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The Journal is released annually, has a scientific character, and specializes in Industrial Design. Its first issue was published in June 2021 by the University of Cádiz, and it moved to the University of Málaga's press for the 2023-2024 academic year, with its fourth issue published in June 2024. Proyecta56, an Industrial Design Journal, originated from a previous project: PROYECTA56. Between 2013 and 2015, the publication had a quarterly format and a popular science character. It was hosted by the cultural center La Térmica (Málaga), involving over 100 industrial design professionals from around the world and participating in national and international exhibitions. For this reason, the current scientific publication maintains a minimum percentage of popular science works, staying true to its origins.

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06 EDITORIAL

proyecta 56

An industrial design journal

editorial junio 2025

Issue 5 of Proyecta56, an Industrial Design Journal highlights how contemporary industrial design extends beyond functionality and aesthetics to tackle challenges deeply connected to human experience, sustainability, and collective well-being.

The works presented explore a remarkable diversity of fields. From bioinspired design for coastal infrastructures that mimic natural processes to protect and regenerate marine ecosystems, to the application of systemic design in medical packaging, which reveals the importance of integrating holistic approaches in highly regulated and critical sectors.

Human-centered design and emotional well-being also emerge as key threads in this edition. The study on mood regulation analyzes interventions aimed at mitigating the “Sunday Blues,” exploring through the WeMo prototype how products can support users in the transition from leisure to the start of the workweek. Beyond proposing specific strategies, this research invites designers to question the balance between promoting well-being and respecting the acceptance of negative mood states as a natural part of life.

In the field of inclusion and health, another article addresses the development of a customized prosthesis for an athlete with forearm agenesis, designed for practicing CrossFit. This project demonstrates how design can enhance autonomy and open doors to participation in high-performance physical activities.

At the same time, the exploration of museum spaces redesigned under interactive and multisensory parameters underscores how design can transform culture into a participatory, stimulating, and memorable experience.

Finally, this issue pays tribute to influential figures such as Inma Bermúdez, whose career shows that sustainability and user experience are essential principles — not accessories — in responsible design practice. Her vision, embodied in everyday products that combine functional beauty with environmental respect, underscores the transformative potential of our discipline.

We thus invite our readers to reflect on the role of industrial design as a catalyst for meaningful change, capable of crafting solutions that blend technological innovation, human sensitivity, and ethical commitment to address the challenges of today and tomorrow.Sincerely,

María Alonso García

Editor of Proyecta56: An Industrial Design Journal

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Research article

Design Considerations for Mood-Regulation Interventions: Insights from a Case Study on the "Sunday Blues"

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Abstract

Design for mood regulation is an emerging design area that is gaining growing interest. However, there is limited guidance on what designers should consider when creating interventions (products, systems, or services) to support everyday mood regulation. To address this gap, we conducted an exploratory case study focused on the "Sunday Blues"—a common dip in mood experienced at the end of the weekend as the new workweek approaches. We designed WeMo, a system aimed at helping users capture weekend highlights, culminating in a visual summary displayed on Monday. We engaged 15 participants in co-constructing stories around their potential use of the system. Participants expressed frustrations with the system's features, concerns about its effectiveness, and obstacles to its application in daily life. Based on these insights, we highlight key considerations for designing mood-regulation interventions, such as balancing mood regulation with other fundamental needs, addressing the complex roots of mood, and respecting the acceptance of negative moods. By identifying user concerns and translating them into design considerations, this study provides actionable guidance for practitioners and contributes to the growing body of research in mood-focused design.

Key words: Case study; Design consideration; Design for experience; Interaction design; Positive design; Mood regulation

Introduction

Sometimes, we feel happy; other times, we feel sad. As we go about our daily lives, we might also feel relaxed, anxious, or even miserable. These inner feelings are what we commonly refer to as our "moods."

Moods are low-intensity, diffuse feeling states that typically persist for hours or longer (Morris, 1989). They are ever-present, tend to gradually evolve, and often operate below conscious awareness (Watson & Clark, 1994). Despite their subtle nature, moods have a profound impact on subjective well-being. When a person is in a positive mood, they tend to perceive their overall life as more satisfying and fulfilling, and they are more likely to recall positive life events compared to when they are in a negative mood (Morris,

1999). Beyond subjective well-being, moods can also significantly affect both physical and mental health. Persistent negative mood states can contribute to mental health problems such as depression and affective disorders (Peeters et al., 2006), and they have been linked to increased risk of physical health issues like heart disease (Cohen et al., 2015). Additionally, moods influence daily functioning by shaping how individuals perceive events, make judgments, and make decisions (Forgas, 1995).

Given the widespread impact mood can have on individuals, effective mood regulation is essential in everyday life (Larsen, 2000; Parkinson et al., 1996). This has encouraged designers and design researchers to explore innovative approaches—through products, systems, or services—to support or enhance mood regulation (Dejene, 2025; Desmet, 2015; Spillers, 2010). A recent scoping review by Peng et al. (2023) provides a comprehensive synthesis of various mood-regulation interventions, including physical products (e.g., MacLean et al., 2013), social robots (e.g., Ullrich et al., 2016), mobile or web-based applications (e.g., Agrawal et al., 2018), and immersive ambient environments (e.g., van de Garde-Perik et al., 2016). The review identifies diverse strategies used in these interventions, such as promoting self-awareness and reflection (e.g., Rajcic & McCormack, 2020), enabling mood-sensitive social interactions (e.g., Pradana & Buchanan, 2017), delivering personalized recommendations (e.g., Hollis et al., 2017), and fostering emotional regulation skills (e.g., De Luca et al., 2018).

While these findings provide a broad overview of intervention possibilities, the potential challenges and design considerations remain underexplored. Previous studies have briefly touched upon issues such as the possible negative effects of encouraging reflection on unpleasant feelings (Hollis et al., 2017), the difficulty of tailoring recommendations to individual users (Besserer et al., 2016), and user discomfort or annoyance caused by intrusive or poorly timed system interventions (Balaam et al., 2010). However, these insights are often tied to specific types of interventions or use cases and do not offer generalizable guidance on what designers should deliberately consider or be mindful of when designing for mood regulation. This lack of understanding can significantly hinder designers' ability to create effective mood-regulation interventions (Overdijk et al., 2022; Peng et al., 2023). To address this, we propose conducting empirical research to explore people's expectations, doubts, and concerns regarding using these interventions in everyday life. These insights can help identify key design challenges and inform future design strategies or principles.

To support this goal, we conducted an exploratory case study investigating prospective users' attitudes and opinions on a mood-regulation system designed to manage the "Sunday Blues"—a common negative mood that emerges during the transition from weekend to workweek. Findings from this case study shed light on end-user expectations and concerns, offering practical recommendations for the design of mood-regulation interventions in real-life contexts.

The remainder of this article is structured as follows: we begin by introducing the exploratory case study focused on the Sunday Blues phenomenon, followed by a description of our research process, including design and prototyping, participant recruitment, data collection, and analysis. Next, we report our findings and discuss their implications for future practice of designing for mood regulation.

Methodology

The Case Study

We selected the "Sunday Blues" as the focus of our case study—a mood characterized by anxiety, sadness, or regret as the weekend concludes and the new workweek approaches (Zuzanek, 2014). Its typical causes include the loss of leisure time, unmet weekend expectations, and

anticipation of upcoming workloads and challenges (Tufvesson, 2022). A recent survey suggests this mood issue is widespread among employees, with 80% of respondents reporting frequent experiences of it (Heitmann, 2018). Given its prevalence and impact on employees' mental health and well-being (Akay & Martinsson, 2009; Mihalcea & Liu, 2006), the Sunday Blues has gained significant attention in popular culture, with numerous blogs and podcasts addressing the topic and suggesting coping strategies (e.g., Headspace, 2021; Pinsker, 2020). Despite this, the phenomenon remains unexplored in scientific research, including within the design research community, highlighting opportunities to explore potential mood-regulation solutions. By designing an intervention to mitigate the Sunday Blues and investigating user insights, we aimed to uncover broader challenges and considerations related to design for mood regulation.

Design

We conceptualized WeMo (short for "Weekend" and "Monday"), a desktop and mobile application designed to ease the transition from weekend to weekday and mitigate the Sunday Blues. At its heart, WeMo encourages users to capture, reflect on, and celebrate meaningful weekend moments, which are then transformed into an artistic visual summary displayed on Monday.

The concept draws upon evidence-based psychological strategies for mood regulation, particularly the benefits of positive memory recall (Josephson, 1996) and gratitude (Rash et al., 2011). By prompting users to document and revisit highlights from their weekend, WeMo helps counteract the anxiety and sadness often associated with the end of the weekend. Rather than dwelling on the approaching workweek, users are guided to focus on their enjoyable weekend experiences, creating a sense of closure and readiness for the days ahead. Presenting their memories as a visual art piece on Monday seeks to foster positive anticipation and reinforce a lasting sense of satisfaction.

Specifically, WeMo offers four core functionalities:

- 1. Weekend Planner & Event Reminders. WeMo helps you transition to the weekend with a sense of excitement and anticipation. On Friday afternoon, while you're still at work, WeMo sends a cheerful notification to your laptop, such as, "Thank God It's Friday! Ready for your weekend plans?" This friendly reminder encourages you to review or finalize your plans, setting the stage for a fulfilling weekend. Gentle phone reminders during the weekend help you to stay mindful of your activities, ensuring you make the most of your time without feeling overwhelmed.
- 2. Photo-Taking Reminders. To help you capture and cherish your weekend highlights, WeMo sends personalized notifications based on your plans. For instance, a message might say, "Make this moment last! Snap a quick photo during your Forest Walk." These reminders encourage you to pause and appreciate special moments, with photos automatically stored in WeMo for later use.
- 3. Sunday Night Review. As the weekend comes to a close, WeMo invites you to reflect on your experiences with a message like, "Had a nice weekend? Upload more photos to keep those memories alive!" This feature allows you to revisit your favorite moments and cherish the joy of the weekend.
- 4. Monday Visual Summary. WeMo carries the weekend's energy into your workweek with a personalized visual summary that integrates your weekend's best moments. When you open your laptop on Monday, you're greeted with a colorful reminder of your weekend experiences, creating an uplifting start to your week.

Video Prototyping

To illustrate WeMo's functionality and user experience, we created a video prototype portraying key interactions between users and the system. We chose video prototyping to elicit feedback on a concept that is not yet technically feasible in its envisioned form (Wong & Mulligan, 2016). This approach allowed participants to immerse themselves in a realistic scenario and reflect on how the proposed design might fit into their own routines (Tognazzini, 1994; Zwinderman et al., 2013). Video-based scenarios are widely used in early-stage design research (e.g., Guo et al., 2024; Jin et al., 2024; McDonnell et al., 2023), particularly when exploring emotionally sensitive topics or future-use contexts, as they avoid the ethical and practical constraints of live deployment while still enabling rich user engagement.

Following the guidelines of Markopoulos (2016), the video was filmed in real-world contexts such as the workplace, home, and outdoor environments. It depicts a user journey across four key scenes, each aligned with a core feature of WeMo: (1) On Friday afternoon, a user updates their weekend schedules; (2) On Saturday morning, the user receives a notification about the "Forest Walk" event, and while enjoying the forest, they receive a photo-taking reminder and capture the scenery; (3) After a fulfilling weekend, the user reviews their photos and reflects on the weekend activities; and (4) On Monday, the user is greeted with a visual summary displayed on their laptop. Figure 1 presents several snapshots of these scenes, and the full video can be accessed through the provided link (https://youtu.be/HJbWA4fiOtA).

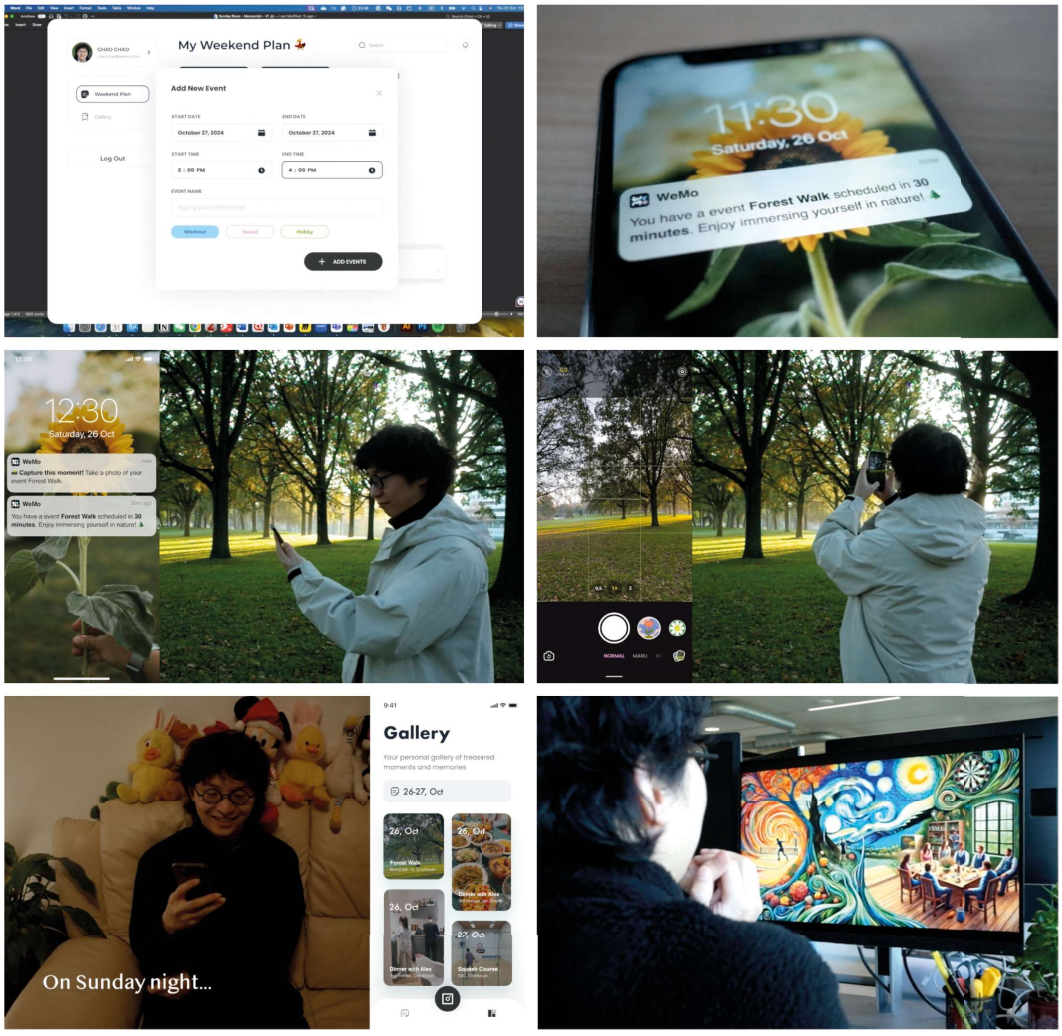

Figure 1. Selected scenes from the video prototype.

Participants

Fifteen participants (aged 24-33; 11 female, 4 male), predominantly researchers from higher education and technology sectors, were recruited through convenience sampling. Detailed demographic information is provided in Table 1. All participants were employed, typically started their workweek on Monday, and frequently experienced or had previously experienced the "Sunday Blues." The sample size was determined following guidance from Hennink and Kaiser (2021), who suggest that 9 to 17 interviews are generally sufficient to reach data saturation. Each participant received a five-euro voucher as compensation, and the study was approved by the Human Research Ethics Committee of Delft University of Technology (reference No. 5088).

Table 1. Overview of participants.

PARTICIPANT CODE	AGE	GENDER	INDUSTRY	OCUPATION	YEARS OF WORK EXPERIENCE IN CURRENT POSITION
P1	26	Female	Higher education	PhD Researcher	>1
P2	28	Male	Higher education	PhD Researcher	>1
P3	29	Female	Higher education	PhD Researcher	>3
P4	30	Female	Healthcare technology	Design Engineer	>2
P5	27	Male	Higher education	PhD Researcher	>2
P6	33	Female	Higher education	PhD Researcher	>1
P7	26	Female	Higher education	PhD Researcher	>2
P8	32	Female	Information technology	Design Engineer	>2
P9	27	Female	Higher education	PhD Researcher	>2
P10	26	Female	Higher education	Learning & Development Specialist	<1
P11	28	Male	Higher education	PhD Researcher	>2
P12	29	Female	Higher education	PhD Researcher	>3
P13	29	Female	Higher education	PhD Researcher	>2
P14	24	Female	Higher education	PhD Researcher	<1
P15	27	Male	Higher education	PhD Researcher	>1

Co-Constructing Stories

To facilitate meaningful conversations with prospective users, we employed the co-constructing stories method (Buskermolen & Terken, 2012), which involves engaging participants in direct dialogue to envision and articulate their thoughts about a proposed design based on personal lived experiences. This method has proven helpful in eliciting rich user feedback and suggestions in various design contexts (e.g., Cerón-Guzmán et al., 2022; Davis et al., 2016; Xue et al., 2019).

Following Buskermolen and Terken's framework (2012), each session was structured into two phases: (1) sensitization, aimed at surfacing participants' past experiences, and (2) envisioning, which encouraged participants to relate these experiences to the design concept and envision future contexts of use. A detailed guide for those sessions is provided in Table 2.

In the sensitization phase, participants first described their typical weekend routines and how they usually felt on

Sunday evenings. They then watched a short sensitizing video depicting a scenario of someone experiencing the Sunday Blues (available at https://youtu.be/hHyy3OJCzJY). To ensure a consistent narrative across phases, this video featured the same character and home setting as the subsequent WeMo video prototype. Afterward, participants were asked to reflect on personal experiences similar to the scenario and share strategies they had developed to cope with those feelings.

The envisioning phase began with participants watching the WeMo video prototype, which presented a fictional story of a user managing the Sunday Blues with the help of the application. After viewing, participants shared their overall impressions of the concept, including what they liked or disliked in the story. They were then encouraged to imagine themselves as the main character in the video, evaluating whether WeMo's four core features could effectively help address the Sunday Blues and identifying potential frustrations and concerns. Next, participants were asked whether they could see themselves using WeMo in daily life, and what barriers, if any, might hinder adoption. Finally, they connected their earlier shared experiences with the Sunday Blues to the design concept, offering suggestions for how it could be improved or adapted to better fit their personal contexts and needs.

Each co-constructing stories session lasted approximately 30 minutes, and all discussions were audio-recorded for subsequent analysis.

Table 2. Co-constructing stories guide.

PHASE	FOCUS	QUESTION OR ACTION
Sensitization	How participants usually spend their weekends	What do you usually do on weekends?
		Do you tend to plan your weekend activities, or do you prefer to just go with the flow? If you do plan, what's your usual approach?
		On Sunday night, do you ever look back on how your weekend went? How does that reflection usually make you feel?
	How we understand the Sunday Blues	The researcher displays the sensitizing video that explains a person's experience with the Sunday Blues.
	How participants usually experience and cope with the Sunday Blues	Can you relate to the person in the video? Did you experience the "Sunday Blues" in a similar way? Could you share a bit more about your experiences?
		How do you usually deal with those feelings? Do you have any specific strategies?
Envisioning	How WeMo specifically works	The researcher displays the video prototype that explains how WeMo functions.
	Participants' overall experiences with WeMo	What's your first thought about WeMo?
		What do you like (most) in the story?
		What do you dislike (most) in the story?
	Participants' micro experiences with WeMo's functionalities	How do you feel about this feature (i.e., Weekend Planner & Event Reminders, Photo-Taking Reminders, Sunday Night Review, or Monday Visual Summary)?
		Do you think this feature could work towards effectively addressing your Sunday Blues? Why?
		Is there anything about this feature that might annoy you or frustrate you? Why?
	Participants' attitudes towards using WeMo	Can you see yourself using WeMo in the future? Why?
		What, if anything, would stop you from using WeMo to help prevent your Sunday Blues?
	Participants' suggestions on WeMo's improvement	How do you think WeMo can be improved or adapted to better fit your personal life?

Data Analysis

All audio recordings were transcribed, and thematic analysis was conducted based on Braun and Clarke's framework (2006): (1) familiarization with the data; (2) coding; (3) generating initial themes; (4) reviewing and developing themes; (5) refining themes; and (6) reporting the results. To ensure reliability, two researchers collaborated throughout the process (Clarke & Braun, 2013). Familiarization occurred during transcription, so the first author began by independently coding all transcripts and generating initial themes, which produced a preliminary codebook. The second author then independently applied this codebook to the transcripts, critically evaluating the existing codes and themes while suggesting modifications and/or additions. Next, the two researchers discussed discrepancies and refined the categories until they reached a consensus, resulting in a more accurate and comprehensive set of codes and themes. Finally, this refined collection was reviewed and finalized by all authors when reporting the results. Our final coding scheme included 3 categories, 10 themes, and 37 codes, presented in Figures 2, 3, and 4, and further elaborated in the results section.

Results

Anticipated Benefits and Frustrations

Participants recognized several benefits associated with WeMo's four core features—Weekend Planner & Event Reminders, Photo-Taking Reminders, Sunday Night Review, and Monday Visual Summary. However, they also anticipated potential frustrations with these features when imagining how they might use WeMo in practice (see Figure 2 for an overview).

Regarding Weekend Planner & Event Reminders

Participants identified the potential benefits of a weekend planner with event reminders. Some saw it as a way to foster a positive weekend mood as early as Friday, with one noting, "It will already give me a feeling that the relaxing moment is coming" (P7). Others felt that it could help create concrete weekend plans more casually than using work calendars, while reminders could help prevent wasted time. These features were seen as contributing to more fulfilling weekends.

However, participants also expressed frustrations. Those favoring unstructured weekends were concerned that planning might feel like extending the workweek, as one stated, "I will feel I'm still on weekdays" (P2). Event reminders were seen as potential stressors, which could lead to user resistance if receiving excessive notifications. Additionally, participants mentioned that reminders might amplify disappointment if plans were missed due to spontaneous decisions like sleeping in.

Regarding Photo-Taking Reminders

Participants who often forget to take photos during weekend events considered reminders helpful for capturing memorable moments.

However, potential frustrations were also noted. Those already in the habit of taking photos felt repetitive prompts would be unnecessary, with one explaining, "I will be definitely taking pictures already" (P14). Participants who rarely take photos saw these reminders as burdensome, likening them to a chore. One compared the experience to another app, saying, "When I get the 'BeReal' notification, I do always see it as a task, as a chore. It doesn't really match with what I want to do on the weekend where I don't want any tasks" (P9).

Regarding Sunday Night Review

Participants noted several benefits of having a Sunday night review of weekend moments. Some regarded it as a distraction from anticipating the upcoming workload, while others saw it as an opportunity to practice gratitude for how they spent their time. Revisiting positive experiences was seen as fostering satisfaction with work-life balance, which could enhance motivation and preparedness for the week ahead. One

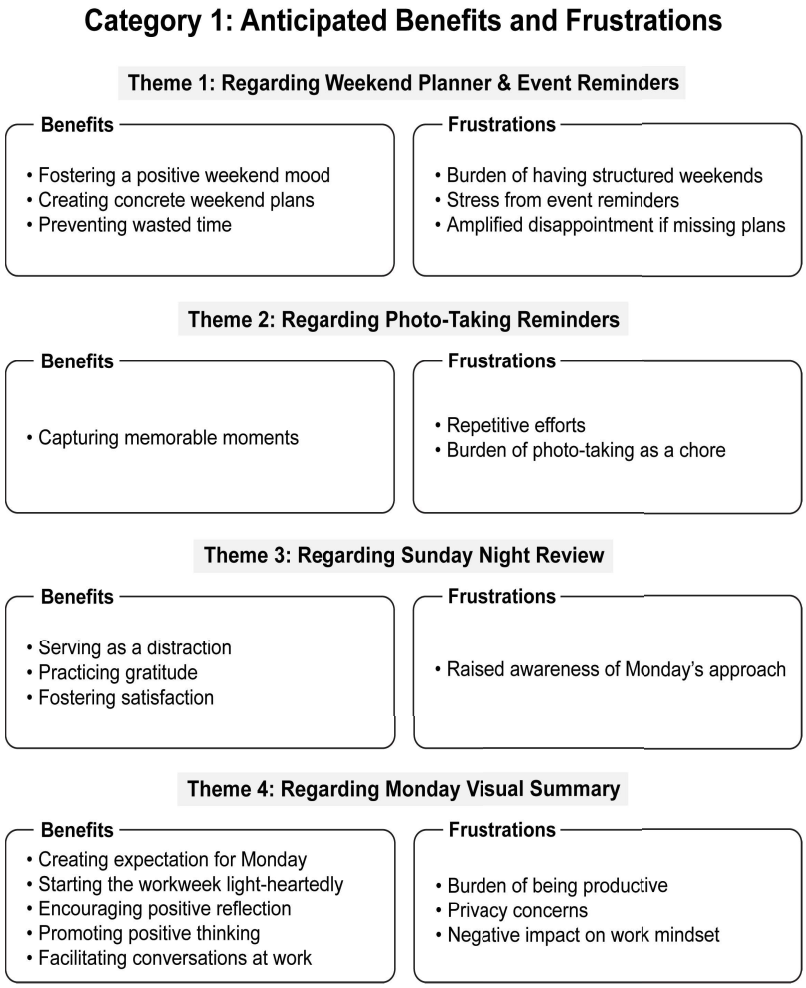

Figure 2. Overview of anticipated benefits and frustrations.

participant noted, "It will make me feel that I still have the energy to face the challenges in the coming week" (P7).

