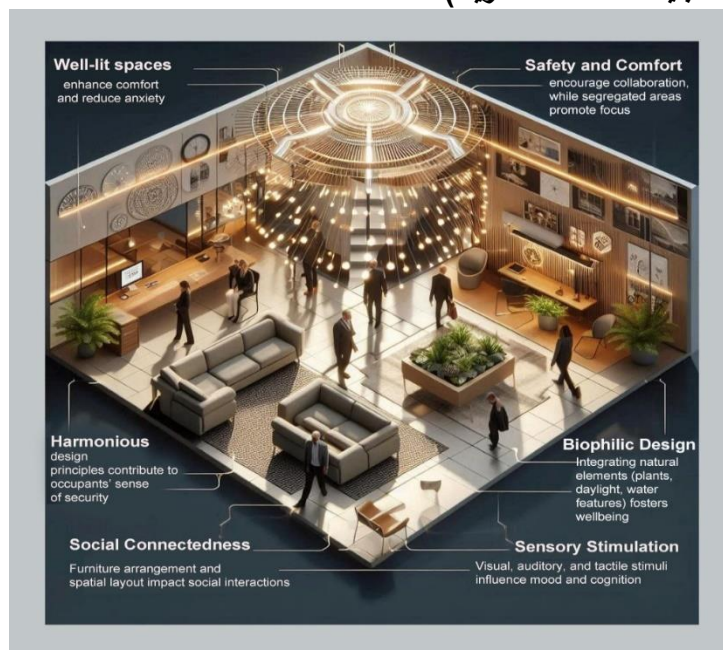


FIGURE 1 EXAMPLES OF THE PSYCHOLOGICAL FACTORS INFLUENCING OCCUPANTS' INTERACTIONS WITH INTERIOR SPACES - DEVELOPED BY THE RESEARCHER

Consequently, there is a pressing need to emphasize relevant theories and conceptual frameworks that inform design decisions promoting environmental activation, such as:

- Environmental Psychology, where the interplay between human behavior and interior spaces takes center stage. Environmental psychology, also known as space psychology, explores how our surroundings influence our emotions, actions, and overall well-being. Lighting, colors, spatial configuration, acoustics, and materials all play a role in shaping our psychological responses within built environments (Kopec, 2020).
- Safety and Comfort: Architects must prioritize safety, social connectedness, ease of movement, and sensory stimulation when designing interior spaces. These factors directly impact occupants' experiences. For instance, a well-lit hallway with clear signage fosters comfort and reduces anxiety. Additionally, according to (Altomonte, Sergio) the principles of design—such as balance, proportion, symmetry, and rhythm—can introduce a sense of harmony.
- Social Connectedness: (Kaup, Migette) The arrangement of furniture and spatial layout significantly influences our sense of comfort and interactions with others. Open plans encourage collaboration, while segregated spaces promote focus and concentration.
- Biophilic Design: Integrating natural elements—such as daylight, plants, and water features—enhances our connection to nature. Biophilic interiors reduce stress, improve focus, and contribute to overall well-being. Imagine a sunlit office adorned with potted plants, where occupants thrive both mentally and physically (Kopec, 2020).

By establishing a coherent relationship between nature, human biology, and the physical, visual, and emotional aspects of architectural spaces (Stouhi, 2023). Architects and designers have collaboratively explored how to utilize the aspects of nature that most impact our relationship with the built environment. Many theorists organize biophilic design principles under three categories: Nature in the space, nature of the space, and natural analogues, all of which determine a physical, visual, and emotional connection to the natural world. This

framework goes beyond materials, light, and ventilation, emphasizing that effective biophilic design lets the earth be the architecture itself or at least a significant part of it. Locally-appropriate design is also crucial, ensuring that the architecture blends seamlessly with its specific surroundings.

The successful application of biophilic design principles stimulates a wide spectrum of benefits. Physically, it improves fitness, lowers blood pressure, and reduces illness symptoms. Mentally, it enhances motivation, productivity, creativity, and decreases stress and anxiety. Behaviorally and cognitively, it leads to improved coping skills, attention span, and increased social interaction. Examples of biophilic design in practice include the iconic Gardens by the Bay in Singapore, where green spaces and vertical gardens foster a more sustainable and livable urban environment. Additionally, projects like the Six Square House by Young Projects demonstrate how integrating natural materials, abundant natural light, and greenery can create harmonious connections between people and their built environments (Stouhi, 2023).