However, a key frustration was mentioned: a Sunday night reminder might trigger the Sunday Blues by raising users' awareness of Monday's approach. One participant remarked, "This kind of reminder can also be a reminder that your time is not so much—it's the end of your weekend" (P2).

Regarding Monday Visual Summary

Participants highlighted various potential benefits of a Monday visual summary. It could create expectation or motivation for Monday, as one explained, "You'd be more curious to go to work and see what's on your screen" (P10). It could also allow users to start the workweek more light-heartedly with "something that is not your email" (P8). The summary could encourage users to appreciate their weekends and themselves, as one shared, "It's like a reward for how nice you had the weekend" (P3). It was also seen as fostering positive thinking by highlighting that "a colorful weekend is coming up again" (P7). Additionally, its social value was noted: "It's a nice conversation starter … it would also stimulate fun because you can show the picture to your colleagues" (P10).

However, participants also mentioned frustrations. Some felt the summary might cause pressure to be productive during weekends, questioning its relevance for unproductive weekends. One participant asked, "What if there are no plans on a certain weekend and the whole goal is to chill, what would my image show?" (P13), anticipating it could lead to feelings of disappointment. Others raised concerns about whether the workplace is an appropriate setting for the summary, emphasizing privacy issues and potential negative impacts on their work mindset.

Concerns about Effectiveness

Participants raised several concerns about WeMo's effectiveness, pointing out factors that could influence its performance in real-world use (see Figure 3 for an overview).

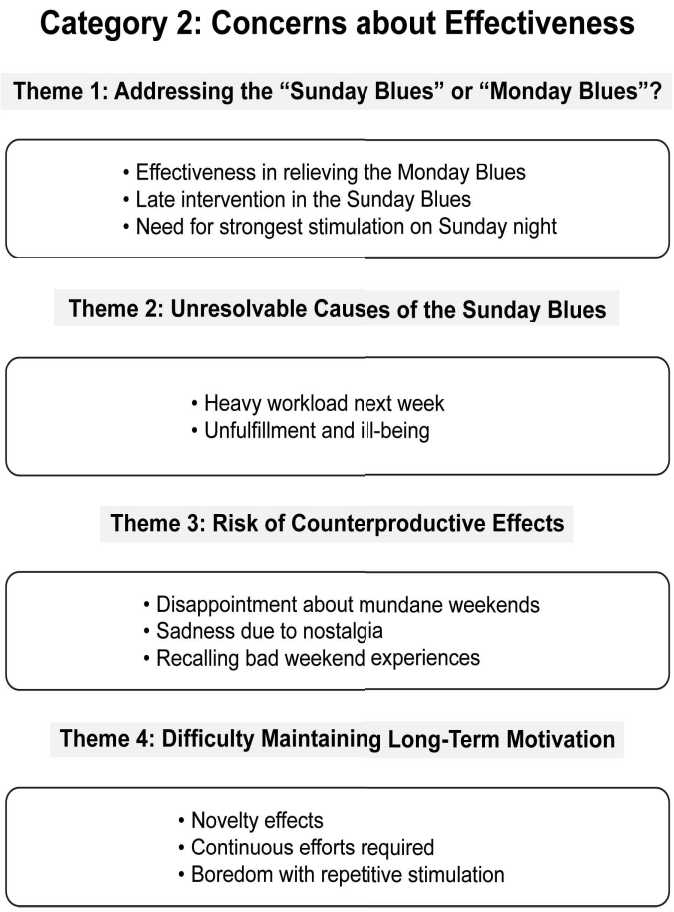

Figure 3. Overview of concerns about effectiveness.

Addressing the "Sunday Blues" or the "Monday Blues"?

Participants questioned whether WeMo would effectively target the "Sunday Blues" or if it would primarily address the "Monday Blues." They anticipated viewing a visual summary of the weekend on Monday could "make you feel not so anxious about your work" (P1). On the other hand, they also pointed out WeMo's delayed intervention in tackling the Sunday Blues. One participant remarked, "Is it a bit late for me? Because at some point, you already start to worry and become stressful about Monday" (P3). Another participant expressed a desire for WeMo to provide its most impactful support, such as the visual summary, on Sunday night, when they feel particularly "meaningless" (P12).

Complex Causes of the Sunday Blues

Participants mentioned that the Sunday Blues could stem from multiple causes, some of which might be impossible to resolve. While reflecting on weekend memories on Sunday night might uplift their mood, participants believed upcoming workloads could negate this benefit. As one put it, "If next week you still have five meetings to go, then probably the memories are not good anymore" (P3). Participants also noted that the Sunday Blues could be due to broader issues of personal fulfillment and well-being. One participant explained, "There's something about day-to-day life that's not really fulfilling you … that makes you already not happy" (P4), suggesting that addressing the Sunday Blues may require solutions beyond WeMo's scope.

Risk of Counterproductive Effects

Participants expressed concern that WeMo might inadvertently amplify feelings of the Sunday Blues. For instance, they noted that revisiting mundane weekends on Sunday night could lead to disappointment, as one explained, "If you only were laying on the couch and watching Netflix all day, then it may remind you of how unproductive your weekend was" (P10). Similarly, reflecting on particularly enjoyable weekends might induce a feeling of sadness, as one participant shared, "Sometimes [looking at photos] makes me more nostalgic" (P8). Additionally, there is a risk of reliving negative weekend experiences, with one participant warning, "It's also possible to remember not perfect or bad memories" (P3).

Difficulty Maintaining Long-Term Motivation

One participant specifically addressed the challenge of sustaining long-term user engagement. They described a "novelty effect" often associated with new apps (P11), which would fade over time. They

also noted the continuous effort required to engage with WeMo, which could feel burdensome and lead to user drop-off. Additionally, they mentioned that the visual summary could lose its appeal over time due to repetition: "Even though the content is based on your personal experience every week, the visual effect can be repetitive. If I see this for several weeks, I will probably get bored" (P11).

Perceived Obstacles to Application

Participants identified several barriers that might prevent them from incorporating WeMo into their daily lives (see Figure 4 for an overview).

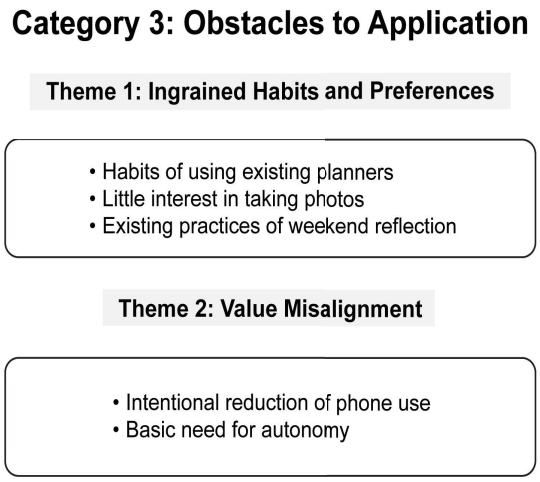

Figure 4. Overview of obstacles to application.

Ingrained Habits and Preferences

Participants noted that their long-standing routines and preferences could hinder their adoption of WeMo. For instance, some participants already rely on existing planning tools and see little need for an additional app. One participant explained, "I actually use Google Calendar as my planner, so I don't know if I would use another planner if it couldn't be synced" (P10). Others expressed a lack of interest in photography, which could prevent them from using the app since photo-taking is its key component. Additionally, several participants described alternative ways of reflecting on their weekends, such as sharing photos with loved ones or posting on social media. These existing practices reduced the perceived need for a dedicated app like WeMo.

Value Misalignment

Participants highlighted a misalignment between their values and those promoted by WeMo. Some participants strive to minimize phone usage and disengage from digital devices during weekends, as one stated, "I don't prefer having new apps on my phone. Maybe it is perfect, but then I feel it's too much about being on the phone" (P15). Others worried that WeMo might undermine their sense of autonomy during weekends. One participant noted that WeMo's structured approach could feel restrictive, stressing that the app should "show respect to the flexibility [of the weekend]" (P2). Additionally, WeMo's emphasis on generating visual summaries through photos felt overly prescriptive to participants. One commented, "It forces people to take pictures" (P11), which could lead to feelings of pressure or obligation.

Discussion

Mood regulation plays a vital role in everyday functioning and overall well-being. This has inspired the emergence of design for mood regulation as an important area of inquiry within design research. However, despite growing interest, there remains a limited understanding of the specific challenges designers encounter and the key considerations necessary for achieving effective design outcomes. To help address this gap, we explored a mood-regulation intervention targeting the Sunday Blues—a common dip in mood experienced on Sunday evenings—using it as a case study to surface the complexities involved in designing for mood regulation.

In this section, we reflect on our findings from the case study and present four key design considerations that can inform and guide future work in the field. We also acknowledge the limitations of our study and outline potential directions for further research.

Design Considerations for Mood-Regulation Interventions

Support Mood Regulation Without Undermining Fundamental Needs

Our findings reveal a potential tension in design for mood regulation: while interventions may effectively support mood regulation, they may also inadvertently conflict with users' other fundamental needs. For example, participants noted that organizing their weekends with various activities through WeMo could help them feel more fulfilled, potentially reducing the likelihood of experiencing the Sunday Blues. However, they also emphasized that this structured approach could significantly undermine flexibility and spontaneity, which they value as essential aspects of their weekend experience.

To address this tension, we recommend that designers proactively investigate and understand users' basic needs during the early design phase and thoughtfully integrate these considerations into the design process to ensure both intervention effectiveness and user experience.

Align Mood-Regulation Interventions with Existing Lifestyles

Our findings suggest that mood-regulation interventions relying on specific user behaviors may struggle with acceptance if they conflict with users' existing lifestyles. For instance, while participants acknowledged the potential benefit of WeMo in addressing their Sunday Blues, they expressed reluctance to adopt the system due to difficulties in implementing the required tasks. Some participants preferred to limit phone use on weekends and were unwilling to consistently take photos during events. Others had developed personal methods for planning or reflecting on weekends and were reluctant to invest in repetitive efforts.

These insights underscore that effective mood-regulation interventions should seamlessly integrate with users' established routines or preferences, minimizing disruptions and fostering sustained engagement without requiring significant behavioral changes.

Tailor Multiple Strategies to the Multifaceted Causes of Mood

Our findings reveal that a single mood-regulation intervention may be insufficient to address all the underlying causes of a negative mood, especially when these causes stem from broader, more complex problems. For example, participants acknowledged WeMo's potential to induce positive moods on Sunday evenings, such as feelings of satisfaction or anticipation. However, they also pointed out that the Sunday Blues is often a result of multiple factors, some of which—like unavoidable heavy workloads or personal ill-being—might fall beyond WeMo's influence. In such cases, the positive moods fostered by WeMo and the Sunday Blues might coexist as separate layers of experience.

To enhance effectiveness, we recommend a holistic design approach that incorporates multiple mood regulation strategies tailored to different types of stressors. For example, an intervention could facilitate avoidance or suggest direct resolution for identifiable and manageable stressors, while offering relief or distractions for stressors that cannot be easily resolved. This approach acknowledges the complexity of mood and enables more adaptive and personalized support.

Avoid Overemphasis on Positivity and Respect Acceptance of Negative Moods

This insight stems from our broader reflections on the research topic of designing for mood regulation. While the Sunday Blues can pose challenges to well-being, many participants appeared to have accepted this feeling as a normal part of their weekly rhythms. Rather than actively addressing it, they seemed to have found ways to live with it.

This raises an important concern: introducing a mood-regulation intervention could unintentionally increase individuals' awareness of the Sunday Blues, potentially

reframing it as a more serious issue than they had previously perceived. Such a shift in perspective could lead them to replace their existing, comfortable ways of coping with a new approach focusing on pursuing positivity at all costs. This might further disrupt their natural mood equilibrium, hindering their ability to accept and navigate negative moods in the long term.

Therefore, we urge designers and design researchers to exercise caution when offering mood-regulation interventions. These solutions should not overshadow the value of accepting negative feelings as a part of the human experience.

Limitations of This Study

This exploratory study has several limitations.

First, we relied on convenience sampling, recruiting participants exclusively from our university. Most are employed researchers with backgrounds in design and engineering, which may have biased their perceptions and thoughts due to a high level of familiarity with technology and design processes. Future studies should involve participants from a broader range of professions, demographics, and backgrounds for a more representative understanding.

Second, participants interacted with a video prototype rather than a fully functional system. As a result, their responses were anticipatory and removed from real-life use contexts. While video prototyping is a valuable tool in early-stage design, future work should involve the development and deployment of functional prototypes in longitudinal, real-world studies to capture deeper and more nuanced user experiences.

Third, the identified challenges and the resulting design considerations were derived from a single case study focused on the Sunday Blues. This may limit the generalizability of our findings to other mood-regulation contexts or user groups. Future research should explore multiple design cases targeting a range of mood states and situational contexts to validate and expand upon our findings.

Despite these limitations, we believe our findings offer valuable initial insights and can serve as a foundation for future inquiry into the complexities of designing for mood regulation and the practical considerations it entails.

Conclusion

In this article, we presented a case study exploring key design considerations for developing mood-regulation interventions, with a particular focus on the experience of the "Sunday Blues." Our findings suggest that effective interventions should address not only mood-related needs but also users' broader lifestyle patterns and other fundamental psychological needs. We also emphasize the value of incorporating different strategies to address the complex and diverse causes of user mood, as well as recognizing that negative moods are often accepted as a normal part of daily life for many individuals. These insights offer a starting point for understanding the nuances of designing for mood regulation, potentially guiding designers and design researchers in their efforts to create more thoughtful and effective solutions. We hope this study contributes to the ongoing development of this field and encourages innovative methods and tools that better support design for mood regulation.

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Articolo di ricerca | Research article

La progettazione degli spazi museali a partire dall'esperienza utente: approcci e pratiche per la conoscenza culturale | Designing museum spaces from the user experience

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Riassunto

Nel contesto attuale, i musei si concentrano particolarmente sull'offerta di servizi orientati al visitatore. Comprendere i comportamenti, le esigenze e le motivazioni dell'utente è di fondamentale importanza per la definizione delle interazioni e dei servizi personalizzati tali da rendere la fruizione inclusiva.

Le attuali sperimentazioni, le tecnologie digitali e le nuove pratiche di "spettacolarità", che generano esperienze "digito-corporale" dell'utente, stanno modellando le funzioni e gli obiettivi di conoscenza artistica per gli spazi culturali, divenendo parte integrante del lavoro dei designer e dei ricercatori in questo campo.

Installazioni interattive e prodotti tecnologici all'avanguardia sono ampiamente impiegati nei musei allo scopo di migliorare l'esperienza dei visitatori, arricchire il contenuto delle esposizioni museali e diversificare le forme narrative, con l'obiettivo di offrire esperienze di visita dinamiche, immersive e multisensoriali.

Il presente articolo, attraverso uno approccio umano-centrico, propone di esplorare la multidimensionalità della progettazione degli spazi museali per l'esperienza del visitatore, approfondendo il concetto di ambiente immersivo e narrativo e il coinvolgimento fisico e percettivo del visitatore nell'interazione con lo spazio e gli oggetti esposti.

Attraverso l'analisi dei casi studio, saranno approfondite alcune tipologie di interazione fisica e tecnologica dei visitatori in contesti culturali, tali da poter definire le linee guida per la progettazione degli spazi museali incentrata sull'utente e sul legame "spazio-persona", utile alla produzione di nuove performance culturali, fisiche e digitali.

Keywords: Interaction Design; Creatività; Design per l'Esperienza; User Experience

Abstract

º In the current context, museums are particularly focused on offering visitor-oriented services. Understanding the user's behaviours, needs, and motivations is of fundamental importance in defining interactions and personalised services that make the use inclusive.

Current experiments, digital technologies and new practices of "spectacularity", which generate "digito-corporal" experiences of the user, are shaping the functions and objectives of artistic knowledge for cultural spaces, becoming an integral part of the work of designers and researchers in this field.

Interactive installations and cutting-edge technological products are widely used in museums to improve visitor experience, enrich the content of museum exhibitions and diversify narrative forms to offer dynamic, immersive and multisensory visitor experiences.

Through a human-centric approach, the article proposes to explore the multidimensionality of the design of museum spaces for the visitor experience, deepening the concept of an immersive and narrative environment and the physical and perceptive involvement of the visitor in the interaction with the space and the exhibited objects.

Through the analysis of approaches and models present in the literature on the design of the visit experience for exhibition spaces and concerning the selected case studies, some forms of physical and technological interaction of visitors in cultural contexts will be explored in order to identify guidelines for the design of museum spaces centred on the user and the "space-user" relationship.

Key words: Interaction Design; Creativity; Design for Experience; User Experience

Introduzione

Secondo la recente definizione dell'ICOM, il museo è un'istituzione al servizio della società, aperta al pubblico, accessibile e inclusiva che offre esperienze diversificate per l'educazione, il piacere, la riflessione e la condivisione di conoscenze. (ICOM, 2022).

Partendo da tale riferimento, i musei oggi sono maggiormente impegnati a diffondere e adottare diverse strategie di coinvolgimento ed interazione con i visitatori per offrire maggiore empatia con gli spazi espositivi e con le mostre in corso. Allo stesso tempo, i musei hanno la responsabilità di garantire che la conoscenza che offrono sia correttamente trasmessa e compresa dai visitatori.

Le esperienze dei visitatori all'interno dei contesti culturali stanno diventando oggetto di esplorazione e di comunicazione, intese come forme performative e interattive sia con gli oggetti esposti che con gli altri utenti presenti all'interno del museo o della galleria d'arte.

In tale contesto, le tecnologie digitali e le interazioni che ne derivano ampliano le modalità di partecipazione dei visitatori, consentendo la divulgazione della conoscenza con il coinvolgimento diretto dell'utente e l'individuazione dei diversi interessi culturali del pubblico.

Gli ambienti museali sono diventati luoghi in cui l'interaction design e la sperimentazione di nuove tecnologie definiscono l'interesse a promuovere nuove modalità di interazione e nuove forme culturali incentrate sulla comprensione, sull'intrattenimento e sull'esperienza dell'utente.

L'interazione può accrescere le modalità di partecipazione e definire esperienze flessibili e personalizzate, eliminando il problema di comunicazione unidirezionale frequente nelle esposizioni "tradizionali".

Sulla base di tali considerazioni, il contributo offre una breve panoramica sul design dell'interazione a supporto dei musei, approfondendo approcci e modelli presenti in letteratura relativi alla progettazione degli spazi museali.

Tra questi modelli, particolare attenzione sarà al lavoro di Mason, (Mason, 2020) in relazione ad alcuni casi studio individuati in letteratura, al fine di identificare il processo di interazione spazio-persona nei luoghi della fruizione culturale e migliorare l'esperienza degli utenti mediante visite dinamiche, immersive, multisensoriali e umano-centriche.

Metodologia

A partire dalla tematica dell'interaction design per gli spazi museali sono stati individuati e analizzati alcuni approcci e modelli presenti in letteratura relativamente alla progettazione dell'esperienza di visita negli spazi espositivi. In particolare, sono stati approfonditi lo studio di Roppola (Roppola, 2013) e il modello di Mason. (Mason, 2020)

A partire da tale riferimento per la progettazione incentrata sull'utente per l'esperienza di visita suddivisa in tre livelli, sono stati individuati alcuni casi studio per la definizione dei tre processi di interazione spazio-persona all'interno di contesti culturali.

Interazione utente e spazio di fruizione

Con lo sviluppo della tecnologia multimediale, l'utilizzo di dispositivi interattivi nei contesti museali pone come obiettivo il trasferimento di contenuti espositivi attraverso lo stimolo della creatività e della condivisione. Differenti studi scientifici evidenziano il crescente interesse dei visitatori nell'interagire con le opere in modo originale e partecipativo (Solima, 2012), in particolare sfruttando le funzionalità e le potenzialità che i nuovi media digitali offrono.

I visitatori sono spesso incuriositi da "spettacoli" offerti dai musei, i quali sono diventati dei "laboratori sperimentali" per artisti e designer, promuovendo eventi culturali di diversa natura a un pubblico ampio e diversificato, lontani ormai dagli obsoleti meccanismi di conservazione passiva dei musei tradizionali.

Un altro aspetto interessante è discusso nel lavoro di Nicholas Serota (Serota, 1996) che considera i visitatori e la comunicazione artistica come processi al centro della trasformazione dei musei. I visitatori sono invitati ad interagire con gli artefatti e con gli artisti attraverso relazioni fisiche, partecipando in prima persona e integrandosi con performance ed eventi.

In tale contesto, la forma espositiva tradizionale sta vivendo un radicale cambiamento e il design dell'interazione contribuisce alla realizzazione e diffusione di esperienze visive, uditive, tattili e multisensoriali, anche attraverso il movimento del corpo e l'interazione nello spazio. Partendo dal concetto fondamentale di "progettazione orientata alle persone", il design dell'interazione mira a soddisfare le esigenze psicologiche e comportamentali dei visitatori per ottenere una diffusione efficiente e ampia della cultura, creando esperienze di visita complete.

Tale approccio ha lo scopo di definire e progettare l'interazione utenti e prodotti/sistemi e descrive il possibile comportamento dell'utente. Ogni volta che una persona utilizza un prodotto, si instaura una sorta di "danza" in cui l'utente si muove e il sistema reagisce. (Garrett, 2010).

Nell'ambito del patrimonio culturale, Wideström presenta un framework di classificazione per i diversi tipi di interattività nei centri e musei scientifici. La classificazione si basa su tre aspetti dell'interazione: (I) livello di partecipazione, che riguarda l'influenza degli utenti sul contenuto della mostra; (II) livello di virtualità che riguarda la quantità di interazione che avviene nello spazio fisico reale rispetto a quello virtuale; (III) livello di collaborazione che riguarda l'interazione sociale tra gli utenti e può distinguersi di natura individuale o collettiva. Tale modello riflette le diverse tipologie di interazioni previste in contesti espositivi scientifici, considerati come centri altamente interattivi che coinvolgono un'ampia gamma di gruppi di target con lo scopo di coinvolgere e educare contemporaneamente, dove materiali e spazi di progettazione digitali e fisici si fondono. (Wideström, 2020)

Le intuizioni derivanti dal design dell'interazione possono anche essere utilizzate per valutare e innovare l'accessibilità delle mostre e per adottare misure tecnologicamente appropriate per soddisfare le esigenze dei visitatori (Saki Asakawa, 2019).

Lo scopo del design dell'interazione, di fatti, non è solo quello di contribuire alla riuscita di mostre "facili da usare" per i visitatori. La conoscenza e l'approfondimento di diversi modi per "creare interazione", insieme alla conoscenza delle tecnologie emergenti, è di fondamentale importanza per innovare i modi di "comprendere" la cultura artistica.

Implementando moderne soluzioni interattive, i musei possono anche creare opportunità di ricerca per il campo del design dell'interazione e le nuove tecnologie possono essere esplorate e valutate in contesti meno vincolanti, proprio come quello dei musei. (Bodin, 2021)

I diversi fattori di una mostra interattiva concorrono alla creazione di esposizioni che siano allo stesso tempo educative, divertenti e facili da comprendere.

Ne è un esempio il progetto di Schauble e Bartlett che hanno utilizzato la teoria educativa per intervistare i bambini sull'"idea" dei fossili e successivamente progettare una mostra in cui i contenuti si basavano sulle considerazioni rilevate e su attività interattive ispirate a scenari presenti nella vita quotidiana (Schauble, 1997). Ulteriore riferimento è il progetto di Asai, Sugimoto e Billinghurst che, ispirati dall'apprendimento collaborativo tra genitori e figli, hanno creato una mostra di realtà aumentata in cui i genitori possono assumere il ruolo di comandanti di missione e i bambini quello di astronauti durante l'esplorazione della superficie lunare (Asai, 2010).

Per questo motivo, la progettazione delle mostre per l'esperienza "collaborativa" dei visitatori diviene parte fondamentale per la realizzazione delle politiche museali di coinvolgimento del pubblico (Reagen, 2014).

Nel tempo, le mostre si sono evolute fino a includere una gamma più ampia di media, sovrapponibili all'arte, alla pubblicità, all'architettura e al design grafico. Si tratta quindi di un'orchestrazione di spazio, media, contenuti e narrazione. (Reagen, 2014)

L'esposizione museale contemporanea rappresenta un'attività di comunicazione e divulgazione aperta e dinamica, che coinvolge gli utenti in un processo in continua evoluzione. Con l'aumento delle modalità di comunicazione, della partecipazione e della consapevolezza comunicativa delle persone, il design dell'interazione diventa parte attiva nella progettazione degli spazi museali, stimolando l'entusiasmo dei visitatori, attraverso legami "spazio-persona" all'interno del contesto culturale e museale, inteso come luogo di connessione fisico e concettuale.

Approcci e modelli per la progettazione dell'esperienza di visita negli spazi espositivi

Negli ultimi due decenni, i musei hanno intrapreso diverse strategie progettuali per creare esperienze più personalizzate e coinvolgenti, come quelle di tipo "affettivo", "partecipativo", "immersivo" e "sensoriale" (Bertrand, 2024). Queste strategie contribuiscono al raggiungimento di obiettivi per gli esperti del settore orientati ad esperienze museali progettate per facilitare la curiosità e l'esplorazione. (Kenderdine, 2012).

Le istituzioni culturali stanno adottando approcci immersivi e interattivi per fornire "modi più dinamici di comunicare con il pubblico, incoraggiare pratiche di partecipazione più ricche e significative e coinvolgere gli utenti con siti, istituzioni, collezioni e temi ad ampio raggio". (Bertrand, 2024).

Per questo motivo, i musei hanno spostato l'attenzione verso pratiche più "orientate al visitatore", adottando strategie progettuali e tecnologiche di coinvolgimento, di allestimento e di esposizione atte alla promozione della cultura in "rete", la competitività, l'economia e il turismo. (Kamariotou, 2021)

Il design, oggi, affronta questioni sociali, legate all'esperienza dell'utente e viene utilizzato come progetto investigativo e di sperimentazione. Lo spazio per l'opera d'arte, ad esempio, sta diventando luogo di "verifica", di aspettative, di coinvolgimento e di percezioni, dove i progetti non necessitano di essere applicati in serie.

Le sperimentazioni, quindi, stanno diventando parte integrante del lavoro dei designer e dei ricercatori in questo campo, poiché si producono risultati molto spesso inattesi che permettono di sviluppare processi originali, con metodi di apprendimento e sperimentazione incentrati sull'utente.

Gli studiosi Laurberg e Schavemaker (Laurberg, 2016) sottolineano come i musei siano sempre più coinvolti in attività speculative e di ricerca, spesso interdisciplinari, ormai ampiamente integrate nell'intero processo della programmazione istituzionale.

La ricerca nella disciplina del design, come acquisizione di conoscenza, offre a curatori e designer la visione narrativa ampliata di un oggetto, di un'opera d'arte, in relazione alla sua rilevanza storica, artistica e molto spesso funzionale, dando luogo a processi iterativi di creazione, di revisione in continuo perfezionamento.

Oggi, le mostre strutturate in termini di design narrativo rivedono il ruolo e le modalità dei fattori tecnologici coordinati in un "copione" che Uwe R. Brückner chiama "partitura" (Brückner, 2011). In questo modo, si può gestire la visita e l'esperienza in maniera semplice e ritmata, definendo i tempi, la scoperta, la percezione, la comprensione e l'assimilazione. L'attenzione del visitatore è progettata in sequenza e la mostra si lascia vivere secondo i diversi stadi di immersività, dove l'intervento digitale diventa esperienza finalizzata al consolidamento di una memoria umanizzata. Per tale esperienza, la progettazione degli spazi espositivi diventa una sorta di catalizzatore che spinge a ricercare nuove informazioni e ad avviare connessioni tra i diversi contenuti mediali (Borsotti, 2023).

L'obiettivo dei designer per la progettazione degli spazi espositivi non è solo quello di soddisfare esteticamente i visitatori ma si pone come scopo la produzione di conoscenza e di interpretazione personale visiva e spaziale. Comprendere le esperienze dei visitatori e i fattori che le influenzano, inoltre, rappresenta un fattore importante per produrre ricerche e sviluppi concettuali, per migliorare la progettazione degli spazi espositivi incentrati sull'utente.

L'esperienza di visita in un museo si identifica come un processo di interazione reciproca o di "dialogo" tra il visitatore e l'ambiente in cui si trova (Reagen, 2014). Difatti, può essere definita come "risposta immediata, soggettiva e personale di un individuo a un'attività, a un ambiente o a un contesto al di fuori del suo ambiente abituale" (Packer J. B., 2013).In particolare, la ricerca condotta da Roppola (Roppola, 2013) rivela come i visitatori si identificano in relazione all'ambiente espositivo e come l'esperienza sia influenzata dal design e dalle decisioni progettuali ad esso connesso.

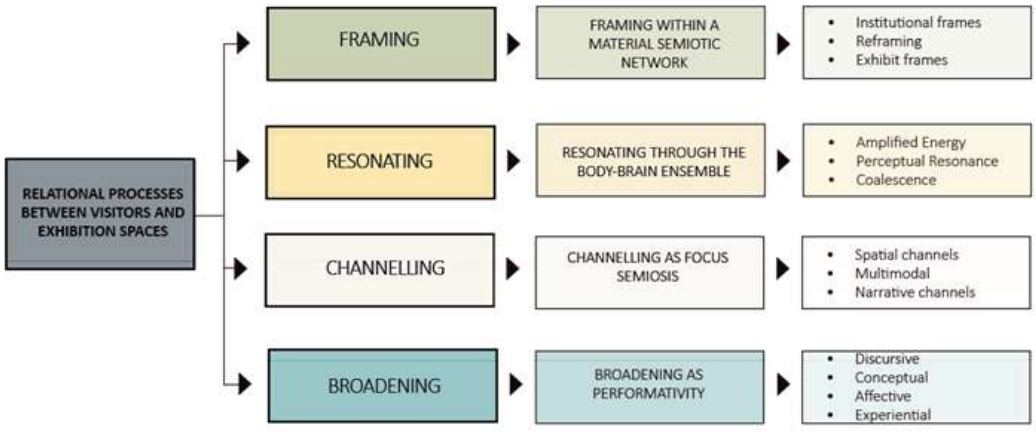

Figura 1. Modello di Roppola relativo ai quattro aspetti chiave nella relazione tra visitatore e spazio espositivo. (schema liberamente reinterpretato dall'autore, 2025).

A partire dall'analisi dei resoconti esperienziali dei visitatori, Roppola individua e classifica i quattro aspetti chiave nella relazione che si instaura tra i visitatori e lo spazio espositivo (Fig. 1). Il primo processo è definito dall'autore "framing" dove i visitatori hanno introdotto una discussione sui musei e sulle mostre in senso generico (istituzionale, di esposizione). Per il secondo aspetto chiave, i visitatori individuano le modalità di attrazione della relazione con gli ambienti espositivi in modo immediato o senza sforzo, un processo che l'autore ha definito "risonanza". In terzo luogo, i visitatori hanno descritto le modalità di guida attraverso lo spazio, i media e i contenuti delle mostre, processo definito come "canalizzazione". Per quanto riguarda il quarto aspetto chiave, i visitatori hanno descritto i modi in cui hanno sperimentato un "ampliamento del sé", un processo definito da Roppola "ampliamento".

Questi quattro processi principali sono stati successivamente suddivisi in gruppi di categorie che descrivono come i visitatori trovano sé stessi in relazione con gli ambienti espositivi.

È quindi evidente che lo studio delle esperienze e delle interpretazioni nelle mostre possa essere significativo per la struttura organizzativa e complessiva degli spazi artistici ma soprattutto per la progettazione museale orientata all'utente. Gli spazi dediti alla cultura, quindi, possono essere riqualificati e plasmati in base alle esigenze del pubblico.

L'approccio alla progettazione incentrata sull'utente per l'esperienza di visita negli spazi espositivi - ibridi e fisici - è approfondito, inoltre, nel contributo di Mason (Mason, 2020) secondo cui tale progettazione deve operare su tre livelli: (I) Esperienza; (II) Interazione; (III) Elementi visivi. (Fig. 2)

In particolare, nel "Level of Experience" sono definiti i "sottolivelli" quali: le unità dell'esperienza, il flusso dell'esperienza e la meta-narrazione, includendo pratiche e metodi di progettazione adatti a progettare strutture esperienziali alla base degli ambienti narrativi.

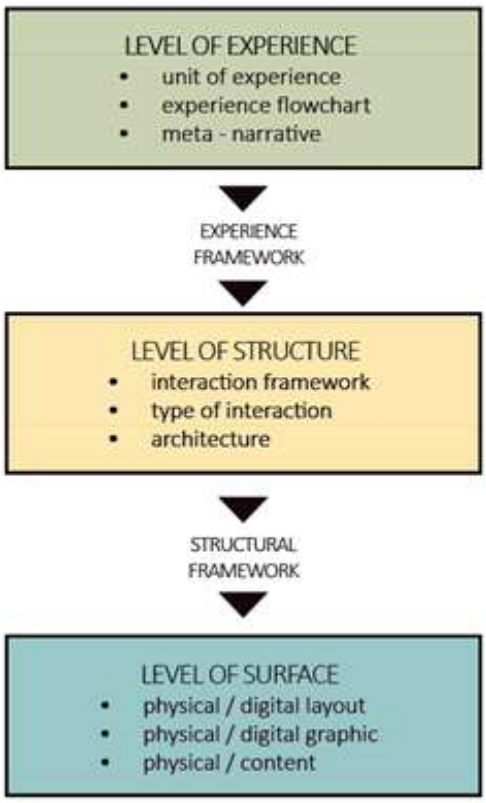

Figura 2. Modello di progettazione per l'esperienza di visita per gli spazi espositivi. (Mason, 2020)

Il "Level of Structure" si concentra sulla struttura generale di interazioni e sull'organizzazione dei contenuti. Secondo Crampton Smith, i designer che lavorano a questo livello rendono "visibile" l'esperienza, (Mason, 2020) definendo le interazioni e strutturando i contenuti che danno forma alle esperienze nel tempo. In questo livello viene creata la struttura per la definizione di tre elementi progettuali interrelati: il primo, il quadro dell'interazione, ovvero la distribuzione delle interazioni chiave secondo una struttura risultante dall'integrazione delle dimensioni fisiche e digitali; in secondo luogo, l'architettura dell'informazione che organizza i contenuti e definisce la distribuzione delle diverse interazioni all'interno dello spazio informativo; e infine, la definizione dei tipi di interazioni che i visitatori possono effettuare all'interno dello spazio informativo.

Nel "Level of Surface", infine, gli elementi di design devono soddisfare la richiesta sensoriale del prodotto, come i fattori di forma dei componenti fisici e digitali, l'aspetto e gli elementi visivi, e i diversi

elementi di design che compongono il prodotto di presentazione dei contenuti, utili alla comprensione della mostra e tali da creare coerenza espositiva tra le interfacce digitali e le componenti grafiche (etichette) degli oggetti esposti.

Anche il contributo di Borsotti & Mason (Borsotti, 2023) definisce come il Visitor Experience Design (VX) è direttamente collegato alla progettazione degli ambienti espositivi definiti "narrativi", data la peculiare attenzione alle relazioni tra persone (visitatori), spazi/luoghi digitali e fisici, contenuti digitali e oggetti esposti.

A tal proposito, Austin definisce un ambiente narrativo come "sito di azione e interazione tra persone, narrazioni e luoghi" (Austin, 2020) sottolineando che la pratica della progettazione di ambienti narrativi è "particolarmente associata ai principi dello User Experience Design".

Il fattore narrativo, dunque, accompagna il binomio discorsivo/immersivo di una mostra rappresentando la capacità di decodificare e trasmettere i significati, maggiormente comprensibili ad un pubblico più ampio.

Attraverso il sistema narrativo, quindi, le mostre e la diffusione della cultura, si relazionano con il visitatore in termini di generazione di conoscenza, non più in termini di riproduzione della stessa. Secondo Borsotti (Borsotti, 2023), per "narrazione" si intende la relazione che si instaura tra "collezione-significato-visitatore" mentre per "ambienti narrativi" si intendono gli spazi immersivi, multisensoriali e interattivi, modellati dalla logica dell'esperienza del visitatore. Inoltre, i termini "discorsivo" e "immersivo" vengono definiti come indicatori di cambiamento nel metodo attuale di offrire cultura all'interno del patrimonio culturale. Con il termine "discorsivo", si intende la forma di progettazione curatoriale, interdisciplinare e sintetica, mentre con "immersivo", si fa riferito esclusivamente alla spettacolarizzazione della mostra (Laurberg, 2016).

Non a caso, Mark Wingley (Wigley, 2016) affronta questo dualismo in termini di progettazione dello spazio espositivo, dove la logica della lettura si contrappone alla logica dell'esperienza, che utilizza il linguaggio della multisensorialità, affermando che sono intrinsecamente intrecciate e dipendenti.

Uno spazio espositivo narrativo, quindi, definisce una struttura di sequenze cognitive che permettono l'esplorazione simultanea dei contenuti di ciò che è esposto, siano essi espliciti o impliciti. Attraverso lo sviluppo di un sistema espositivo narrativo, le mostre si relazionano con il visitatore in termini di riproduzione di conoscenza e di generazione di conoscenza (Brückner, 2011).

La progettazione per gli spazi espositivi di tipo "narrativo", quindi, non solo mostra ma soprattutto evoca, rivela, coinvolge, emoziona e stimola il fruitore a livello percettivo e fisico. Di fatti, la narrazione amplifica il significato di "discorsivo" declinandolo come capacità comunicativa del sistema relazionale "collezione-significato-visitatore" di proporre molteplici modalità di accesso e approfondimento.

Strumenti e metodologie per l'esperienza utente negli spazi museali.

Le esperienze dei visitatori all'interno di uno spazio culturale possono essere definite anche come percorsi psicologici, intimi e personali in grado di determinare la qualità della visita. Di fatti, gli utenti possono essere attivamente coinvolti nella narrazione, nell'interpretazione e nella trasformazione della loro percezione, sia emotivamente che fisicamente. Così un singolo prodotto può suscitare una gamma diversificata di esperienze dei visitatori (Packer J. &., 2016).

Lo studio condotto dall'autrice Leahy dal titolo "Museum Bodies: The Politics and Practices of Visiting and Viewing" (Leahy, 2016) mostra come molti dei nostri comportamenti all'interno dei musei contemporanei, siano stati plasmati dalle istituzioni artistiche e culturali, come ad esempio camminare (e non correre) nelle gallerie, sussurrare piuttosto che parlare e il divieto di toccare. Il lavoro di Leahy mira a

riorientare la nostra attenzione dal museo inteso come collezione di oggetti al museo come luogo di pratiche sociali, psicologiche e corporee.

La progettazione per gli spazi museali, tenendo conto del livello di esperienza e di interazione utente-spazio di fruizione, rappresenta il punto di partenza per definire un insieme di fattori in grado di soddisfare i bisogni, le emozioni e le aspettative dei visitatori.

Di seguito, sono stati introdotti ulteriori casi studio, che introducono le "nuove tendenze progettuali". Tali riferimenti sono stati selezionati a partire dal contributo di Mason precedentemente descritto che prevede i tre macro-livelli per la progettazione dell'esperienza di visita.

Al "Level of Experience" è stato associato il caso studio "The Weather Project" che individua tre elementi di progettazione quali: (I) le unità di esperienza; (II) il flusso dell'esperienza; (III) l'esperienza meta-narrativa. Tali riferimenti definiscono il risultato di combinazione di conoscenze provenienti, ad esempio, dai servizi curatoriali e dai visitatori oltre a determinare percorsi di visita nello spazio museale.

Con l'installazione "The Weather Project" del 2003, l'artista danese Olafur Eliasson creava l'illusione del sole in una città solitamente caratterizzata da nebbia e grigiore, per coinvolgere in maniera totalizzante i visitatori nella Turbine Hall della Tate Modern di Londra (Fig. 3). L'artista, attraverso l'utilizzo di "fogli specchiati" sospesi al soffitto, di un semicerchio retroilluminato da cira 200 luci monofrequenza e il suo riflesso, ha creato l'immagine di un enorme tramonto, visto attraverso la nebbia artificiale emessa nella sala.

In questo contesto, il livello di esperienza è totalizzante, percettivo e cognitivo. Può essere considerato come una combinazione di elementi che, messi a sistema (unità di esperienza, il flusso dell'esperienza e la meta narrazione), generano valore alla visita e definiscono il processo di interazione spazio-persona completamente immersivo.

Figura 3. The Weather Project. Foto di Tate Photography (Andrew Dunkley & Marcus Leith) su Olafureliasson

Per il "Level of Structure" di Mason, sono stati presi in considerazione i casi studio di Tino Segale e Carsten Höller che focalizzano l'interesse sull'interazione e la mobilità dei visitatori all'interno di una galleria d'arte, sviluppando nuove pratiche di "spettatorialità". Questo livello si concentra sulla distribuzione delle interazioni chiave dall'integrazione delle dimensioni fisiche e spaziali, e sull'organizzazione dei contenuti per l'interazione con lo spazio informativo.

Nello specifico, "These Association", installazione ideata dal berlinese Tino Sehgal nel 2012 e commissionata dalla Turbin

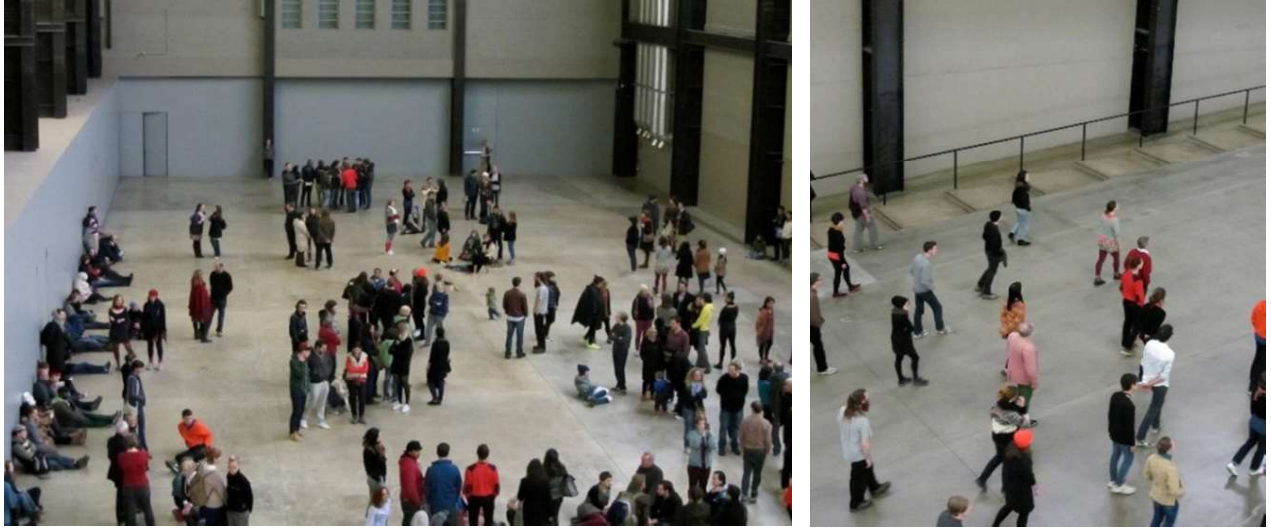

Figura 4. Tino Seghal, These Associations, Tate Modern, Unilever Series Commission, 2012. Foto su johiggins

Hall del Tate Modern di Londra, mostra il processo di iterazione e interazione tra utenti sconosciuti, senza oggetti o quadri da guardare, dove partecipanti volontari sono stati diretti dall'artista per muoversi nella sala e "inscenare" conversazioni. Tale pratica genera connessioni e conversazioni naturali, improvvise ed aperte, all'interno del museo e tra persone sconosciute. (Fig. 4).

L'intervento di Sehgal consiste interamente in incontri tra persone che si muovono inconsapevolmente senza direzioni in una nuova forma d'arte a metà tra teatro, performance art e danza. In questo modo, i visitatori diventano partecipanti attivi senza l'utilizzo di nessun dispositivo tecnologico durante la performance.

Così come il seguente caso studio associato al Level of Structure, ovvero l'esperimento di Firenze, "The Florence Experiment" (2018) dell'artista Carsten Höller e del neuroscienziato Stefano Mancuso si identifica come una miscela di arte e ricerca scientifica attraverso l'installazione interattiva all'interno del cortile di Palazzo Strozzi a Firenze.

Si tratta di uno spazio espositivo en plein air dove l'installazione artistica contemporanea mette in discussione la storia dell'architettura rinascimentale del palazzo che la ospita. Carsten Höller, per questo progetto, ha così reimmaginato il modo in cui si vive e ci si muove nello spazio aperto. Di fatti, entrando nel cortile, gli utenti si sono trovati di fronte a due imponenti bobine d'acciaio avvolte attorno a un palo verticale che collegava il terzo piano del palazzo al cortile, e si estendevano verticalmente per circa sessanta metri di altezza. (Strozzi, 2018).

Figura 5. The Florence Experiment. Foto di Samantha Vaughn

Figura 6. The Florence Experiment. Foto di Andrea Paoletti su theflorentine.

Höller, noto per i suoi interventi artistici di natura concettuali, ha realizzato due scivoli gemelli, intrecciati e interattivi, che hanno trasformato il palazzo in un parco giochi temporaneo per adulti e bambini, riconfigurando così il modo in cui gli utenti sperimentano il sito familiare di Palazzo Strozzi. (Fig. 5-6)

Concentrandosi, quindi, sugli aspetti fisiologici e psicologici del visitatore, si assiste all'esperienza totalizzante di visita in cui il "soggetto viene messo in mostra". I visitatori non sono solo spettatori ma divengono parte attiva dell'installazione anche con il proprio corpo.

Per i casi studio selezionati, l'interazione avviene tra persone come espressione di creatività. L'interazione gestuale attraverso il "movimento" del corpo, ad esempio, rappresenta un fattore importante per la progettazione di mostre ed esposizioni incentrate sull'utente. Inoltre, entrambi i progetti si concentrano principalmente non sulla tecnologia ma sulla definizione di esperienze a forte impatto fisico-emotivo.

Al "Level of Surface", sono stati infine associati i casi studio di seguito descritti, "Connected" e "Zoom Pavillion". Secondo Mason, in questo livello, gli elementi del design sono di fondamentale importanza nel soddisfare le richieste sensoriali del prodotto fisico-digitale, e definito come mezzo utile alla comprensione delle mostre tale da essere un ponte tra la componente espositiva dell'opera e le interfacce digitali.

Difatti, le installazioni al Nxt Museum, quali Connected (2022) di Knol e Zoom (2022) di Lozano e Hemmer, sono caratterizzate dell'uso della tecnologia al fine di promuove l'esperienza interattiva del visitatore.