Not to forget the role of smart sensors, IoT devices, and data analytics in optimizing environmental conditions, which helped to investigate how sustainable design impacts occupants' health, productivity, and satisfaction.

2. Methodological Approaches

Compare research methods (Quantitative vs. Qualitative) commonly used in sustainable interior design studies. Quantitative methods (surveys, measurements) provide numerical data, while qualitative methods (interviews, case studies) offer deeper insights. However, some studies combine both approaches to benefit from such a diverse toolkit. Creating a holistic understanding of environmental activation, informing better design practices. Shaped by research, industry practices, and visionary designers. Early studies in the late 20th century focused on energy-efficient materials and passive solar design. Researchers explored insulation, glazing, and lighting systems to reduce energy consumption. Notable works like the "Passive Solar Handbook" by Mazria (1979) emphasized these principles. However, contemporary research takes a holistic approach, considering not only energy efficiency but also health, well-being, and social equity. The emergence of the circular economy framework emphasizes closed-loop systems, minimizing waste and maximizing resource reuse. Examples of successful cost-effective sustainable projects include IKEA's circular economy initiatives, the energy-efficient office building "The Edge" in Amsterdam, and Patagonia's Worn Wear program. These projects demonstrate that sustainable practices need not be cost-prohibitive and can align financial viability with environmental responsibility. As the field continues to evolve, interdisciplinary collaboration and ongoing research remain essential for resilient and regenerative design.

Although, progress in sustainable design, gaps persist in our understanding of environmental activation. Key questions remain unanswered:

- How can we objectively measure the impact of design decisions on occupants' well-being?
- What strategies enhance efficiency and effectiveness in interior spaces?
- Are there overlooked factors that significantly influence environmental activation?

Several trials have been done through this paper to address these gaps by proposing an analytical approach to quantifying environmental activation in sustainable interior design, listing valuable insights into the field, and empowering designers to make informed choices. Focusing on the relationship between the number of outputs to the number of inputs. Regarding that the main goal of efficiency measurement is to maximize the number of outputs and minimize the waste of resources [materials, energy, efforts, money, and time]. To achieve $\text{Efficiency} = \text{OUTPUT}/\text{INPUT} * 100\%$.

So, the relationship between the outputs to achieve Effectiveness throughout achieving the planned or targeted outputs = Quality.

Based on the interior design definition, this profession has three main elements that should be taken into consideration (Fig.2).

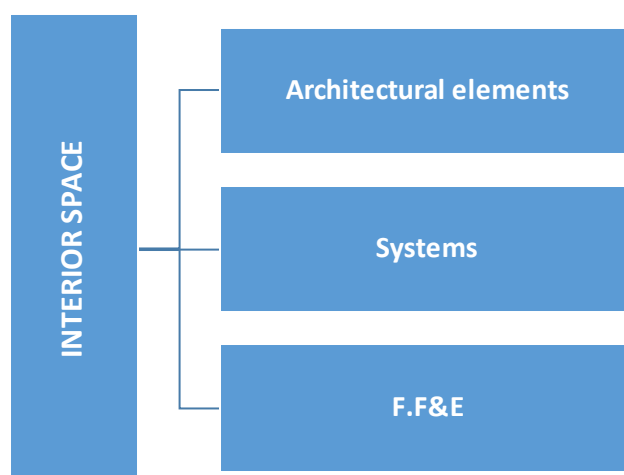


FIGURE 2 INTERIOR SPACE ELEMENTS

Each category or Sub-category of these elements should be weighted. On the other hand, Space Conformance Monitoring (elements integration). [Here, it is important to monitor the compatibility between the different elements within the vacuum and to what extent are properly working to achieve its requirements]. (**Conformance Testing:** It is a methodology used to ensure that a product, process or systems meets a defined set of standards/requirements).