Nello specifico, Connected (2020), installazione dell'artista audiovisivo Roelof Knol, unisce i visitatori in un rituale di connessioni attraverso elementi visivi interattivi proiettati sul pavimento, formando nuove reti tra i visitatori che "vivono" la mostra. Poiché lo spazio personale diventa spazio condiviso, "Connected" esamina lo "spazio che abitiamo" e invita i visitatori a familiarizzare con gli altri, in modo confortevole e sicuro. (Fig. 7)

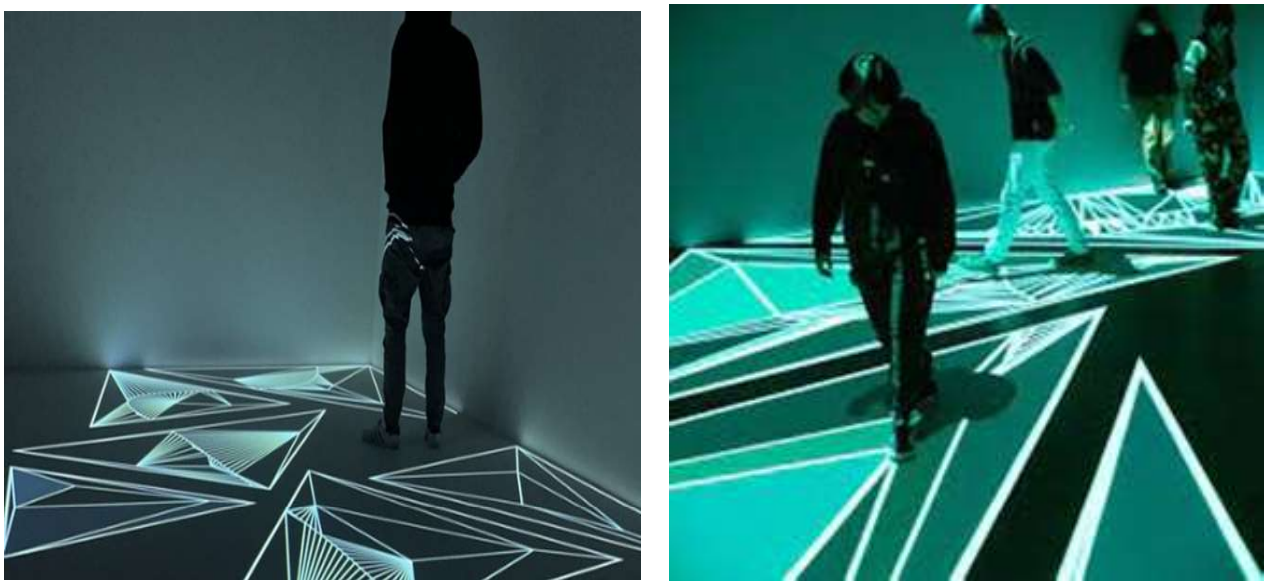

Figura 7. Connected. Foto di Roelof Knoll su Roelof Knol.

Zoom Pavilion del 2015, (Fig. 8), invece, è un'installazione interattiva che consiste nella proiezione immersiva su tre pareti, alimentata da 12 sistemi di sorveglianza computerizzati e direzionati sul pubblico. L'opera utilizza algoritmi di riconoscimento facciale per rilevare la presenza dei partecipanti e registrare le relazioni spaziali all'interno dello spazio espositivo. Rappresenta, allo stesso

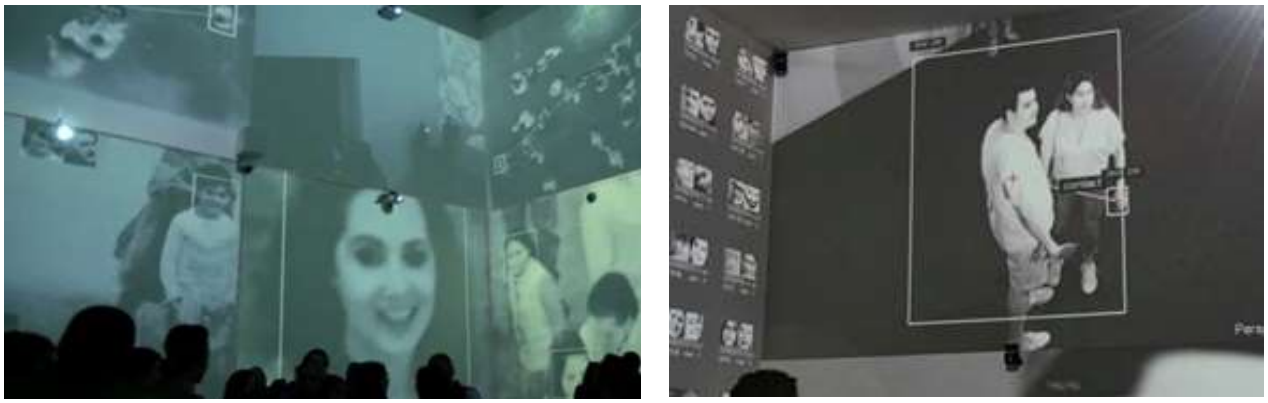

Figura 8. Zoom Pavilion.Foto di Rafael Lozano-Hemmer su lozano-hemmer.

tempo, una piattaforma sperimentale per l'auto-rappresentazione con la presenza di un microscopio di grandi dimensioni che connette i visitatori tra di loro, e con telecamere robotiche che zoomano e amplificano le immagini del pubblico con ingrandimenti fino a 35x. In questo modo, le sequenze di zoom disorientano gli utenti poiché cambiano l'intero "paesaggio" dell'immagine, passando da ampie inquadrature facilmente riconoscibili della folla a primi piani astratti e indefiniti. Questo lavoro sottolinea la costruzione temporanea dello spazio connettivo in relazione alle tecnologie di rilevamento e controllo.

Per tali casi, la caratteristica principale è rappresentata dalla presenza di applicazioni tecnologiche umano-centriche che offrono ai visitatori esperienze immersive e approfondiscono le esperienze fisico-digitali.

Le pratiche artistiche e multisensoriali per lo spazio espositivo nei casi studio selezionati, dimostrano come l'utente sia direttamente influenzato dalla narrazione dei media e dagli ambienti narrativi progettati per comunicare storie e stimolare la definizione di ulteriori livelli di interazione spazio-persona.

Processi di interazione e linee guida per la progettazione degli spazi museali esperienziali e umano-centrici.

Le attuali sperimentazioni e ricerche in questo contesto si concentrano principalmente sugli aspetti sensoriali degli utenti e sulle pratiche "artistiche" che combinano corpo-spazio-tempo.

L'esperienza del visitatore all'interno dello spazio espositivo attraverso "il corpo", per esempio, è una tra le principali pratiche museologiche utilizzate per creare "legami diretti" con il museo e il patrimonio. I visitatori dovrebbero muoversi in un "tempo" che sia "ritmicamente risonante", non solo con le indicazioni definite dal curatore della mostra ma soprattutto sulla base delle esigenze del visitatore. (Leahy, 2016)

L'utilizzo delle attuali applicazioni tecnologiche presenti nei contesti museali definisce esperienze innovative e personalizzate, in cui i dispositivi agiscono come facilitatori e diffusori di informazioni.

La tecnologia digitale interattiva, di fatti, è oggi tema ricorrente in numerose ricerche nell'ambito dei Beni culturali.

Nel nuovo paradigma post-digitale, le dimensioni tecnologiche e fisiche si intrecciano dando forma a nuove direttive nella progettazione degli spazi espositivi. Nell'ultimo decennio, i musei sono maggiormente orientati verso pratiche che mirano a migliorare le visite attraverso spazi informativi ibridi fisico-digitali.

Il museo post-digitale tiene in considerazione la progettazione di spazi immersivi nel nuovo paradigma che non separa l'esperienza digitale dall'esperienza museale complessiva. Secondo lo studio di Borsotti nell'ultimo decennio, l'interesse si è spostato verso studi che indagano modalità coinvolgenti e significative per migliorare la visita al museo in termini di esperienza del visitatore; a tal proposito, alcuni studiosi offrono diversi esempi di progetti che considerano centrale il design dell'esperienza del visitatore. (Borsotti, 2023)

Tra gli studi che pongono in evidenza l'importanza dell'esperienza, il lavoro di Calise, ad esempio, affronta le variazioni temporali del rapporto tra i musei, i visitatori e i loro corpi, indagando in che misura gli sviluppi tecnologici contribuiscono ad influenzare le scelte espositive e curatoriali. Il corpo del visitatore, nella sua materialità e nelle sue abitudini di movimento, verrà visto attraverso "la lente tecnologica", utilizzata come pratica museale immersiva e di interazione. (Calise, 2023)

Da ciò emerge che la progettazione degli spazi espositivi può essere in grado di combinare componenti fisiche e digitali, tali da offrire strumenti utili per concepire l'ambiente narrativo come "un insieme di esperienze" senza tralasciare l'interazione, le esigenze e le aspettative del visitatore.

Dai casi-studio analizzati, si evince che la progettazione degli spazi espositivi è solitamente guidata dalla necessità di fornire ai visitatori servizi capaci di integrare strumenti e sistemi di interazioni fisico-digitali-spaziali, senza tralasciare in questo processo il "fattore umano".

Secondo Falk e Dierking (Falk, 2000), l'interazione e la partecipazione dei visitatori rappresentano due modalità per i musei di creare nuove esperienze di visita. Con queste premesse, il contributo propone, a partire del modello di Mason, alcune considerazioni e indicazioni sui processi di interazione spazio-persona, utili alla definizione delle possibili linee guida per la progettazione di spazi museali umano-centrici ed esperienziali.

Dall'analisi del caso studio "The Weather Project", si evince che il processo di interazione è di tipo "immersivo" in quanto mostra che lo spazio espositivo contribuisce ad arricchire l'esperienza dei visitatori che possono vivere il contesto preso in considerazione.

Nel caso dei progetti "These Association" e "The Florence Experiment", il processo di interazione risulta di tipo "creativo", poiché il corpo dell'utente è parte integrante dell'installazione.

Infine, i casi studio "Connected" e "Zoom Pavilion", evidenziano un processo di interazione legato alla tecnologia che risulta essenziale ai fini dell'esperienza di visita.

In sintesi, per la progettazione degli spazi museali esperienziali e umano-centrici è necessario che vengano presi in considerazione i differenti processi di interazione dell'utente, a partire dal processo di interazione "immersivo" (che considera maggiormente i fattori cognitivi), il processo di interazione di tipo "creativo" (che introduce il fattore "corporale" di visita in maniera "diretta") e, infine, il processo di interazione "tecnologico" (attraverso l'uso di tecnologie emergenti che definiscono i canali attuali di comunicazione multimodali e multimediali).

L'esperienza del visitatore, quindi, con la combinazione dei fattori precedentemente esposti, risulterà partecipata fisicamente nello spazio, generando legami concettuali e affettivi di tipo diretto tra il visitatore e lo spazio, oltre ad esperienze narrativo-immersive, con l'utilizzo di strumenti e sistemi intermodali e avanzati.

In questo modo, lo spazio museale sarà in grado di riflettere gli interessi e le esigenze dei visitatori divenendo flessibile (utilizzando, ad esempio, lo spazio fisico in modo coinvolgente) e versatile, grazie all'uso di tecnologie capaci di produrre molteplici scenari che esaltino la percezione.

Attraverso la metodologia progettuale che pone le pratiche, gli approcci e gli strumenti al servizio dell'utente, si identificano ambienti museali in grado di miscelare spazio fisico e digitale, interazione creativa, corporale e tecnologica, per esperienze partecipate e immersive.

Conclusioni

La progettazione degli spazi espositivi per l'esperienza utente è ormai fattore chiave per il coinvolgimento dei visitatori attraverso l'utilizzo di contenuti digitali, forme e oggetti artistici per la comprensione culturale totalizzante e la promozione della conoscenza.

Le tecnologie digitali e le nuove pratiche di "spettacolarità" incentrate sull'esperienza fisico-corporale dell'utente, stanno modellando le funzioni e gli obiettivi degli spazi culturali, proponendo musei capaci di offrire, alla più ampia gamma di utenti, esperienze di visita multimodali e multisensoriali.

Nel contesto dei Beni Culturali, la ricerca nell'ambito dell'interaction design offre ai curatori museali visioni narrative più ampie. In tal senso, le pratiche di progettazione per gli spazi dediti alla cultura, valorizzano e accrescono l'importanza delle esperienze dell'utente nel processo di visita.

Dall'analisi effettuata e dalla ricognizione dei principali casi studio selezionati e analizzati, si evince l'importanza del design dell'interazione in ambito museale per favorire nuove modalità di comunicazione e di esperienze e rimodulare i contenuti esposti sulla base delle specifiche esigenze dei visitatori.

In tal senso, sia il visitatore che lo spazio fisico del museo, rappresentano gli elementi fondamentali per la progettazione degli spazi museali esperienziali, poiché entrambi necessari e caratterizzanti.

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Designing museum spaces from the user experience | La progettazione degli spazi museali a partire dall'esperienza utente:

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Abstract

In the current context, museums are particularly focused on offering visitor-oriented services. Understanding the user's behaviours, needs, and motivations is of fundamental importance in defining interactions and personalised services that make the use inclusive.

Current experiments, digital technologies and new practices of "spectacularity", which generate "digito-corporal" experiences of the user, are shaping the functions and objectives of artistic knowledge for cultural spaces, becoming an integral part of the work of designers and researchers in this field.

Interactive installations and cutting-edge technological products are widely used in museums to improve visitor experience, enrich the content of museum exhibitions and diversify narrative forms to offer dynamic, immersive and multisensory visitor experiences.

Through a human-centric approach, the article proposes to explore the multidimensionality of the design of museum spaces for the visitor experience, deepening the concept of an immersive and narrative environment and the physical and perceptive involvement of the visitor in the interaction with the space and the exhibited objects.

Through the analysis of approaches and models present in the literature on the design of the visit experience for exhibition spaces and concerning the selected case studies, some forms of physical and technological interaction of visitors in cultural contexts will be explored in order to identify guidelines for the design of museum spaces centred on the user and the "space-user" relationship.

Keywords: Interaction Design – Creativity – Design for Experience– User Experience

Introduction

According to the recent ICOM definition, a museum is an institution that serves society, is open to the public, accessible and inclusive, offering diverse experiences for education, enjoyment, reflection and knowledge sharing. (ICOM, 2022).

Based on this reference, museums today are more committed to disseminating and adopting different strategies of engagement and interaction with visitors in order to offer more empathy with the exhibition spaces and current exhibitions. At the same time, museums are responsible for ensuring that the knowledge they offer is correctly conveyed and understood by visitors.

Visitors' experiences within cultural contexts are becoming the object of exploration and communication, understood as performative and interactive forms with the objects on display and with other users within the museum or art gallery.

In this context, digital technologies and the resulting interactions broaden how visitors can participate, enabling the dissemination of knowledge with direct user involvement and the identification of different cultural interests of the public.

Museum environments have become places where interaction design and experimentation with new technologies define the interest in promoting new modes of interaction and new cultural forms focused on understanding, entertainment and user experience.

Interaction can enhance participation modes and define flexible and personalised experiences, eliminating the one-way communication problem often typical of "traditional" exhibitions.

Based on these considerations, this contribution offers a brief overview of interaction design in support of museums, investigating approaches and models in the literature relating to the design of museum spaces.

Among these models, particular attention will be paid to the work of Mason (Mason, 2020) about some case studies identified in the literature in order to identify the process of space-person interaction in places of cultural fruition and improve the user experience through dynamic, immersive, multisensory and human-centric visits.

Methodology

Starting from the topic of interaction design for museum spaces, several approaches and models in the literature concerning the design of the visitor experience in exhibition spaces were identified and analysed. In particular, the study by Roppola (Roppola, 2013) and Mason's model were examined. (Mason, 2020)

Starting from this reference for user-centred design for the three-level visitor experience, several case studies were identified to define the three space-person interaction processes within cultural contexts.

User interaction and space fruition

With the development of multimedia technology, interactive devices in museum settings aim to transfer exhibition content through the stimulation of creativity and sharing. Various scientific studies point to the growing interest of visitors in interacting with works in an original and participative way (Solima, 2012), particularly by exploiting the features and potential offered by new digital media.

Visitors are often intrigued by "spectacles" offered by museums, which have become "experimental laboratories" for artists and designers, promoting cultural events of various kinds to a broad and diverse audience, far from the obsolete passive conservation mechanisms of traditional museums.

Another interesting aspect is discussed in the work of Nicholas Serota (Serota,

1996), who considers visitors and artistic communication to be processes at the centre of the transformation of museums. Visitors can interact with the artefacts and artists through physical relationships, participating in person and integrating with performances and events.

In this context, the traditional exhibition form is undergoing a radical change. Interaction design contributes to creating and diffusing visual, auditory, tactile and multisensory experiences through body movement and interaction in space. Starting from the fundamental concept of "people-oriented design", interaction design aims to meet the psychological and behavioural needs of visitors to achieve efficient and widespread dissemination of culture, creating complete visiting experiences.

This approach aims to define and design the interaction between users and products/ systems and it describes the possible behaviour of the user. Every time a person uses a product, a "dance" is established in which the user moves and the system reacts. (Garrett, 2010).

In cultural heritage, Wideström presents a classification framework for different types of interactivity in science centres and museums. The classification is based on three aspects of interaction: (I) level of participation, which concerns the influence of users on the content of the exhibition; (II) level of virtuality, which concerns the amount of interaction that takes place in real physical space as opposed to virtual space; (III) level of collaboration, which concerns the social interaction between users and can be distinguished as individual or collective. This model reflects the different types of interactions envisaged in science exhibition contexts, considered highly interactive centres involving a wide range of target groups to engage and educate simultaneously, where digital and physical materials and design spaces merge. (Wideström, 2020)

Insights from interaction design can also be used to evaluate and innovate the accessibility of exhibitions and to take technologically appropriate measures to meet visitors' needs (Saki Asakawa, 2019).

The purpose of interaction design is not only to contribute to "user-friendly" exhibitions for visitors. The knowledge and exploration of different ways to "create interaction", together with knowledge of emerging technologies, is of fundamental importance to innovate ways of "understanding" artistic culture.

By implementing modern interactive solutions, museums can also create research opportunities for interaction design and new technologies can be explored and evaluated in less constrained contexts, such as museums. (Bodin, 2021)

The different factors of an interactive exhibition contribute to the creation of exhibitions that are, at the same time, educational, entertaining and easy to understand. An example of this is the project by Schauble and Bartlett, who used educational theory to survey children about the "idea" of fossils and then design an exhibition in which the content was based on the considerations noted and interactive activities inspired by scenarios from everyday life (Schauble, 1997). A further reference is the project by Asai, Sugimoto and Billinghurst, who, inspired by collaborative learning between parents and children, created an augmented reality exhibition in which parents can take on the role of mission commanders and children of astronauts while exploring the lunar surface (Asai, 2010).

For this reason, the design of exhibitions for the "collaborative" visitor experience becomes a fundamental part of implementing museum policies for audience engagement (Reagen, 2014).

Over time, exhibitions have evolved to include a wider range of media, overlapping with art, advertising, architecture and graphic design. It is, therefore, an orchestration of space, media, content and narrative. (Reagen, 2014)

The contemporary museum exhibition represents an open and dynamic

communication and dissemination activity involving users in an ever-evolving process. As people's modes of communication, participation and communicative awareness increase, interaction design becomes an active part of the design of museum spaces, stimulating visitors' enthusiasm through "people-space" links within the cultural and museum context, understood as a place of physical and conceptual connection.

Approaches and models for designing the visitor experience in exhibition spaces

Over the past two decades, museums have undertaken various design strategies to create more personalised and immersive experiences, such as "affective", "participatory", "immersive", and "sensory" experiences (Bertrand, 2024). These strategies contribute to achieving objectives for experts in the field, which are oriented towards museum experiences and designed to facilitate curiosity and exploration. (Kenderdine, 2012).

Cultural heritage institutions are adopting immersive and interactive approaches to provide "more dynamic ways of communicating with audiences, encourage richer and more meaningful participatory practices and engage users with sites, institutions, collections and wide-ranging themes".(Bertrand, 2024).

For this reason, museums have shifted their focus to more "visitor-oriented" practices, adopting design and technological strategies of engagement, exhibition and display to promote "networked" culture, competitiveness, economy and tourism. (Kamariotou, 2021)

Nowadays, design addresses social issues related to user experience and is used as an investigative and experimental project. For example, the space for the work of art is becoming a place of "verification" of expectations, involvement, and perceptions, where projects do not need to be applied in series.

Experimentations, therefore, are becoming an integral part of the work of designers and researchers in this field because they produce very often unexpected results that allow original processes to be developed with user-centred learning and experimentation methods.

Scholars Laurberg and Schavemaker (Laurberg, 2016) highlight how museums are increasingly involved in speculative and research activities, often interdisciplinary, now widely integrated into the entire institutional planning process.

As an acquisition of knowledge, research in the discipline of design offers curators and designers an expanded narrative vision of an object, of a work of art, about its historical, artistic and very often functional relevance, giving rise to iterative processes of creation, revision and continuous improvement.

Today, exhibitions structured in terms of narrative design revise the role and modalities of technological factors coordinated in a "script" that Uwe R. Brückner calls a "score". (Brückner, 2011). In this way, the visit and experience can be managed simply and rhythmically, defining time, discovery, perception, understanding and assimilation. The visitor's attention is designed in sequence, and the exhibition can be experienced according to different stages of immersiveness, where digital intervention becomes an experience aimed at consolidating a humanised memory. For this experience, the design of exhibition spaces becomes a catalyst that prompts one to search for new information and make connections between different media content. (Borsotti, 2023).

The aim of designers in designing exhibition spaces is to satisfy visitors aesthetically and produce knowledge and personal visual and spatial interpretation. Understanding visitors' experiences and the factors that influence them is also important in producing research and conceptual developments to improve the design of user-centred exhibition spaces.

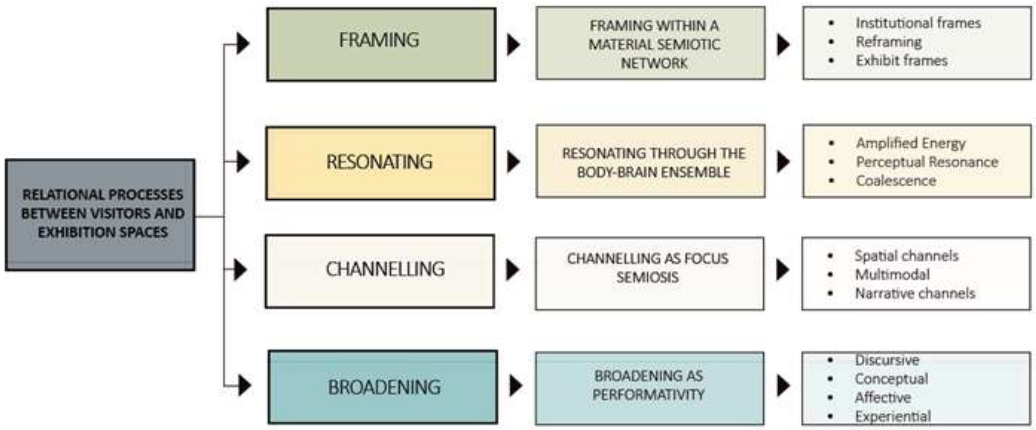

Figure 1. Roppola's model of the four key relationship aspects between visitor and exhibition space. (scheme freely reinterpreted by the author, 2025).

The experience of visiting a museum is a process of mutual interaction or "dialogue" between the visitor and his or her environment. (Reagen, 2014). It can be defined as an "immediate, subjective and personal response of an individual to an activity, environment or context outside his or her usual environment". (Packer J. B., 2013). In particular, the research conducted by Roppola (Roppola, 2013) reveals how visitors identify themselves about the exhibition environment and how the experience is influenced by design and related design decisions.

Based on the analysis of visitors' experiential reports, Roppola identifies and classifies four key aspects in the relationship established between visitors and the exhibition space (Fig. 1). The author defines the first process as "framing" where visitors introduce a discussion about museums and exhibitions in a generic (institutional, exhibition) sense. For the second key aspect, visitors identify how they are attracted to the exhibition environment immediately or effortlessly, a process the author called "resonance". Thirdly, visitors described how they were guided through the exhibition space, media and content, a process defined as "channelling". Regarding the fourth key aspect, visitors described how they experienced a "widening of the self", a process defined by Roppola as "widening".

These four main processes were then divided into categories describing how visitors find themselves about exhibition environments.

It is, therefore, evident that the study of experiences and interpretations in exhibitions can be significant for the organisational and overall structure of art spaces but, above all, for user-oriented museum design. Spaces dedicated to culture can, therefore, be redeveloped and shaped according to the needs of the public.

The user-centred design approach for the visitor experience in exhibition spaces - hybrid and physical - is further explored in Mason's contribution, according to which

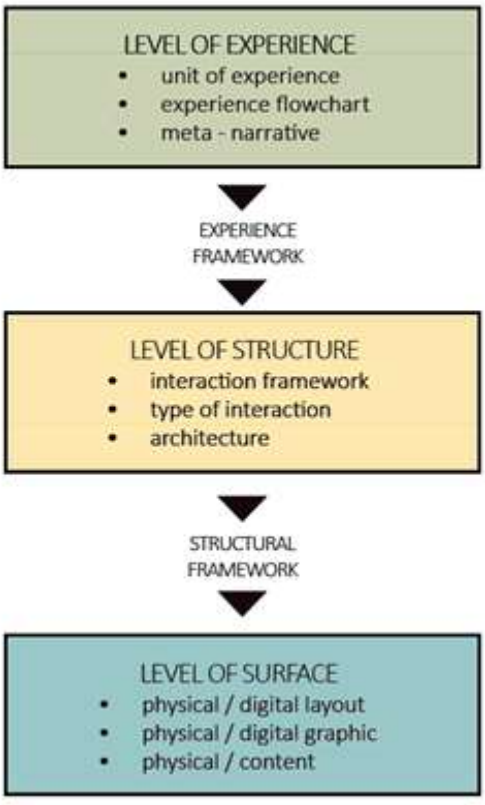

Figure 2. Design model for the visitor experience for exhibition spaces. (Mason, 2020)

such design must operate on three levels: (I) Experience, (II) Interaction, and (III) Visual elements. (Mason, 2020) (Fig. 2).

In particular, the "Level of Experience" defines "sub-levels" such as the units of experience, the flow of experience and the meta-narrative, including practices and design methods suitable for designing experiential structures underlying narrative environments.

The "Level of Structure" focuses on interactions and content organisation structure. According to Crampton Smith, designers at this level make the experience "visible" (Mason, 2020) by defining interactions and structuring content that shapes experiences over time. At this level, the structure is created for the definition of three interrelated design elements: first, the interaction framework, as the distribution of key interactions according to a structure resulting from the integration of the physical and digital dimensions; second, the information architecture that organises the content and defines the distribution of the different interactions within the information space; and finally, the definition of the types of interactions that visitors can perform within the information space.

Finally, in the "Level of Surface", the design elements have to satisfy the sensory demand of the product, such as the form factors of the physical and digital components, the appearance and visual elements, and the different design elements that make up the product presentation of the content, which are useful for understanding the exhibition and create display coherence between the digital interfaces and the graphic components (labels) of the exhibits.

The contribution of Borsotti & Mason (Borsotti, 2023) also defines how Visitor Experience Design (VX) is directly related to the design of exhibition environments defined as "narrative", given the special focus on the relationships between people (visitors), digital and physical spaces/places, digital content and exhibits.

In this regard, Austin defines a narrative environment as a "site of action and interaction between people, narratives and places" (Austin, 2020) emphasising that the practice of designing narrative environments is "particularly associated with the principles of User Experience Design".

The narrative factor, therefore, accompanies the discursive/immersive combination of an exhibition by representing the ability to decode and transmit more comprehensible meanings to a wider audience. Through the narrative system, therefore, exhibitions and the dissemination of culture relate to the visitor in terms of knowledge generation, no longer knowledge reproduction. According to Borsotti (Borsotti, 2023), the term "narrative" refers to the relationship established between "collection-visitor", while "narrative environments" refers to immersive, multisensory and interactive spaces shaped by the logic of the visitor's experience. Furthermore, "discursive" and "immersive" are indicators of change in the current method of offering culture within cultural heritage. The term "discursive" refers to the form of curatorial, interdisciplinary and synthetic design, while "immersive" refers exclusively to the spectacularization of the exhibition. (Laurberg, 2016).

It is no coincidence that Mark Wingley (Wigley, 2016) discusses this dualism in terms of exhibition space design, where the logic of reading is contrasted with the logic of experience, which uses the language of multisensoriality, claiming that they are intrinsically intertwined and dependent.

A narrative exhibition space, therefore, defines a structure of cognitive sequences that allow the simultaneous exploration of the contents of what is on display, whether explicit or implicit. Through the development of a narrative exhibition system, exhibitions relate to the visitor in terms of knowledge reproduction and knowledge generation. (Brückner, 2011).

Narrative exhibition space design, therefore, not only shows but also evokes, reveals, involves, excites and stimulates the user on a perceptive and physical level. Narrative amplifies the meaning of discursive by declining it as the communicative capacity

of the "collection-visitor" relational system to propose multiple modes of access and investigation.

Tools and methodologies for user experience in museum spaces.

Visitor experiences within a cultural space can also be defined as psychological, intimate and personal journeys that can determine the quality of the visit. Users can be actively involved in the narration, interpretation and transformation of their emotional and physical perceptions. Thus, a single product can evoke a diverse range of visitor experiences. (Packer J. &., 2016).

The study conducted by the author Leahy, entitled "Museum Bodies: The Politics and Practices of Visiting and Viewing" (Leahy, 2016), shows how many of our behaviours within contemporary museums have been shaped by artistic and cultural institutions, such as walking (and not running) in galleries, whispering rather than speaking, and the prohibition of touching. Leahy's work aims to reorient our attention from the museum as a collection of objects to the museum as a site of social, psychological, and corporeal practices.

Designing museum spaces, considering the level of experience and user-space interaction, represents the starting point for defining a set of factors capable of satisfying visitors' needs, emotions and expectations.

Further case studies have been introduced below, introducing the "new design trends". These references have been selected starting from Mason's contribution described above, which foresees the three macro-levels of the design of the visit experience.

The "Level of Experience" case study "The Weather Project" has been associated with it, which identifies three design elements: (I) the units of experience, (II) the flow of experience, and (III) the meta-narrative experience. These references define the result of the combination of knowledge from curatorial services and visitors and determining visit paths in the museum space.

With the installation "The Weather Project" of 2003, the Danish artist Olafur Eliasson created the illusion of the sun in a city usually characterised by fog and greyness to involve the visitors in the Turbine Hall of the Tate Modern in London (Fig. 3). The artist, through the use of "mirrored sheets" suspended from the ceiling, a semicircle

Figure 3. The Weather Project. Photo by Tate Photography (Andrew Dunkley & Marcus Leith) on Olafur Eliasson

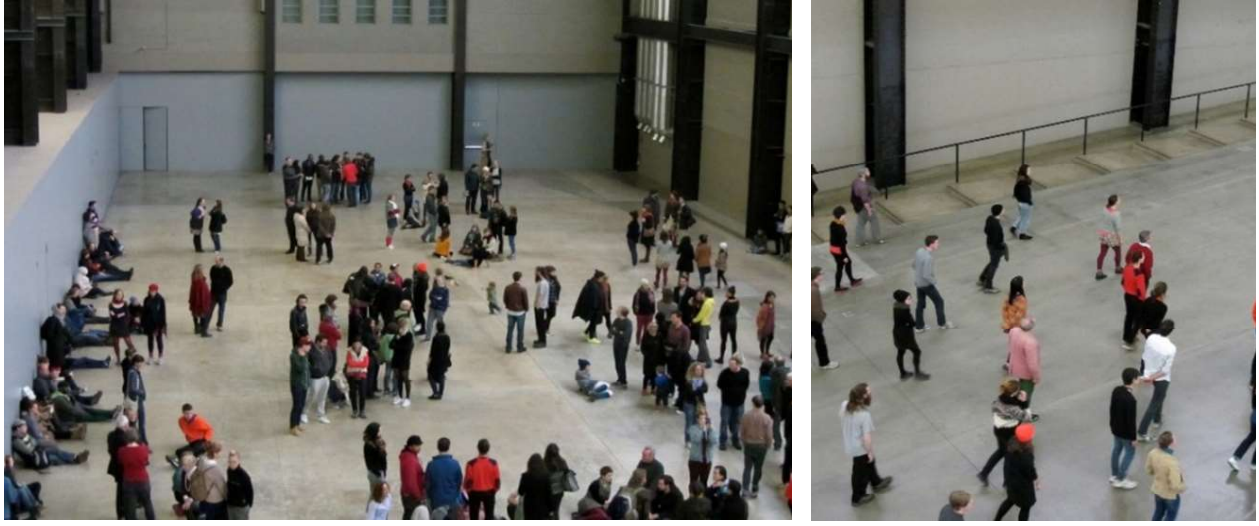

Figure 4. ino Seghal, These Associations, Tate Modern, Unilever Series Commission, 2012. Photo on johiggins

backlit by about 200 single-frequency lights and its reflection, created the image of a huge sunset, seen through the artificial fog emitted in the hall.

In this context, the experience level is totalising, perceptive and cognitive. It can be considered as a combination of elements that, when put into a system (unit of experience, the flow of experience and the meta-narration), generate value to the visit and define the completely immersive space-person interaction process.

For Mason's "Level of Structure", the case studies of Tino Segale and Carsten Höller were considered, focusing on the interaction and mobility of visitors within an art gallery, developing new practices of "spectatorial". This level focuses on the distribution of key interactions, from integrating physical and spatial dimensions to organising content for interaction with the information space.

Specifically, "These Association" is an installation conceived by Berlin-based Tino Sehgal in 2012 and commissioned by the Turbin Hall of the Tate Modern in London. It shows the process of iteration and interaction between unknown users without objects or paintings to look at, where the artist directed voluntary participants to move around the room and "stage" conversations. This practice generates natural, sudden, open connections and conversations within the museum and between unknown people. (Fig. 4).

Sehgal's intervention consists entirely of encounters between people who move unconsciously without directions in a new art form halfway between theatre, performance art and dance. In this way, visitors become active participants without using any technological device during the performance.

Like the following case study associated with the Level of Structure, the Florence Experiment, "The Florence Experiment" (2018) by artist Carsten Höller and neuroscientist Stefano Mancuso identifies itself as a blend of art and scientific research through the interactive installation inside the courtyard of Palazzo Strozzi in Florence.

It is an open-air exhibition space where the contemporary art installation questions the history of the Renaissance architecture of the building that hosts it. For this project, Carsten Höller has thus reimagined how one lives and moves in the open space. In fact, upon entering the courtyard, users found themselves in front of two imposing

Figure 5. The Florence Experiment. Photo by Samantha Vaughn su theflorentine

steel coils wrapped around a vertical pole that connected the third floor of the building to the courtyard and extended vertically for about sixty meters in height. (Strozzi, 2018).

Höller, known for his conceptual art interventions, created twin, intertwined, interactive slides that transformed the palace into a temporary playground for adults and children, thus reconfiguring the way users experience the familiar site of Palazzo Strozzi. (Fig. 5-6)

By focusing on the physiological and psychological aspects of the visitor, we witness the totalising experience of visiting in which the "subject is put on display". Visitors are not only spectators but also become active in the installation with their own bodies.For the selected case studies, people interact as an expression of creativity. For example, gestural interaction through the "movement" of the body is an important factor in designing user-centred exhibitions and displays. Furthermore, both projects focus not on technology but on defining experiences with a substantial physical-emotional impact.

Finally, the following case studies, "Connected" and "Zoom Pavillion", were associated with the "Level of Surface". According to Mason, for this level, the design elements are of fundamental importance in satisfying the sensorial requests of the

Figure 6. The Florence Experiment. Photo by Andrea Paoletti su theflorentine.

physical-digital product. They are defined as a useful means for understanding the exhibitions, such as being a bridge between the exhibition component of the work and the digital interface.

Indeed, installations at the Nxt Museum, such as Connected (2022) by Knol and Zoom (2022) by Lozano and Hemmer, are characterised by the use of technology to promote the visitor's interactive experience.

Specifically, Connected (2020) is an installation by audiovisual artist Roelof Knol that unites visitors in a ritual of connections through interactive visuals projected onto the floor, forming new networks between visitors who "experience" the exhibition. As personal space becomes shared, "Connected" examines the "space we inhabit" and invites visitors to become

Figure 7. Connected. Photo by Roelof Knoll on Roelof Knol.

familiar with others comfortably and safely. (Fig. 7)

Zoom Pavilion (2015). (Fig. 8), on the other hand, is an interactive installation consisting of an immersive projection on three walls, powered by 12 computerised surveillance systems directed at the audience. The work uses facial recognition algorithms to detect the presence of participants and record spatial relationships within the exhibition space. It also represents an experimental platform for self-representation with a large microscope that connects visitors to each other and robotic cameras that zoom and amplify images of the audience with magnifications of up to 35x. In this way, the zoom sequences disorient the users as they change the entire "landscape" of the image, from easily recognisable wide shots of the crowd to abstract and undefined close-ups. This work highlights the temporary construction of connective space to sensing and control technologies.

For such cases, the main feature is the presence of human-centric technological applications that offer visitors immersive experiences and deepen physical-digital experiences.

The artistic and multisensory practices for the exhibition space in the selected case studies demonstrate how the user is directly influenced by the media narrative and by the narrative environments designed to communicate stories and stimulate the definition of further levels of space-person interaction.

Interaction processes and guidelines for the design of experiential and human-centric museum spaces.

Current experiments and research in this context focus mainly on the sensorial aspects of users and on "artistic" practices that combine body-space-time.

For example, the visitor experience within the exhibition space through "the body" is one of the main museological practices used to create "direct links" with the museum and the heritage. Visitors should move in a "time" that is "rhythmically resonant", not only with the indications defined by the exhibition curator but, above all, based on the visitor's needs. (Leahy, 2016)

The use of current technological applications present in museum contexts defines innovative and personalised experiences in which devices act as facilitators and disseminators of information. Interactive digital technology is, in fact, a recurring theme in numerous research projects in the field of Cultural Heritage. In the new post-digital paradigm, technological and physical dimensions intertwine, shaping new guidelines in the design of exhibition spaces. In the last decade, museums have increasingly oriented themselves towards practices that aim to improve visits through hybrid physical-digital information spaces.

The post-digital museum considers the design of immersive spaces in the new paradigm that does not separate the digital

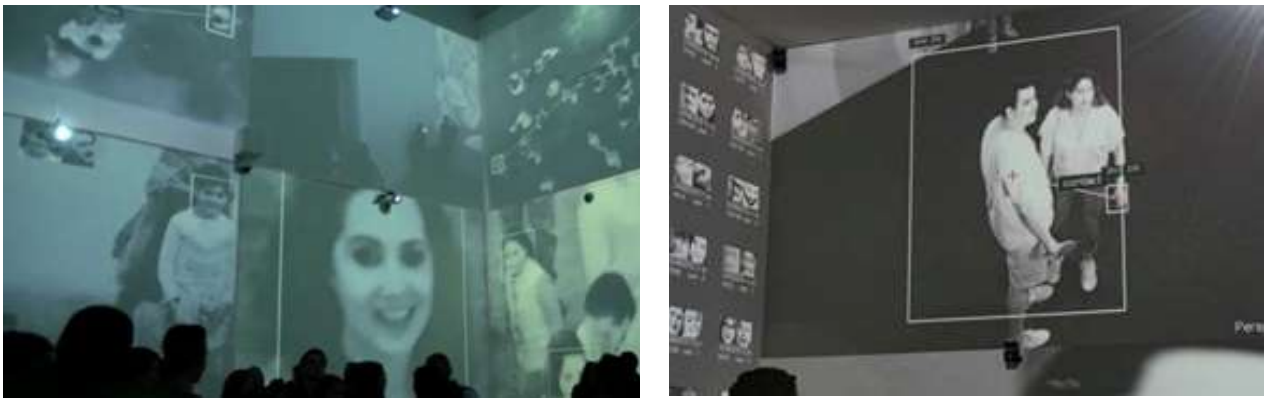

Figure 8. Zoom Pavilion.Photo by Rafael Lozano-Hemmer su lozano-hemmer.

experience from the overall museum experience. According to Borsotti's study, in the last decade, interest has shifted towards studies that investigate engaging and significant ways to improve museum visits in terms of visitor experience; in this regard, some scholars offer several examples of projects that consider the design of the visitor experience as central. (Borsotti, 2023)Among the studies that highlight the importance of experience, Calise's work, for example, addresses the temporal variations in the relationship between museums, visitors and their bodies, investigating to what extent technological developments contribute to influencing exhibitions and curatorial choices. In its materiality and movement habits, the visitor's body will be seen through "the technological lens", used as an immersive and interactive museum practice. (Calise, 2023)

From this, it emerges that the design of exhibition spaces can combine physical and digital components, such as offering useful tools to conceive the narrative environment as "a set of experiences" without neglecting the visitor's interaction, needs, and expectations. From the case studies analysed, it emerges that the design of exhibition spaces is usually driven by the need to provide visitors with services capable of integrating physical-digital-spatial interaction tools and systems without neglecting the "human factor" in this process.

According to Falk and Dierking (Falk, 2000), visitor interaction and participation represent two ways for museums to create new visitor experiences.

With these premises, this paper proposes, starting from Mason's model, some considerations and indications on the processes of space-person interaction that are useful for defining possible guidelines for the design of human-centric and experiential museum spaces.

From the analysis of the case study "The Weather Project", it emerges that the interaction process is of an "immersive" type as it shows that the exhibition space contributes to enriching the experience of visitors who can experience the context taken into consideration. In the case of the projects "These Association" and "The Florence Experiment", the interaction process is "creative" since the user's body is an integral part of the installation. Finally, the case studies "Connected" and "Zoom Pavilion" highlight a technology-related interaction process essential to the visitor experience.

In summary, in order to design experiential and human-centric museum spaces, it is necessary to take into consideration the different user interaction processes, starting from the "immersive" interaction process (which takes cognitive factors into greater consideration), the "creative" interaction process (which introduces the "corporeal" factor of the visit in a "direct" manner) and, finally, the "technological" interaction process (through the use of emerging technologies that define the current multimodal and multimedia communication channels).

Therefore, the visitor's experience with the combination of the previously exposed factors will be physically shared in the space, generating direct conceptual and affective links between the visitor and the space, in addition to narrative-immersive experiences, with the use of intermodal and advanced tools and systems.

In this way, the museum space will be able to reflect the interests and needs of visitors by becoming flexible (for example, engagingly using the physical space) and versatile, thanks to the use of technologies capable of producing multiple scenarios that enhance perception. Through the design methodology that places practices, approaches, and tools at the user's service, museum environments are identified as being able to mix physical and digital space, creative, corporal, and technological interaction for participatory and immersive experiences.

Conclusions

The design of exhibition spaces for user experience is now a key factor in engaging visitors through digital content, forms and artistic objects for total cultural understanding and the promotion of knowledge.

Digital technologies and new practices of "spectacularity" focused on the physical-corporeal experience of the user are shaping the functions and objectives of cultural spaces, proposing museums capable of offering multimodal and multisensory visiting experiences to the widest range of users. In the context of Cultural Heritage, research in the field of interaction design offers museum curators broader narrative visions. In this sense, design practices for cultural spaces enhance and increase the importance of user experiences in the visit process.

From the analysis carried out and the survey of the main case studies selected and analysed, the importance of interaction design in museums emerges to promote new methods of communication and experiences and remodel the contents exhibited based on visitors' specific needs.

In this sense, both the visitor and the museum's physical space represent the fundamental elements for the design of experiential museum spaces since both are necessary and characterising.

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Research article

Industrial Design for bio-inspired solutions in coastal protection

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Abstract

Coastal erosion, extreme climatic events, and biodiversity loss are major consequences of climate change, posing significant threats to both the environment and society. Addressing these challenges has led to a growing focus within industrial design on innovative, interdisciplinary approaches inspired based bioinspired design. Natural ecosystems have evolved over millions of years to create highly efficient structures that dissipate wave energy, stabilize shorelines, and support biodiversity, offering valuable models for sustainable coastal protection. These biological principles serve as a reference model for the design of high-performance and sustainable coastal defense solutions.

This study reviews the state of the art in coastal protection systems and introduces the conceptual development and preliminary experimental validation of simplified bioinspired models designed to enhance shoreline resilience. The hydraulic efficiency of these models was assessed through experimental testing, exploring their potential as innovative mitigation strategies against irregular and extreme wave conditions.

This research contributes to the development of next-generation submerged barriers, inspired by the morphology and functionality of natural systems, constructed from sustainable materials, and optimized for both hydraulic efficiency and ecological support. Following a top-down approach, key functional traits of biological structures were analyzed, abstracted, and translated into three distinct bioinspired design solutions for coastal protection.

The results provide a foundation for advancing sustainable coastal protection strategies, demonstrating the added value of bioinspired solutions in enhancing both shoreline resilience and ecological integration.

Keywords: Enviromental Design; Biometics; Ecodesign; Design for sutanaibility, Coastal Protection

Introduction

Climate change is accelerating, bringing well-documented consequences such as sea level rise, coastal flooding, erosion, and more frequent extreme weather events (IPCC, 2023; Di Luccio et al., 2018). Coastal zones -key areas of rich ecosystems and nearly 40% of the global population - are increasingly vulnerable due to rising seas, intensified storm activity, and unregulated urban expansion (IPCC, 2021–2023). At the

same time, unsustainable exploitation of resources and ecosystem degradation threaten both environmental balance and the livelihoods of coastal communities.

In response, new economic models such as the Blue Economy (Pauli, 2009) emphasize the sustainable and regenerative use of marine resources. This paradigm supports economic, social, and ecological value creation through nature-based and technology-driven solutions promoting low-impact activities like renewable marine energy, sustainable fisheries, and responsible tourism. Within this framework, design becomes strategic: a tool to develop resilient coastal solutions that reconcile environmental protection with long-term development goals.

Coastal barriers are central to this challenge, offering critical regulation and protection services (Bridges et al., 2013; Unguendoli et al., 2023). Historically, these have included emerged or detached breakwaters, massive structures built parallel to the shoreline, dating back millennia (Haggi, 2010). While effective at dissipating wave energy (Franco, 1996; Sharifahmadian, 2015), such "grey" infrastructure has caused unintended damage, including current disruption, seabed degradation, and landscape alteration (Hawkins et al., 2015; Saengsupavanich, 2022; Perricone et al., 2023).

In the 1980s, engineers introduced low-crested submerged breakwaters (SBs) (Browder et al., 1996), initially seen as more environmentally benign. However, only in the last decade, thanks in part to EU projects like THESEUS and DELOS (THESEUS, 2024; DELOS, 2024), have their ecological impacts been thoroughly examined. While SBs minimize visual intrusion, they can disrupt sediment transport and, under certain conditions, accelerate shoreline erosion (Postacchini et al., 2016; Duarte Nemes et al., 2019; Ranasinghe et al., 2006).

More permeable SBs have been proposed to mitigate these issues (Hur et al., 20129), and the bio-inspired approach explored in this study follows this direction. Yet, the link between permeability and sediment dynamics remains poorly understood. As grey infrastructure shows its limits, a growing shift toward green, adaptive, and ecologically integrated solutions is gaining momentum (Singhvi et al., 2022). This article revisits a bio-inspired design model discussed and explored in detail in the article "Biopinspired Coastal Barriers" by Perricone et al. (Perricone et al., 2024).

Nature-Based Solutions, Bio-Inspired Approach, and Design Invention

Within the landscape of contemporary design, the bio-inspired approach emerges not as a superficial mimicry of nature's aesthetic, but as a deep cognitive and methodological strategy grounded in the systemic observation of the living world. Nature is understood here as a dynamic system one that organizes, adapts, and evolves through complex processes over vast evolutionary timescales. From this perspective, designers extract models of resilience, efficiency, and optimization, translating them into operative tools capable of addressing the systemic complexity of today's environmental, technological, and social challenges.