Therefore, defining the project Scope of Work will always be the path to List the weighted goals and objectives for your project. [In this phase it's too important to classify the objectives to be sure that all stakeholders' needs are covered. So you can use the stakeholders' management figure (Fig.3) to fit each objective in the right corner (Fig.4). Using a right corner will help you to weigh each goal or objective correctly.]

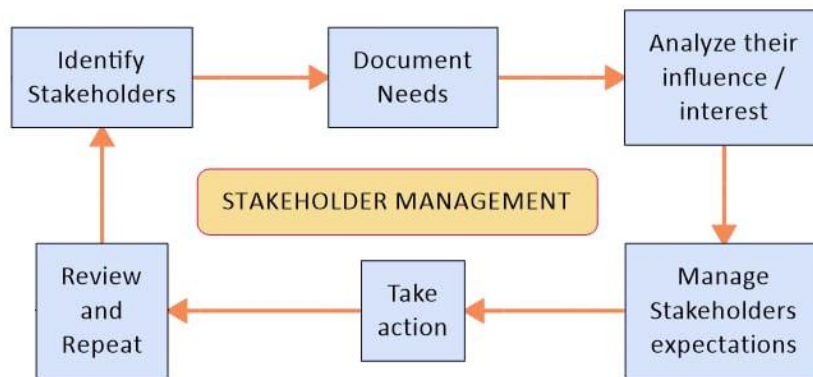


FIGURE 3 STAKEHOLDERS MANAGEMENT

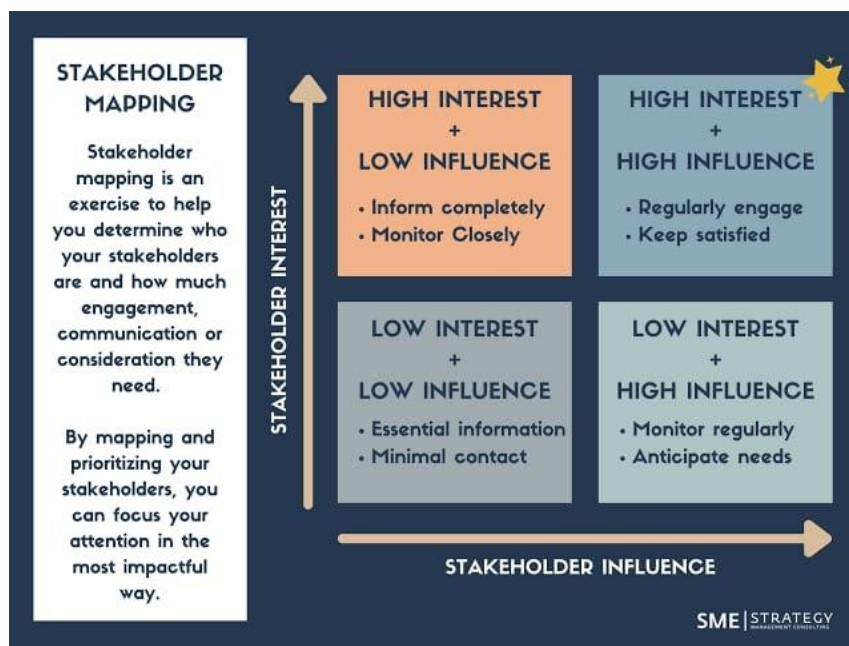


FIGURE 4 STAKEHOLDERS MAPPING

Stakeholder Engagement Assessment Matrix

Stakeholder	Unaware	Resistant	Neutral	Supportive	Leading
Stakeholder 1	C			D	
Stakeholder 2			C	D	
Stakeholder 3				CD	

C = current engagement
 D = desired engagement

FIGURE 5 STAKEHOLDERS' ENGAGEMENT ASSESSMENT MATRIX

Using stakeholders' engagement assessment matrix will be particularly useful at this stage. (Fig.5)

Then translate the Scope of work to a clear list of deliverables using WBS formats. (Fig.6)
 [Here each point of deliverables should be weighted with expertise according to the project objectives. The sum of all points or items should equal (1). 100% rule].