This interdisciplinary lens had already been anticipated in the early 1970s by Victor Papanek, who attributed to design a proactive and ethical role in shaping solutions to ecological and social issues. For Papanek, nature was not only an aesthetic source but also a methodological guide for the development of sustainable and adaptive models (Papanek, 1971; Skjerven, 2019). This position contributed to a broader epistemological shift: design began to be redefined not merely as a formal discipline but as a critical and generative practice, oriented toward emergent needs and capable of reshaping the relationships between form, function, and technological innovation (Buono, 2018).

The present contribution emerges from this lineage and proposes a bio-inspired design approach aimed at mitigating the

impacts of wave motion on vulnerable coastal zones. The research developed through a collaborative and interdisciplinary process, incorporating diverse domains of knowledge from morphology and biomimetics to computational modeling, materials science, and hydrodynamic simulation. In a hyper-technological and rapidly evolving context, the designer-as-inventor operates within networks of collaboration and knowledge transfer, where innovation arises through cross-contamination and the reconfiguration of disciplinary boundaries (Buono, 2018).

Such an integrative approach activates what can be described as distributed design intelligence, oriented toward the development of sustainable and adaptive solutions. In this context, bio-inspired design does not merely imitate natural forms, but leverages biological strategies as catalysts for systemic invention producing scalable, efficient, and context-sensitive outcomes.

Two complementary trajectories shaped the methodological framework of this research. The first concerns "designing according to nature", where functional principles observed in biological systems are abstracted and transferred into industrial design processes. The second involves "designing for invention", whereby the design process becomes a space for radical exploration, generating new functions, new meanings, and previously unarticulated relationships among systems, materials, and environments.

The concept of Design for Patent exemplifies this dual commitment. It represents not only a path toward intellectual property creation but also a broader interpretative and epistemological platform, through which technical, cultural, and scientific dimensions converge to produce original systems and components (Capece et al., 2019; 2020). This approach enables the definition of a shared ontological and linguistic domain (what we might call a patent vocabulary) that structures innovation within a transdisciplinary framework.

Rather than producing mere visual or formal novelty, the objective becomes the generation of meaningful design: forms that respond to latent needs, enhance everyday life, and operate within regenerative ecological logics. Historic figures like Borromini and D'Ascanio remind us that invention and vision have long converged in the most impactful forms of design, where the artifact is both technically sound and culturally transformative (Buono, 2018).

Today, technologies such as 3D printing, topological optimization, and FEM simulations allow biomimetic strategies to be translated into adaptive geometries that can be digitally and then experimentally tested and validated. Through this lens, the interaction between biological intelligence, digital modeling, and material science creates a productive design space where conceptual ideas are transformed into resilient, high-performance systems.

The convergence between bio-inspired design and invention thus outlines an expanded framework for contemporary practice: one that transcends binary oppositions between nature and artifice, form and function, engineering and creativity. Here, design is redefined as a systemic act, i.e., a practice that is simultaneously ecological, aesthetic, and political. Through this synthesis, the artificial-natural divide is overcome, and the design process itself becomes a tool for sustainable innovation, weaving together ecological, social, and technological threads within a dynamic and meaningful whole (Flusser, 2003).

This expanded role is particularly relevant to the development of new coastal infrastructures, where the imperative is not only to reduce erosion or dissipate wave energy, but to create morphologies that support biodiversity and minimize environmental disruption. Nature-Based Solutions (NbSs) offer a compelling pathway in this regard, using habitats such as seagrass meadows, coral reefs, and mangroves to stabilize coasts and provide essential ecosystem services (Bridges et al., 2013; Narayan et al., 2016; Perricone et al., 2024).

However, these strategies are not without limitations: they often require long timeframes, extensive spatial requirements, and are sensitive to anthropogenic and seasonal variables (Schoonees et al., 2019; Seddon et al., 2020). For this reason, hybrid systems combining natural habitat creation with artificial scaffolding, are increasingly adopted to ensure immediate effectiveness and structural reliability in high-turbulence contexts (Stachew et al., 2021; Perricone et al., 2024).

The development of 3D-printed artificial reefs, some explicitly bio-inspired, represents a recent trend in this field. Notable examples include the Modular Artificial Reef Structure (MARS) by Reef Design Lab (Reef Design Lab, 2025) and 3DPARE modules for coral reef restoration (3DPARE, 2025). Of particular interest is the work by Stachew, Houette, and Gruber (2021), who proposed a mangrove-inspired barrier system demonstrating the feasibility of translating natural growth strategies into multifunctional infrastructural designs.

Objectives of the Study

In an international context marked by the urgency of integrated, sustainable transitions, reflected in initiatives such as the UN 2030 Agenda, the European Green Deal, and the New European Bauhaus, this research seeks to offer a design-led contribution to the discourse on coastal resilience.

The aim of the study is to explore the potential of bio-inspired geometries for the development of next-generation coastal barriers. Through a top-down design approach, the project identifies critical challenges and opportunities in wave energy dissipation, abstracts key functional traits from biological models, and translates them into simplified yet scalable prototypes. These are then tested under controlled conditions to evaluate their capacity for wave transmission, reflection, and dissipation.

This work is part of a broader design vision: the speculative construction of a "submerged forest", composed of artificial yet bio-integrated barriers that protect and regenerate the marine ecosystem. In this vision, technical performance is not detached from ecological and cultural significance but fully embedded within it.

Three prototypes were developed and experimentally tested to assess their hydrodynamic efficiency. This methodological path involved critical evaluation of biological strategies, patent precedents, and structural feasibility within an interdisciplinary research environment bringing together designers, engineers, and marine biologists within the Department of Engineering at the University of Campania "Luigi Vanvitelli."

The result is not merely a sequence of experiments, but the formulation of a design ontology grounded in invention. The project engages with new "cultural, technological, social, and mental landscapes," as Capece et al. (2019) suggest, recasting the act of invention not as a terminal goal, but as an interpretive and generative tool. The Design for Patent framework becomes both a lens for understanding complexity and a method for structuring innovation.

Ultimately, the study proposes a set of preliminary solutions that aim to integrate wave energy dissipation, ecological permeability, and material adaptability into a unified system. These prototypes demonstrate the potential of a design practice that is not only responsive, but visionary, which are capable of navigating the intersections between environmental urgency and creative possibility.

Methodology, design development

This research explores a bio-inspired approach as a critical and creative framework for rethinking coastal infrastructures. Nature, understood not as a mere aesthetic reference but as a systemic and intelligent source of knowledge, becomes both model and mentor in the development of multifunctional and ecologically integrated solutions (Chayaamor-Heil et al., 2023).

This paradigm is particularly relevant in the design of coastal barriers, where the need for protection intersects with the opportunity to generate habitats and foster biodiversity (Perricone et al., 2023; Stachew et al., 2021).

From a general methodological standpoint, translating natural strategies into design applications involves five core phases (Figure 1):

- 1. Problem Definition: Understanding the design needs and constraints; identifying the specific challenges to be addressed.
- 2. Identification of Biological Strategies: Studying natural models (organisms and ecosystems) to recognize relevant strategies in similar contexts.
- 3. Abstraction of Functional Mechanisms: Extracting key characteristics or mechanisms and converting them into applicable design principles.
- 4. Transfer: Contextualize and adapt the abstracted models to the designing of new artefacts
- 5. Development and Evaluation: Designing and assessing proposed solutions in terms of performance and feasibility, including modeling and testing activities (Perricone et al., 2024).

The project unfolds through a design-driven methodology that merges environmental sciences, sustainable engineering, and industrial design. At its core lies the reinterpretation of natural logics biological structures, adaptive mechanisms, and ecological strategies into engineered artifacts. This translation is not imitative but interpretative, requiring abstraction, critical framing, and contextualization. The process begins by identifying the ecological and infrastructural challenges posed by increasing coastal erosion particularly in contexts like Italy, where over 1,000 km of coastline are currently exposed to erosive dynamics (ISPRA, 2022). These areas are often environmentally and socioeconomically fragile, and conventional engineering responses have proven insufficient or unsustainable, both in terms of material impact and spatial consequences.

Traditional coastal infrastructures, such as seawalls, groins, and rubble-mound breakwaters, are typically rigid, mono-functional, and materially intensive. While effective in wave attenuation, they often introduce new environmental disturbances and lack the adaptive capacity required in the face of climate change. Their homogeneity reduces habitat complexity and may inhibit marine biodiversity, even encouraging the proliferation of invasive species (Bulleri et al., 2010; McLachlan et al., 2018). Moreover, their construction and maintenance involve high resource consumption and significant CO_2 emissions, raising questions of long-term ecological and energetic viability.

In contrast, the bio-inspired perspective proposes an alternative mode of thinking: one in which design is informed by nature's capacity for resilience, interdependence, and multifunctionality. From a methodological standpoint, the project follows a top-down trajectory, beginning with a critical analysis of context and proceeding through

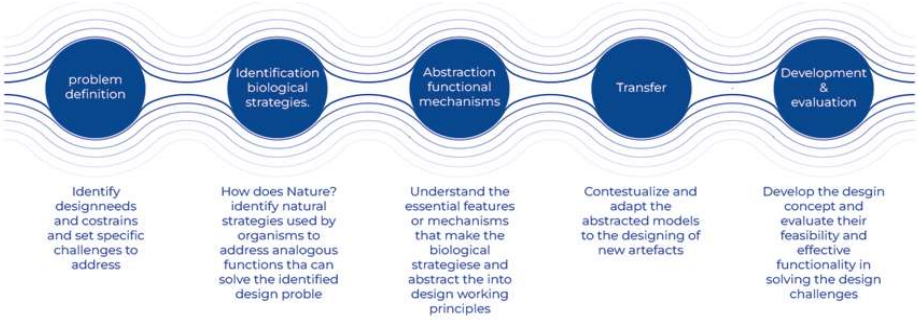

Figure 1. This diagram shows the phases followed in the bio-inspired design process.

the exploration of natural analogues. The abstraction of biological principles such as surface modulation, porosity, modular growth, and dynamic feedback is then rearticulated through design. This process leads to the conceptualization of a new generation of coastal devices that are not only protective, but also regenerative, porous to flows (hydrodynamic and ecological), and compatible with local ecosystems.

A review of existing technologies, including both traditional breakwaters and more recent hybrid solutions, highlights the limitations of current systems. Several patented designs such as WO2013081352A1 (2012) and US4818141 (1989) illustrate standardized approaches based on modular concrete units engineered for wave dissipation. Despite their structural efficiency, these systems often rely on precise calibrations and are vulnerable to environmental changes. Their rigid geometries and impermeable bodies contrast sharply with the complexity of marine systems. Likewise, innovations that integrate wave energy harvesting such as US8004105B2 (2011) or EP3078844B1 suggest a shift toward multifunctionality, but remain constrained by technological complexity, limited permeability, and challenges in maintenance and adaptability.

In summary, both categories, traditional coastal defenses and hybrid energy-generating systems, highlight the urgent need for a new generation of multifunctional, adaptable, and ecologically integrated solutions.

The design hypothesis developed here seeks to overcome these criticalities through a systemic and responsive design logic. Rather than imposing static forms onto dynamic environments, the aim is to create infrastructural systems that interact with marine processes, encouraging sediment deposition, biotic colonization, and energy dissipation through form and materiality. The result is not a finished object but an open system: modular, repairable, and ecologically embedded. It is precisely this convergence between design culture, ecological intelligence, and material ethics that defines the project's contribution to contemporary discourse on resilient infrastructures.

Ultimately, the bio-inspired breakwater conceived through this methodology does more than resist waves: it proposes a new relational model between human infrastructure and natural systems. One that is not extractive, but co-productive.

Bio-Inspired strategy and design development

Rethinking coastal protection in the face of climate intensification, erosion, and habitat loss demands a radical shift from inert engineering to responsive, living systems. Natural environments have long embodied resilient strategies of adaptation, protection, and regeneration. Marine ecosystems such as coral reefs, oyster beds, mangrove forests, salt marshes, and seagrass meadows stand out as sophisticated infrastructures shaped by evolution over geological time scales (Perricone et al., 2024). Far from being passive landscapes, these systems actively modulate hydrodynamic forces, stabilize sediments, and enhance biodiversity while also providing essential ecosystem services like carbon sequestration, water filtration, and local climate regulation (Narayan et al., 2016; Barbier, 2012).

Within this ecological repertoire, seagrass meadows emerge as especially relevant models for bio-inspired design. These submerged plant systems such as Posidonia oceanica, endemic to the Mediterranean have adapted morphologically and physiologically to the marine photic zone over 70 million years. Anchored by dense networks of roots and rhizomes, they form expansive underwater carpets capable of trapping sediments, slowing currents, and dissipating wave energy along the water column. More than biological organisms, these systems act as ecological engineers: enhancing seabed stability, offering habitat to marine life, and acting as dynamic buffers between sea and shore (Perricone et al., 2023; Ondiviela et al., 2014).

What makes seagrasses particularly compelling as design analogues is their dual role structural and ecological. Their distributed, flexible geometries interact fluidly with water, altering flow without resisting it, transforming motion into equilibrium. In contrast to rigid barriers, these systems absorb and adapt. Emulating them suggests more than biomimicry: it opens the door to a new design ethic one that envisions infrastructure as porous, adaptive, and coexistent with the ecosystems it occupies.

From this theoretical and ecological framework, the research moves toward design translation. Hydrodynamic studies of seagrass meadows have identified several critical principles: submerged vegetation dissipates wave energy through flow redirection and turbulence induced by friction. Factors such as plant density, biomass, leaf stiffness, and the submergence ratio (plant height relative to water depth) are key in determining the extent of attenuation (Ondiviela et al., 2014; Cavallaro et al., 2018). Meadows with greater vertical occupation of the water column demonstrate more effective reduction of wave forces (Fonseca et al., 1992; Augustin et al., 2009; John et al., 2016). Notably, John et al. (2016) identified the most influential parameters in wave transmission as relative plant height, meadow density, and the width of vegetated areas wider meadows reducing wave run-up by up to 41%. These insights were abstracted and synthesized into a set of bio-inspired design hypotheses (Figure 2).

The objective was not to replicate natural forms, but to distill their functional logic into engineered components for coastal protection systems that move beyond mere resistance. The proposed solutions aim to merge defense, adaptability, and environmental performance through modular structures that integrate seamlessly with dynamic marine environments.

Among the features of the proposed system are:

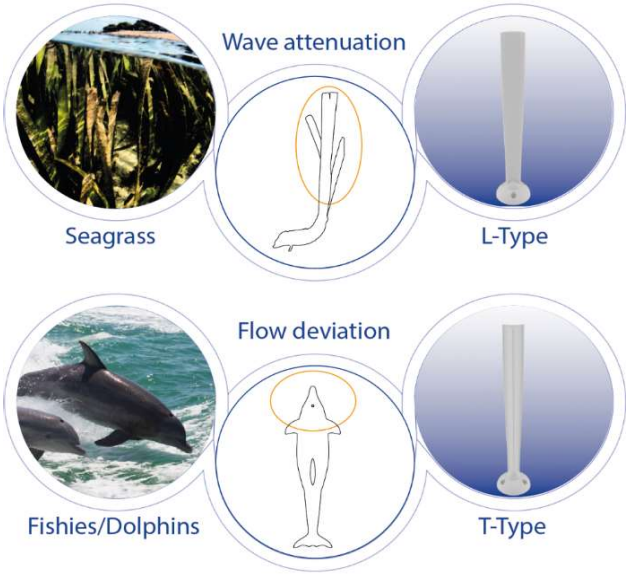

Figure 2. This figure shows the marine organisms that inspired the shape and function of the breakwater modules.

- The conversion of omnidirectional wave motion into kinetic or electrical energy, allowing for renewable energy generation in varying sea conditions.
- Adaptability and reversibility, with installation possible on different seabed types.
- Low-impact assembly, ease of disassembly and relocation.
- Strong ecological integration, encouraging colonization and sediment stability.
- The ability to attenuate wave energy, particularly from storm surges and extreme marine weather events.

The research situates itself within the field of maritime infrastructure design, seeking to reconceive elements like seawalls and breakwaters not as impermeable monoliths, but as responsive ecotechnical systems. The project led to the development of four primary prototype morphologies, informed by the biomechanical principles of seagrass meadows and hydrodynamic efficiency:

- L-Type: Inspired by the flat, elongate shape of Posidonia leaves, designed for low resistance and high sediment interaction.

- T-Type: Characterized by a triangular cross-section, optimized to redirect wave flow and enhance impact resistance.
- HT-Type: A hybrid variant of the T-Type, integrating a circular upper module to increase visibility and enable the mounting of environmental sensors or navigational instruments.
- C-Type: A simplified cylindrical geometry developed for controlled testing of drag and flow behavior.

The T-Type model, in particular, draws inspiration from the streamlined shapes of aquatic organisms such as dolphins and pelagic fish, whose elongated bilateral morphologies reduce drag and allow rapid, forceful reentry into water (Perrin et al., 2009; Jung, 2021). These principles were adapted into geometric forms capable of dissipating wave energy while resisting structural fatigue.

Experimental Configuration and Data Analysis

All prototypes were developed using Rhinoceros 3D (v7) and fabricated through Fused Deposition Modeling (FDM) with an Anycubic Chiron 3D printer. The selected material PETG (Polyethylene Terephthalate Glycol) was chosen for its mechanical strength, chemical resistance, thermal stability, and recyclability, aligning with the project's circularity goals. The models were printed at a 1:25 scale, respecting Froude similarity for hydrodynamic testing, with a layer height of 0.20 mm, 20% infill density, and a print speed of 50 mm/s.

This first phase of experimental development marks a critical step in the exploration of bio-integrated infrastructures systems that do not dominate the marine environment but dialogue with it, adapting to its dynamics, and, in doing so, transforming the role of coastal defense into one of ecological collaboration.

The geometric and dimensional specifications of the prototypes are detailed in Figure 3 and Table 1

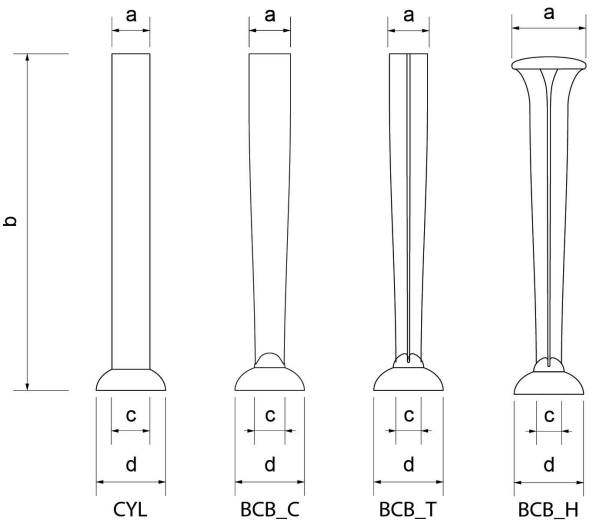

Figure 2. Model prototypes: technical drawing indicating (a) upper width, (b) height, (c) lower width, and (d) base diameter. Corresponding dimensions are provided in Table 1.

Table 1. Main geometrical parameters of the tested models. All measurements are given in millimetres (mm).

	a mm	b mm	c mm	d mm
CYL	27	250	27	50
BCB_C	30	250	20	50
BCB_T	27	250	18	50
BCB_H	53	250	18	50

The models were subsequently tested in a laboratory setting to evaluate their hydrodynamic performance and their effectiveness in dissipating wave energy. The results of these experiments are discussed in the following sections.

In a time marked by accelerating erosion and intensifying climate phenomena, the defense of coastal landscapes can no longer rely on inert, monolithic infrastructures. The experimental work presented here explores an alternative line of inquiry: the testing of bio-inspired, modular geometries developed through digital fabrication and deployed under controlled wave conditions. Conducted at the Maritime Engineering Laboratory of the University of Campania "Luigi Vanvitelli," the research examines the hydrodynamic behavior of prototypes designed not to resist nature, but to engage

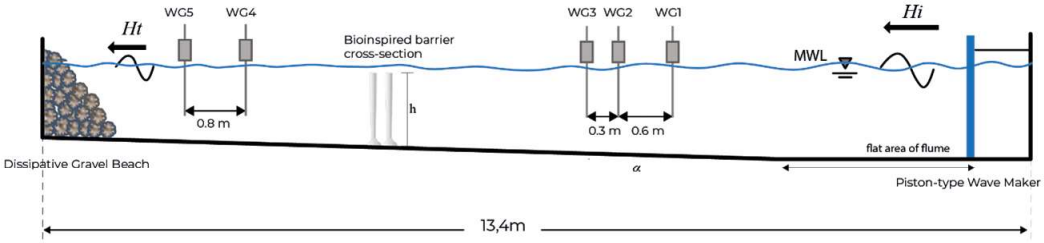

Figure 4. Schematic representation of the wave flume and the experimental setup.

Figure 5. Photographic view of the laboratory setup and model arrangement.

with its fluid logics. The experimental apparatus was set up within a 13.4 m long, 0.8 m wide, and 0.6 m deep wave flume, featuring a non-erodible bottom and a 3 m flat initial section followed by a sloped seabed inclined at a 1:22 gradient, simulating nearshore bathymetry (Figures 4 and 5).

A piston-type paddle system, controlled via AwaSys software (v5, Aalborg University, 2010), generated regular and irregular wave conditions with active reflection absorption. A gravel beach placed at the downstream end dissipated residual wave energy and minimized re-reflections. Open lateral boundaries ensured hydrodynamic circulation behind the models, avoiding artificial pressure buildup.

Wave data was collected through a system of five resistive gauges positioned according to Klopman and van der Meer's method (Klopman et al., 1999), enabling the calculation of incident and reflected components using the Mansard and Funke separation technique (Mansard & Funke, 1980). Sampling was conducted at 30 Hz, and the transmission coefficient (Kt) served as the principal metric for evaluating wave attenuation across all configurations.

Six experimental configurations were tested, each composed of sixteen printed units mounted on a CNC-milled, perforated steel plate (800 mm × 439 mm × 20 mm). The T-Type and HT-Type morphologies, based on a triangular profile, were also tested in inverted orientations (rT-Type and rHT-Type), with their bases rotated 180° toward the incoming wave (Figure 6).

These modifications were introduced to study the effect of geometric directionality on performance.

Four distinct wave regimes were generated:

- Weak regular waves (Hi < 0.06 m), simulating low-energy sea states.
- Moderate regular waves (0.07 m < Hi < 0.14 m), corresponding to average energy conditions.
- Extreme regular waves (0.15 m < Hi < 0.20 m), just below breaking thresholds.
- Storm irregular waves (Hi = 0.14 m), with peak periods of 0.8, 1.2, and 1.6 seconds, based on a JONSWAP spectrum (γ = 3.3).

This classification was conceived to replicate the variability of real-world marine dynamics, from calm to turbulent. The wave steepness (s), defined as the ratio of height to wavelength, was adopted as a key interpretive parameter in assessing energy transformation and dissipation processes.

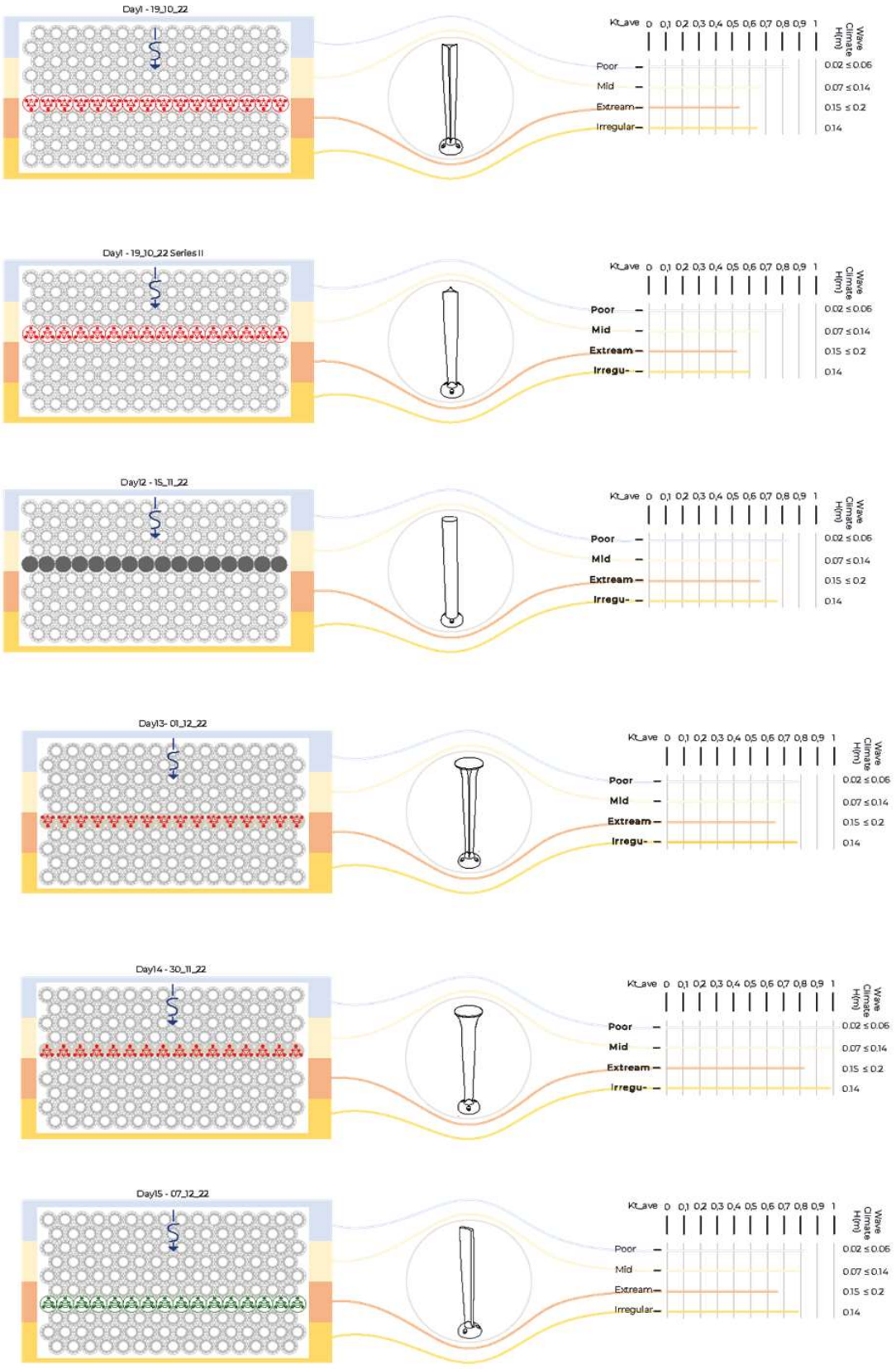

Figure 6. Schematic diagram of the model distribution set-up in the different configurations and representation of the data collected.

The results (Figure 6) revealed clear differences in performance across morphologies. The C-Type, cylindrical and symmetrical, behaved as expected: consistent and relatively unresponsive to varying wave energies, serving as a neutral hydrodynamic reference. The T-Type consistently demonstrated the lowest Kt values, effectively dissipating wave energy across all conditions. Conversely, the inverted rT-Type showed a degradation in performance, highlighting how orientation affects the interaction between form and flow.

The HT-Type, featuring a cylindrical upper head, showed decreased efficiency compared to its base form an effect amplified in the rotated configuration (rHT-Type), where transmission increased by 18%. This suggests that the added mass or altered turbulence patterns introduced by the upper element may disrupt the flow redirection mechanisms fundamental to its intended function.

When compared with traditional rock breakwaters which average Kt values between 0.41 and 0.42 under similar wave regimes (Hassanpour et al., 2023) the bio-inspired prototypes yielded promising results. The rT-Type, for instance, achieved average transmission coefficients of 0.65 under weak, moderate, and extreme conditions, and 0.61 during storm simulations. This is particularly significant given that only a single row of units was deployed, whereas conventional systems require substantial material volumes and seabed coverage to perform similarly.

Beyond numerical comparisons, the behavior of the models points to an adaptive logic. In low-energy conditions, higher transmission may be ecologically beneficial: it supports water exchange, sediment transport, and oxygen circulation, helping to avoid stagnation and allowing natural processes to persist. Under storm conditions, the sharp drop in Kt values ensures effective wave attenuation, reducing the risk of coastal flooding and erosion.

The poor performance of the HT-Type suggests a need for further morphological optimization. One hypothesis attribute this to the interference generated by the upper cap, which may alter pressure fields and inhibit desired turbulence patterns at the model's base. Future iterations will explore alternative head forms and sectional voids to improve hydrodynamic responsiveness.

A critical dimension of the study is the volumetric and environmental efficiency of the proposed system. Conventional breakwaters are materially intensive and ecologically invasive. The modularity, reduced mass, and reversibility of the prototypes presented here open a path toward a new generation of eco-technical infrastructures deployable, maintainable, and compatible with nature-based solutions. As Davis et al. (2006) note in the context of San Diego Bay, the removal of rigid dams to restore tidal marshes can achieve erosion control while fostering habitat regeneration.

Integrating such bio-inspired components with soft engineering strategies such as beach drainage systems (Damiani et al., 2009) could significantly reduce the ecological cost of wave control structures, while expanding their functionality and responsiveness.

Importantly, the results of this experimental phase provided the empirical foundation for the development of a patentable invention, which received a positive international search report on all three evaluative criteria. Yet as Cocco (1985, p. 151) reminds us:

"Invention is the idea of practical interest, which can normally be patented; it is essentially the product of theoretical activity."

This project does not aim merely to produce a form, but to frame a new epistemology of infrastructure one in which performance is not just structural, but ecological and systemic. A model not of resistance, but of resonance with the living fluidity of the marine environment

Conclusions: Toward a New Culture of Coastal Design

This study explores the development of bio-inspired models for coastal protection, from the initial literature review and conceptual design to prototyping, testing, and evaluation. Through this trajectory, the project sought to contribute meaningfully to the field of design-led solutions for shoreline defense, assessing their effectiveness in terms of wave energy attenuation, environmental impact reduction, and potential for integration into sustainable and socially accepted infrastructures.

The exploration of multifunctional coastal protection systems at the intersection of industrial design, marine biology, and coastal engineering, represents a frontier where ecological logic and technological invention converge. The results offer tangible evidence that a nature-inspired design approach can rival, and in some cases outperform, conventional rock breakwaters not only in hydrodynamic efficiency but also in adaptability, volume reduction, and potential for ecological integration.

The comparative performance of the tested prototypes is significant. The T-Type model consistently yielded the lowest wave transmission coefficients (Kt), demonstrating an effective capacity to dissipate energy under both regular and storm wave conditions. Its rotated variant (rT-Type), while slightly less efficient, still performed markedly better than baseline geometries. In contrast, the HT-Type and rHT-Type models revealed limitations, likely due to interference generated by their upper cap elements—raising important questions about how additional volumetric features impact flow behavior. The C-Type, serving as cylindrical control, and the L-Type, with leaf-like biomorphic geometry, showed consistent and predictable behavior but lower energy attenuation.

These findings underscore the potential of bio-inspired geometries not only as experimental artifacts but as prototypes for patentable systems. The models served as the foundation for an industrial invention that has received positive evaluation across all patentability criteria demonstrating the compatibility of design research with innovation-driven processes.

However, invention here is not understood exclusively as novelty or technological optimisation. Design should also be understood as a creative act of invention, a form of theoretical and practical activity that identifies emerging needs and reconfigures the relationships between form, function and performance of materials (Buono M. 2018). This project has embraced this philosophy, prioritising original thinking, ecological intelligence and process-based innovation.

The integration of parametric design, additive manufacturing, and experimental testing proved essential in bridging abstract biomimetic principles with engineered realities. Through this process, complex natural behaviors such as turbulence modulation, sediment interaction, and permeability regulation, were translated into tangible morphologies, revealing a new language of form that is neither ornamental nor rigidly technical, but performative.

Compared to traditional breakwaters, bio-inspired systems show clear advantages in spatial economy, reversibility, and environmental compatibility. Their permeable structure supports natural flows, helping to avoid anoxic stagnation while allowing for seasonal adaptability. Such systems may also be combined with other soft protection strategies, as suggested by Levy et al. (2022) and Damiani et al. (2009), creating hybrid approaches where wave energy is absorbed offshore while beach health and sediment transport are preserved.

Importantly, a preliminary model has been proposed to correlate average Kt values with prototype geometry and surface friction mechanisms, offering a first step toward predictive modeling of future systems. This could inform the macroscale design of bio-integrated infrastructures, tailored to local hydrodynamics and ecological conditions.

However, further refinement particularly in terms of ultrastructural analysis, material composition, and biotic compatibility, will be needed to translate laboratory insight into real-world applications.

The work demonstrates that multifunctional, bio-inspired structures can serve as catalysts for a new culture of coastal engineering one did not root in resistance, but in resonance with the systems it seeks to protect. It affirms the power of design not merely as a mode of making, but as a tool for reimagining how human interventions relate to the planetary scale.

In conclusion, a nature-based design philosophy offers a promising paradigm shift. It suggests a future in which coastal defenses are no longer imposed upon ecosystems, but emerge from within them, shaped by their rhythms, informed by their intelligence, and integrated into their complexity. This vision demands more than technical acumen; it requires collaborative action, inclusive planning, and a political will attuned to long-term resilience.

As we confront increasing uncertainty and ecological vulnerability, design must reassert its role not as a passive responder, but as a proactive agent of transformation. The protection of coastlines, like the regeneration of life itself, must become a shared project, capable of blending innovation with care, structure with adaptation, and vision with responsibility.

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Research article

Beyond Boundaries: User-Centered Product Design and Validation of a Mechanical Female Left Arm Low-Elbow Prosthesis for CrossFit Training

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Abstract

The objective of this work was to design and preliminarily validate a mechanical prosthesis for a female patient with below-elbow agenesis, emphasizing a user-centered product design approach. The device is intended to assist in CrossFit training, enabling dynamic movement while improving muscular balance and quality of life. The project involved the design of the forearm structure using polymer matrix composite material (epoxy resin) reinforced with laminated carbon fiber (prepreg), excluding the hand and wrist mechanisms from the current scope.

SolidWorks software was employed for mechanical design and simplified validation, while composite material properties were estimated through the micromechanical Chamis model using eLamX software. Despite the innovative integration of CAD tools, important simplifications were necessary, particularly regarding dynamic loading assumptions and socket coupling, which are acknowledged as limitations.

This work demonstrates the potential of multidisciplinary collaboration in prosthetic development, although further research and testing are required before manufacturing a fully operational device. Ethical approval was obtained from the relevant institutional review board, and the patient's informed consent was secured in accordance with the Declaration of Helsinki.

Key words: Simulation, Product design; Prototype; Product development; Case Study; Socian innovation; Customization

Introduction

Left arm agenesis represents a rare congenital anomaly occurring during embryonic development. This condition results in a unilateral or bilateral disruption of either the proximal or distal growth of the upper limbs (Dohin et al., 2016). Consequently, individuals affected by this congenital defect exhibit either complete or

partial absence of the left upper limb from birth. Clinically, this condition commonly presents as a transverse defect resembling a transradial amputation (below the elbow, as depicted in Figure 1), characterized by adequate soft tissue coverage of the distal portion and the presence of knuckles or nodules, referred to as mamelons.

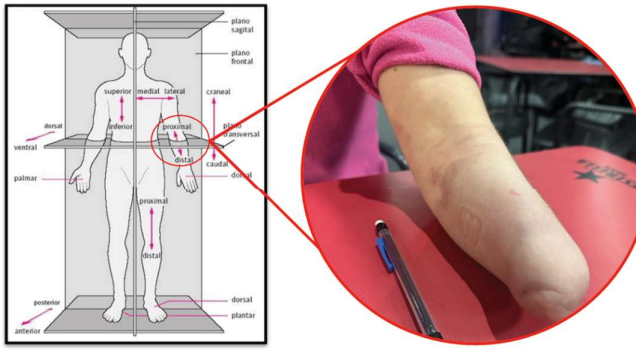

Figure 1. Transverse defect, transradial amputation type [Own source]

This congenital abnormality can result from genetic factors, environmental influences, or a combination of both (Dolk et al., 2010). The impact of agenesis on an individual's life can vary significantly, often presenting challenges related to functionality, mobility, and muscular imbalances within the body. Agenesis affects not only physical functionality but also significantly impacts mobility, muscular balance, and the psychological well-being of patients (Dolk et al., 2010). A personalized prosthetic device can greatly enhance users' independence, self-esteem, and participation in demanding physical activities.

Beyond individual cases, upper limb absence affects a substantial portion of the population. According to the World Health Organization, approximately one million limb amputations are performed globally each year, with projections suggesting that this number will increase due to trauma, vascular diseases, and congenital conditions. In Spain, approximately 60,000 individuals are living with some form of amputation (Valero, 2023). However, access to functional prostheses, particularly for sports and active lifestyles, remains extremely limited due to prohibitive costs and low availability in public healthcare systems.

According to the World Health Organization (WHO), access to assistive technologies, such as prosthetic and orthotic devices, remains critically limited worldwide, with only one in ten individuals who require these products receiving them. This significant gap in access is primarily attributed to several interrelated barriers, including the high financial cost of such devices, limited public awareness of their availability and benefits, and a widespread shortage of adequately trained professionals and specialized healthcare services (World Health Organization, 2017). This inequitable distribution of assistive products not only undermines the functional autonomy and mobility of individuals but also generates far-reaching consequences by restricting their opportunities for meaningful social inclusion, active participation in community life, and access to economic activities.

The price of advanced myoelectric prostheses can exceed €40,000, excluding most patients from access to such devices (Belter et al., 2013). Standard prostheses are typically designed for everyday use and cannot withstand the high-intensity, repetitive movements in sports like CrossFit. This creates a clear need for prosthetic solutions that balance mechanical robustness, cost-efficiency, and athletic usability.

Mari Carmen, a 34-year-old woman born with left forearm agenesis, seeks to improve her athletic performance in CrossFit —a sport characterized by dynamic, high-intensity functional movements. This real-world case underscores the urgent need for prosthetic solutions designed from a user-centred perspective, ensuring alignment between the functional goals of the patient and the mechanical performance of the device.

From a product design perspective, such needs call for approaches that go beyond traditional biomechanical engineering and consider human-based design methodologies, engaging patients in the development, iteration, and validation of prosthetic components(Cordella et al., 2016). The active involvement of the user

ensures that the prosthesis accommodates their daily and sporting habits, muscular asymmetries, and comfort expectations, thus improving long term adoption and physical performance.

Incorporating sustainable materials and manufacturing processes into prosthetic design aligns with global efforts to achieve the United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being) and SDG 12 (Responsible Consumption and Production). The use of biodegradable materials, such as polylactic acid (PLA), and recycled components can reduce environmental impact and promote a circular economy in prosthetics manufacturing in daily activities usages (Orthotic & Prosthetic Centers, 2023).

Furthermore, advancements in 3D printing technology have enabled the production of customized prosthetic limbs that are both cost-effective and environmentally friendly. By utilizing sustainable materials and additive manufacturing techniques, it is possible to create prostheses that meet individual needs while minimizing waste and resource consumption (The Guardian, 2017).

The main objective of this work is to design and preliminarily validate the forearm structure of a mechanical prosthesis to support CrossFit training, using composite materials and commercial CAD tools. This initial development phase explicitly excludes the design of the hand and wrist (socket) mechanisms, which will be addressed in future work.

The scope of the study is limited by necessary modeling and simulation simplifications, particularly in dynamic loading conditions and socket connection issues. These constraints are acknowledged throughout the document to ensure methodological transparency.

Methodology

Physical acquisition of design parameters:

Before initiating the digital modeling process, physical measurements were conducted on both arms of the patient. On the right arm, three radial reference marks were placed distally: one at 40 mm from the condyle, and two additional marks at 100 mm intervals along the forearm (Figure 2.a). The total distance from the condyle to the ulna's head was recorded as 240 mm. A similar procedure was followed for the left residual limb ("stump"), where two marks were placed at 40 mm and 100 mm from the condyle (Figure 2.b), with a total length of 170 mm.

Circumferential measurements at each mark were performed to estimate corresponding diameters of right arm (d_E, d_I, d_i) and left arm (d_i, d_E), as illustrated in Figure 3 and summarized in Table 1. These geometric parameters, directly obtained from the patient, were cross validated with 3D scan outputs to ensure consistency, reducing measurement error to within ±3% across key dimensions.

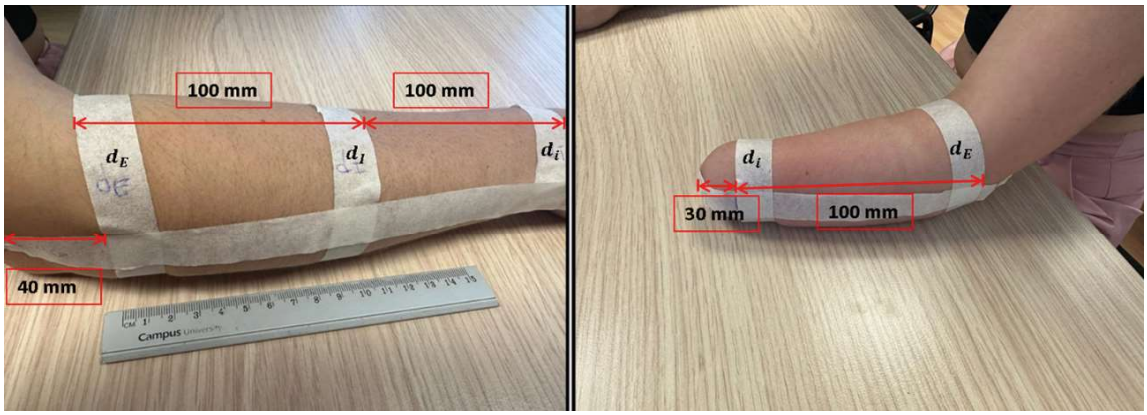

Figure 2. Placement of reference marks on a) the right arm b) the left arm [Own source]

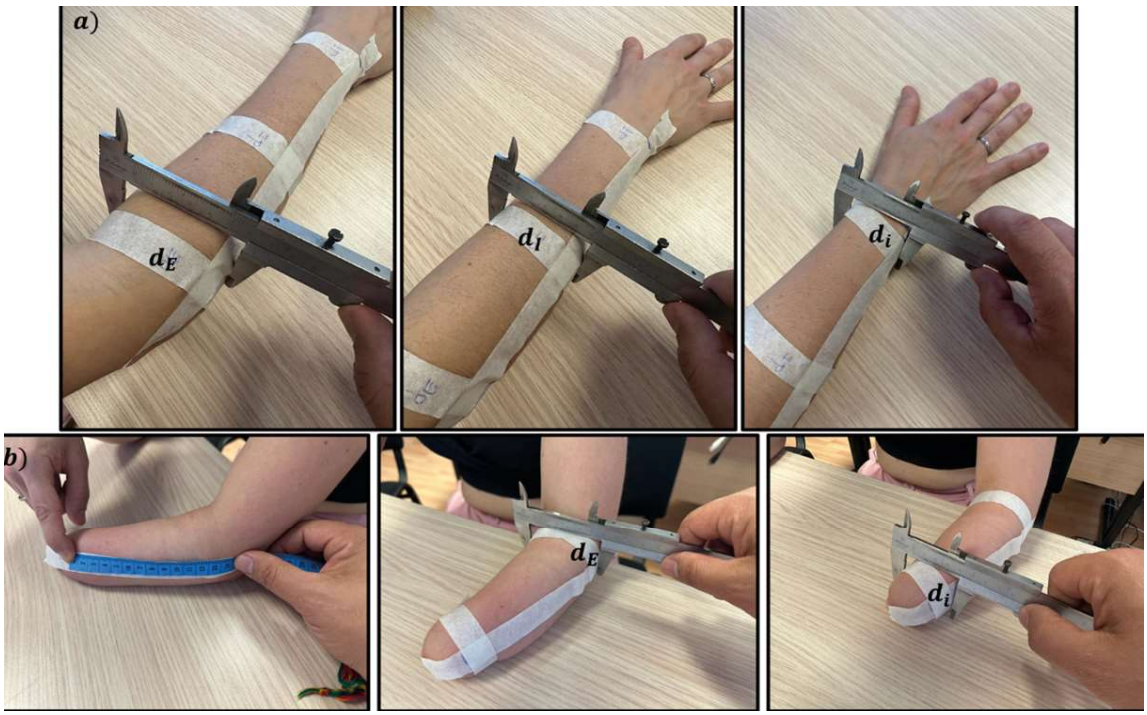

Figure 3. Measurement of reference circles on a) the right arm b) the left arm [Own source]

amputation type [Own source]

Table 1. Summary of calculations and measurements of design parameters [Own source].

		RIGHT ARM			LEFT ARM		
		d_E	d_I	d_i	d_E		d_i
FORMULAS		RESULTS (mm)					
Perimeter	$P = 2\pi r$	240	208	149	214		140
Radious	$r = \frac{P}{2\pi}$	38,2	33,1	23,7	34,1		22,3
Diameter	$d = 2r$	76	66	47	68		44
		Condyle-wrist length (mm)			Condyle-stump length (mm)		
		240			170		

Digital acquisition of design parameters:

In addition to manual measurements, a 3D scan using Polycam LiDAR technology was conducted to capture the morphology of both arms. While 3D scanning ensures greater spatial resolution, the complementary use of 2D measurement was justified for critical dimensions such as reference diameters, given the potential noise and irregularities in point cloud data (especially at edges and occluded zones). This hybrid acquisition approach balanced accuracy and data processing efficiency. Figure 4 shows the raw scan results and the processing steps taken to delimit the working volume before importing the mesh into SolidWorks.

Prior to embarking on the modeling process for the prosthetic components, it was crucial to calibrate the scale of the digital format to correspond with real dimensions. Utilizing the compiled dataset, as outlined in Table 1, the Condyle-Wrist Length was determined, establishing the distance between d_E and d_i at 200 mm.

Subsequently, utilizing the measurement tool within SolidWorks on the data mesh, a measurement of 0.1998 mm was obtained between identified points d_E, and d_i. A scaling factor of 1000% was applied to match the real anatomical distance of 199.8 mm as shown in Figure 5.

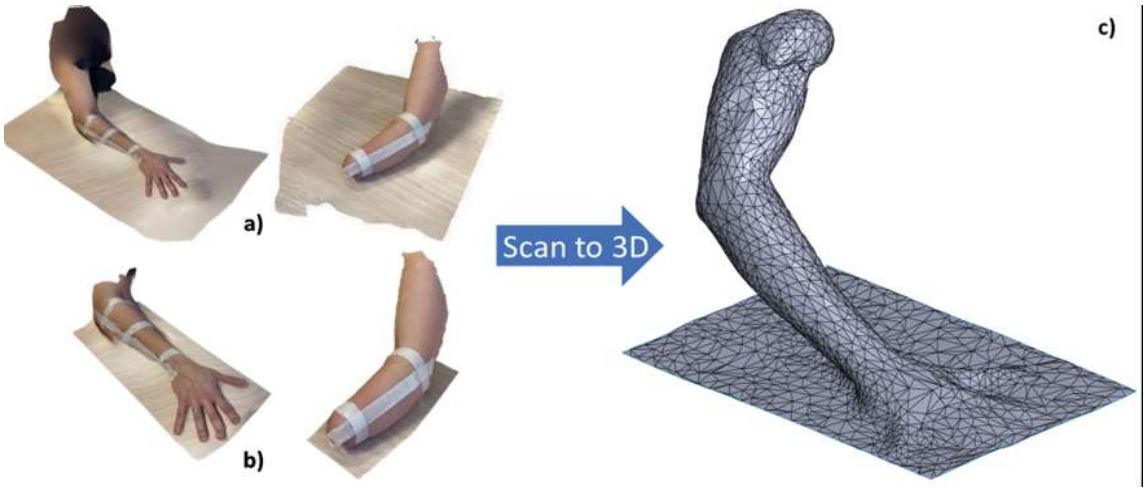

Figure 4. a) Scanning result of both extremities. b) Result of the maximum delimitation of the working volume. c) Imported data into SolidWorks after pre-processing treatment. [Own source].