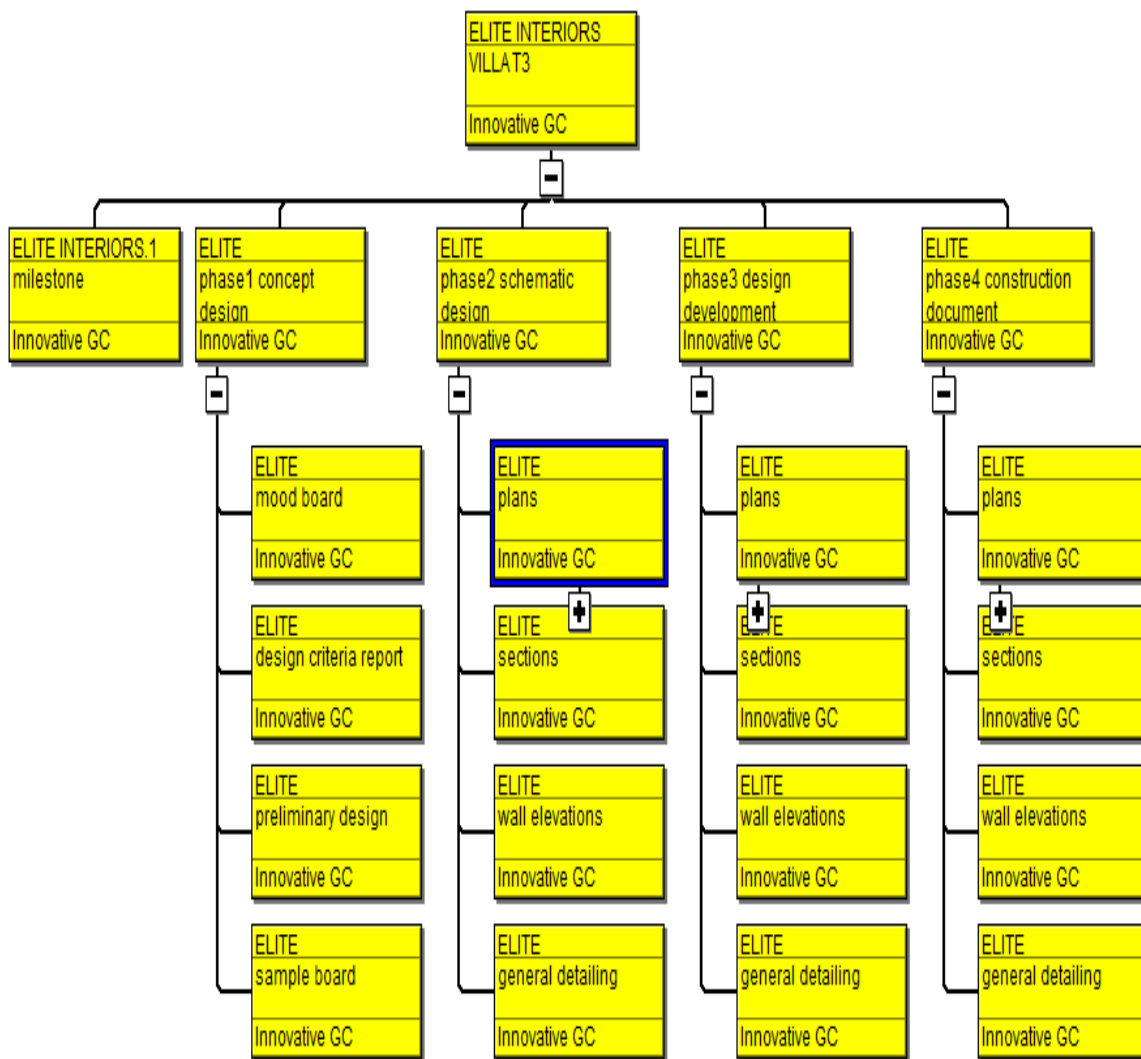


FIGURE 6 WBS SAMPLE

The main aim of these procedures is to measure decision quality even if it is a design or construction phase. Even when working on a report to assess a specific design to renovate an interior space, there is a need to apply this methodology twice. One for the existing and the other for the new one. This method will help to compare between the two cases arithmetically. Supported with proper metrics to measure both inputs and outputs, such as:

1. **Environmental Activation of Inner Space Components:**
 - o **Energy Efficiency Metrics:** Assess the energy performance of specific components (e.g., lighting, HVAC systems, appliances) within the interior space. Use metrics like energy consumption (kWh), energy cost, and energy intensity (kWh/m²).

- **Indoor Air Quality (IAQ) Metrics:** Measure air quality parameters (e.g., CO₂ levels, VOCs, particulate matter) to evaluate the impact of design decisions on occupants' health and well-being.
- **Daylighting Analysis:** Quantify natural light penetration using metrics such as daylight factor, illuminance levels, and spatial distribution of daylight.
- 2. **Quantitative Metrics and Decision-Making:**
 - **Decision Quality Metrics:** Evaluate the effectiveness of design decisions by considering user satisfaction, functionality, and aesthetics. Use surveys, post-occupancy evaluations, or usability testing.
 - **Resource Utilization Metrics:** Quantify material usage (e.g., square footage of flooring, wall finishes, furniture) and compare it to project requirements. Minimize waste by optimizing material selection.
 - **Cost-Benefit Analysis:** Assess the cost-effectiveness of design choices. Calculate the return on investment (ROI) for sustainable features (e.g., energy-efficient lighting, recycled materials).
- 3. **Network Measurement Concepts:**
 - **Graph Theory Metrics:** Apply network analysis to design elements (e.g., furniture layout, circulation paths). Measure connectivity, centrality, and flow efficiency.
 - **Collaboration Metrics:** Evaluate collaboration among project stakeholders (designers, contractors, clients). Assess communication networks and information flow.
 - **Project Activity Metrics:** Monitor project milestones, task dependencies, and critical paths. Use tools like Gantt charts or PERT diagrams.

Not to forget that the used metrics should align with the specific project goals and context. Regular monitoring and data collection throughout the design process will provide valuable insights for informed decision-making.

3. Discussion:

This paper suggested an innovative framework that integrates quantitative metrics. These metrics allow designers to objectively evaluate their decisions, considering factors such as energy efficiency, indoor air quality, and material utilization. By optimizing space anatomy—including layout, spatial organization, and material selection—designers enhance decision quality. For instance, thoughtful placement of windows for natural light, selection of low-VOC materials, and efficient HVAC systems contribute to occupant well-being. Additionally, we apply network theory to design elements, revealing hidden relationships and improving collaboration. By fostering connections among occupants and stakeholders, we enhance social connectedness within these spaces. Ultimately, this approach empowers designers to create environmentally conscious spaces that benefit occupants and the planet.

4. Results:

The key insights of this research could be divided as following:

Environmental Activation of Inner Space Components:

- The study emphasizes a holistic and systemic design model, which empowers the foundation of contemporary sustainable interior design.

- This model focuses on the environmental activation of inner space components. These components play a crucial role in enhancing building mechanical systems' performance and improving indoor environment quality parameters.
- By activating specific elements within the interior, designers can optimize resource utilization while minimizing waste.

Quantitative Metrics and Decision-Making:

- The approach integrates quantitative metrics, allowing designers to make informed choices.
- Difficult analytical study dissects space anatomy, providing insights into how design decisions impact overall quality.
- By evaluating the relationship between outputs (design decisions) and inputs (resources), designers can optimize their choices.

Network Measurement Concepts:

- Leveraging network measurement concepts, the study explores intricate relationships among diverse design elements and project activities.
- This approach contributes significantly to elevating decision-making processes within sustainable interior design.

5. Conclusion:

This analytical approach provides valuable insights for designers, enabling them to create environmentally conscious and efficient interior spaces. By quantifying activation and leveraging network concepts, sustainable design can be elevated to benefit both occupants and the planet. Environmental activation within sustainable interior design is a critical area of study. It transcends mere aesthetics and directly impacts human occupants. When interior spaces are thoughtfully designed, they promote well-being, productivity, and comfort. Additionally, sustainable design choices reduce resource consumption and contribute to a healthier planet. Understanding environmental activation allows designers to create spaces that resonate with users while minimizing ecological footprints.

There is still a need to suggest areas for further research (e.g., dynamic network analysis, and real-time monitoring), and to encourage interdisciplinary collaboration to advance sustainable interior design.

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