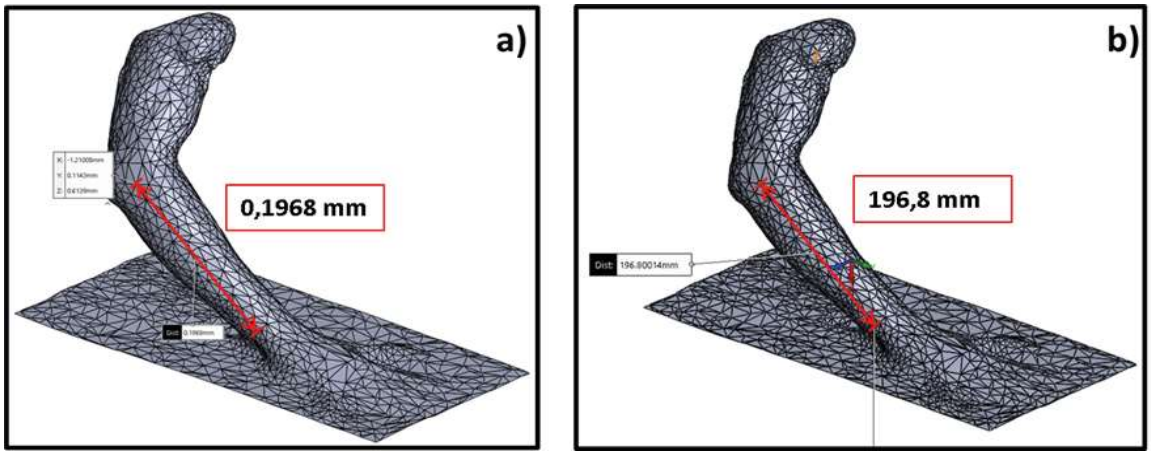

Figure 5. a) Reference distance before scaling adjustment, b) Reference distance after a 1000% scale adjustment [Own source].

Mechanical design:

Specifications regarding the mechanical stress characteristics for the forearm were established. Given the novel and pioneering nature of this project, there are no existing precedents or available data in scientific or sports literature concerning the levels and types of stress to which a prosthesis intended for CrossFit exercises may be subjected. Therefore, for this design stage, the geometric parameters obtained from the patient were coupled with the following mechanical parameters. These parameters represent a collaborative estimation by Mari Carmen, based on her sports objectives and training frequency.

For design and simulation in SolidWorks, several assumptions and simplifications were made regarding the workload on the prosthesis.

To assess the response of the prosthesis during pull-up exercises, it was assumed that the component would undergo pure tension, considering a maximum patient weight of 90 kg.

Traction Force: $\left[\left(\frac{70\,kg}{2}\right) * 9.81\,{}^{m}/_{s}\right] = 340\,N.$

When evaluating the performance of the prosthesis during devil press, push-ups, military press, and handstand exercises, it is assumed that the component will undergo pure compression. This entails a maximum weight handling capacity of 35 kg per arm.

Compression Force : $\left[\left(\frac{90\,kg}{2}\right) * 9.81\,{}^{m}/_{s}\right] = 440\,N.$

Other exercises (bicep curls, kettlebell swings) were acknowledged to involve combined torsion and bending loads but were excluded at this stage.

While it is recognized that dynamic movements such as pull-ups and push-ups involve complex, time-varying loads, these simplifications were necessary to

enable preliminary static validation within SolidWorks. Further dynamic simulation studies are recommended for future phases to ensure safety under real CrossFit conditions.

Estimation of the mechanical properties of the laminae by means of eLamX:

The mechanical properties of a lamina of epoxy resin polymer matrix composite material reinforced with long carbon fibers were derived from the individual characteristics of each constituent component using eLamX free software from Dresden University, based on the Chamis Model, also known as the "Modified Law of Mixtures". The individual elastic properties of the commercial reference XC 130 300g UD Prepreg Carbon Fiber, manufactured by Easy Composites, are summarized in Table 2 as input parameters.

Table 2. Summary of matrix and reinforcement properties [Own with data from Ali &

Epoxy Matrix Data:			T700 carbon fiber reinforcement data		
ρ_m=	1,2	g/cm^3	ρ_f=	1,8	g/cm^3
E_m=	3500	MPa	$E_{\parallel f}$=	379212	MPa
G_m=	1296,2962	MPa	$E_{\perp f}$=	62053	MPa
ν_m=	0,35		$G_{\parallel f}$=	75842	MPa
X_{tm}=	55	MPa	$G_{\perp f}$=	48263	MPa
X_{cm}=	103	MPa	ν_{LTf}=	0,2	
S_m=	55	MPa	ν_{TTf}=	0,25	
v_f=	0,6		X_{tf}=	2500	MPa
			X_{cf}=	1500	MPa

Within the eLamX interface, the material XC 130 300g UD is generated, incorporating the properties outlined in Table 2. The volume percentage of fibers is set at 60%, and the micromechanical Model of Chamis is selected to estimate the combined properties. As a result, eLamX outputs provided elastic constants (E_1, E_2, G_{12}, ν_{12}), which were then imported manually into SolidWorks to define a custom orthotropic material ("XC130 300g UD Prepreg Carbon Fibre") for simulations. This establishes the workflow integration between eLamX and SolidWorks. The combined mechanical properties of the composite sheet are displayed in Table 3 as design parameters.

Table 3. Summary of the estimation of the elastic and resistant properties of the laminae [Own source].

CHAMIS MICROMECHANICAL MODEL					
ρ=	1,56	g/cm^3	G_{xy}=	5.432	MPa
E_x=	228.927	MPa	G_{xz}=	5.432	MPa
E_y=	13.007	MPa	G_{yz}=	5.265	MPa
E_z=	13.007	MPa	X_t=	1.500	MPa
ν_{xy}=	0,26		Y_t=	46	MPa
ν_{xz}=	0,26		X_c=	900	MPa
ν_{yz}=	0,2352		Y_c=	86	MPa
SC=	46	MPa	L_e=	1.350	MPa

The accuracy of the micromechanical estimations was cross validated by comparing graphic ("carpet plot") predictions with Classical Lamination Theory (CLT) results, showing deviations below 4%, which is considered acceptable for preliminary mechanical design stages.

Furthermore, a quasi-isotropic laminate stacking sequence ([0°/45°/-45°/90°] s) was selected to approximate isotropic in-plane behavior, ensuring uniform mechanical response under multidirectional loads.

Graphic estimation of the "quasi-isotropic" of the laminate:

The "quasi-isotropic" point in a laminate set is identified as the stacking sequence that approaches isotropic behavior within the plane. This entails achieving a mechanical response that is uniform in all directions. This is typically accomplished through the selection of a symmetric and balanced stacking sequence. The objective is to evenly distribute the

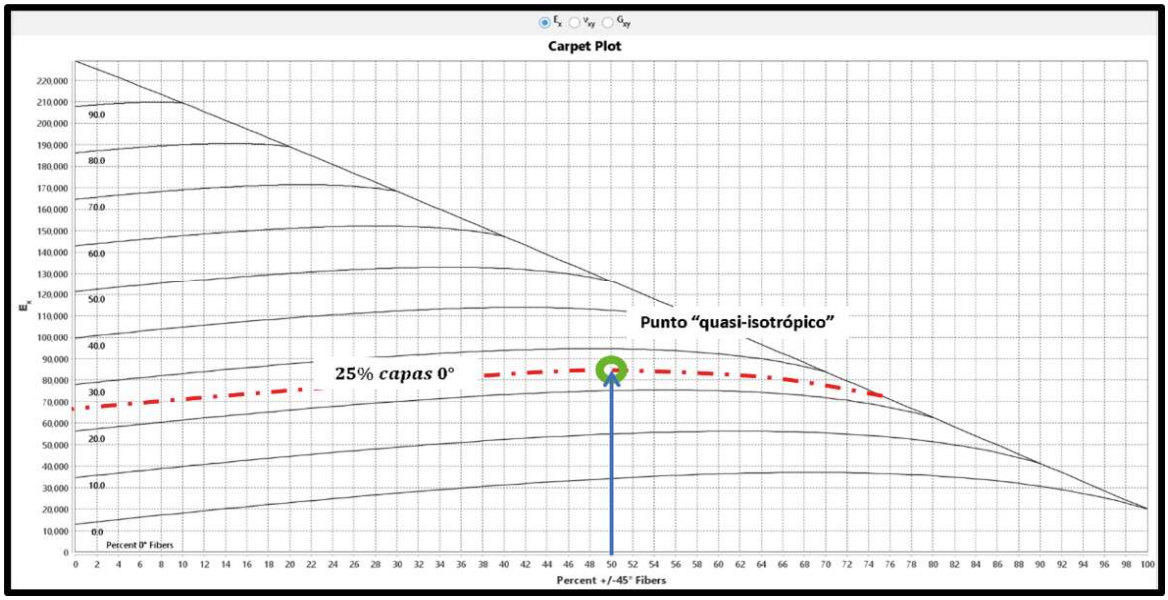

Figure 6. Localization of the "quasi-isotropic" point on the "carpet plot" diagram related to the longitudinal modulus E_x within the laminate family of the specified type $[0_m /\pm 45_n / 90_p]_s$ *[Own source]*

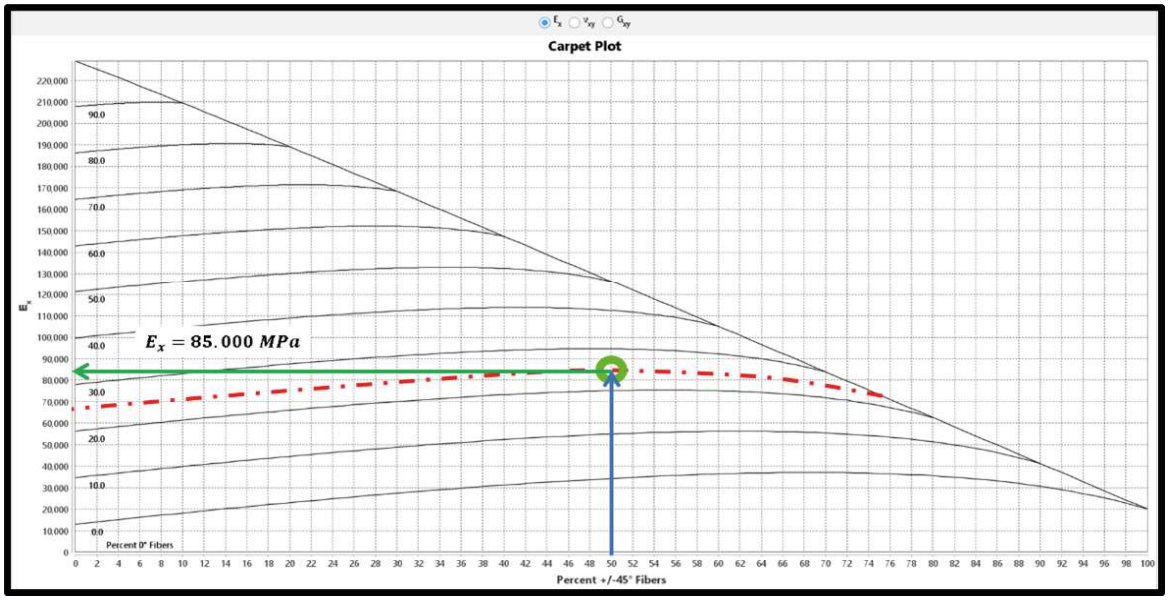

Figure 7. Longitudinal modulus estimation E_x through the "carpet plot" [Own source].

reinforcement orientations throughout the laminate layers, resulting in consistent mechanical properties in multiple directions.

Using the eLamX software, the stacking sequence is designed using the carpet-plot feature.

This feature illustrates three elastic constants: E_x, ν_{xy} and G_{xy} on the x-axis, allowing the selection of the desired property from the options. The order axis depicts the percentage of sheets intended to have an orientation of ± 45°.

In order to ascertain the "quasi-isotropy" point, the laminate structure should feature an equal number of plies/sheets oriented at angles as per the following relationship:

$$\frac{180°}{N+\theta°}$$ where N>3 and θ° represents the initial orientation.

When N=4 and θ°=0°, the relation (1) yields 45°. Thus, to reach the "quasi-isotropic" point, the orientations of the layers must be:

0°, +45°, 90° and 135° (-45°)

The stacking sequence configuration should guarantee an equal number of layers with all the specified angles. Typically, for a stacking sequence:

[0/45/-45/90/90 /-45/45/0]s

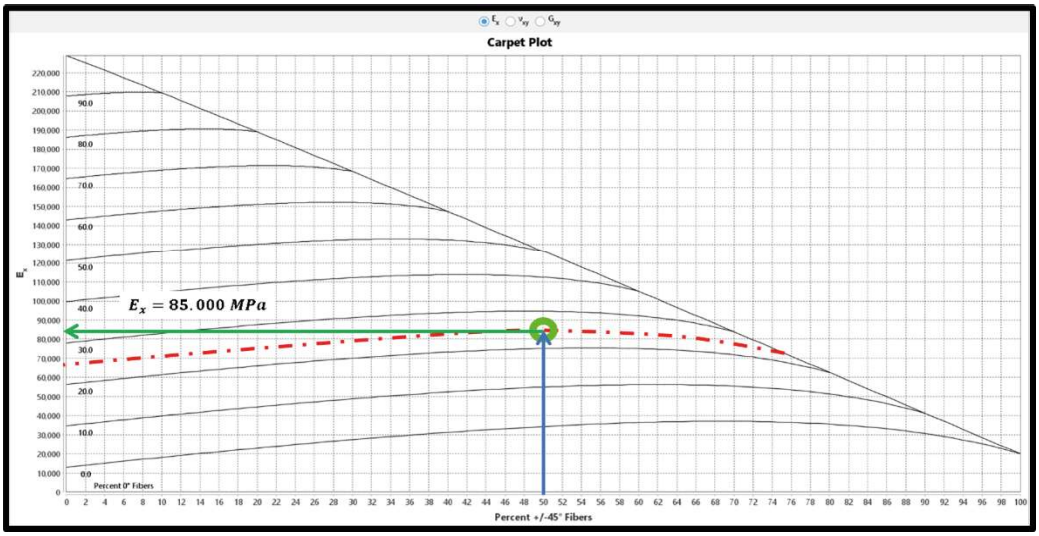

Figure 8. Estimation of shear modulus G_{xy} through the "carpet plot" [Own source].

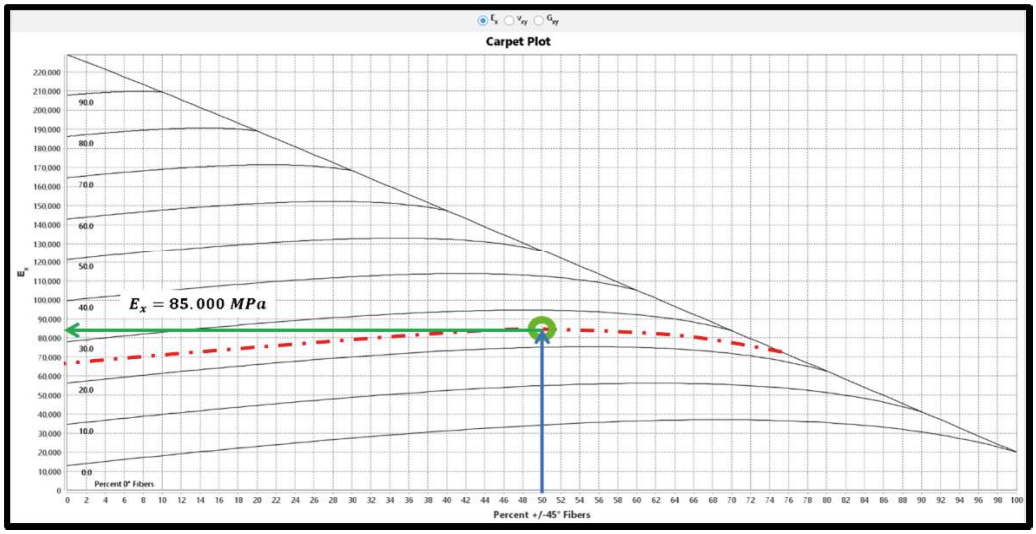

Figure 9. Estimation of Poisson´s ratio ν_{xy} through the "carpet plot" [Own source].

For this laminate family, the "quasi-isotropic" point is determined by the distribution of layers as follows:

25%→0°→ 4 layers

50%→45° and 135°→ 8 layers

25%→0°→ 4 layers

With this information, "carpet-plot" is used as depicted in Figure 6 to locate the point. Under these conditions, a uniform distribution of orientations around the circumference, and designated layer percentages at specific orientations can be asserted that the laminate will demonstrate "quasi-isotropic" properties.

In (Rivas Hernández, 2023), it's noted that the variability in estimating the mechanical properties of a composite laminate between the graphic method (carpet-plot) and the classical lamination theory (CLT) is minimal, and the results obtained through this graphical methodology are deemed acceptably valid. To graphically ascertain the properties of the laminate using the "carpet plot" diagram, for instance, in the case of the longitudinal modulus E_x, a horizontal line (green line) is extended from the "quasi-isotropic" point until it intersects the ordinate axis, as illustrated in Figure 7.

The procedure is replicated to determine the shear modulus G_{xy} and Poisson's ratio ν_{xy}, following analogous steps illustrated in Figures 8 and 9, respectively.

Since the objective was to attain a material with "quasi-isotropic" properties, the longitudinal modulus is identical to the transverse modulus, denoted as $E_x=E_y$. Consequently, Poisson's ratios are also equal, $\nu_{xy}=\nu_{yx}$. Thus, the mechanical properties of a laminated composite material XC 130 300g were estimated graphically. Table 4 presents the results obtained and the comparison with those obtained through Classical Laminate Theory (CLT).

Results

Closure mechanism: As stated from the outset, the present work exclusively focuses on the design and preliminary validation of the forearm prosthetic structure, excluding from its scope the detailed engineering of the hand mechanism and the socket coupling. These components, although critical for the final functionality of the prosthesis, were considered out of reach for this initial phase and are intended to be developed in future work.

Recognizing the need for mechanical simplicity and agility during CrossFit activities, a barrel cam mechanism was proposed for the closure of the hand. This solution, illustrated in Figure 10, allows for the manual activation of a grasping motion by means of a simple rotational movement, minimizing energy expenditure and complexity.

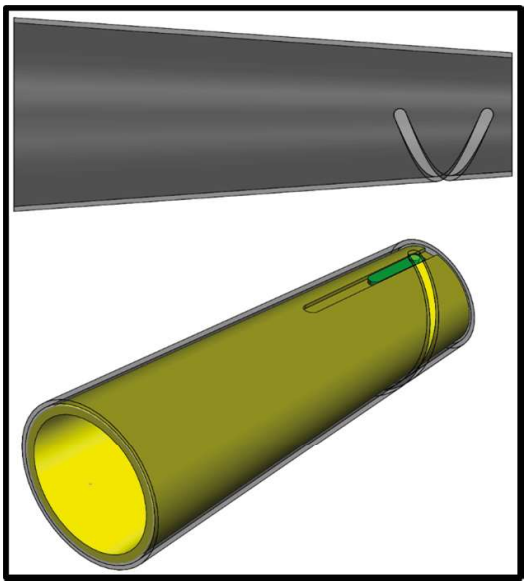

Figure 10. Slotted barrel and assembly coupling [Own source].

Table 4. Comparison of the laminate property estimations between "carpet plot" and CLT. [Own with

Carpert plot			CLT		
E_x=	85.000	MPa	E_x=	85.010,10	MPa
G_{xy}=	32.000	MPa	G_{xy}=	32.225,60	MPa
ν_{xy}=	0,32		ν_{xy}=	0,319	

Hand development:

One of the critical factors that greatly influences the functionality of the prosthesis, and inevitably its cost, is the engineering and robotics involved in an electronically actuated hand. The comprehensive design of a hand and its systems can serve as a dedicated topic for a bachelor's or master's thesis. However, for the scope of this initial stage, the hand design was limited to adjusting the physical characteristics of the patient's right hand without developing a full kinematic or actuation system. Figure 11 shows the simplified hand design model. This adjustment encompassed the height, width, and thickness of the palm on one hand, and the dimensions of the fingers on the other, as depicted in Figure 11.

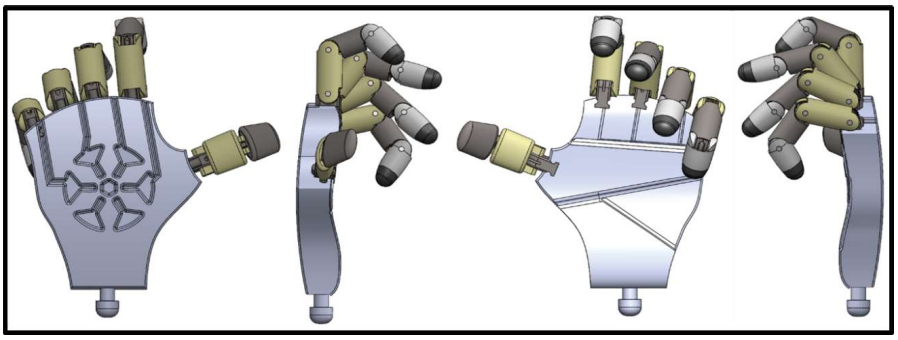

Figure 11. Left hand design [Own source].

Mechanical Female Left Arm Low-Elbow Prosthesis for CrossFit Training:

The main components of a mechanical prosthesis have been designed, which will allow for high-intensity activity without sacrificing the characteristic dynamism of CrossFit training. Currently, there is no all-encompassing solution like the one proposed that enables this sports practice (Figure 12). From here, the designs of the remaining subsystems of hand and wrist can be finalized, paying special attention to the socket, as it is the element that integrates the prosthesis with the user and plays a crucial role in its optimal functioning.

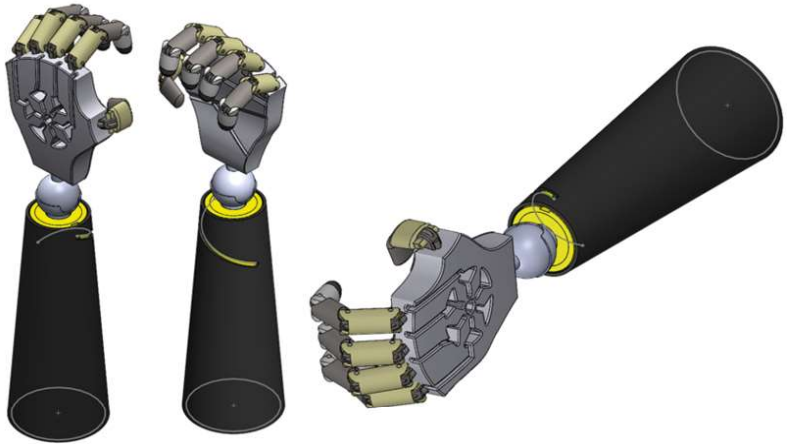

Figure 12. Mechanical Female Left Arm Low-Elbow Prosthesis [Own source].

Validation process: SolidWorks stands out as a robust digital tool for mechanical design and product validation. However, its capability to simulate composite materials is limited in the academic version. Notably, SolidWorks lacks composite materials in its material library. Consequently, to simulate components designed with composites, custom creation of materials is necessary. The data presented in Table 3 illustrates the properties estimated through the Chamis micromechanical model. Utilizing this information, the material "XC130 300g UD Prepreg Carbon fiber" is generated within the SolidWorks material library.

Table 5. Evaluation of the maximum normal stress failure criterion (Rankine criterion) in tension.

RANKINE CRITERION						
S_x=	2,92	MPa	<	Y_t=	46	MPa
S_y=	1,06	MPa				
S_z=	13,81	MPa	<	X_t=	1.500	MPa
τ_{xy}=	0,26	MPa	<	SC=	46	MPa
τ_{xz}=	0,26	MPa				MPa
τ_{yz}=	0,2352	MPa				MPa

To streamline the configurations of various load modes for simulation, the focus was directed towards the closure mechanism, given its pivotal role within the prosthesis. For this project, 8 layers were symmetrically stacked (totaling 16 layers), all composed of the same material. Each layer has a thickness of 0.3 mm (cured), with a reference angle set at 0° degrees.

Static tension analysis: This test evaluates the behavior of the component during a "pull-up." Figure 13 illustrates the plotting of the maximum normal stresses and the maximum shear stresses generated by a tensile force of 440 N.

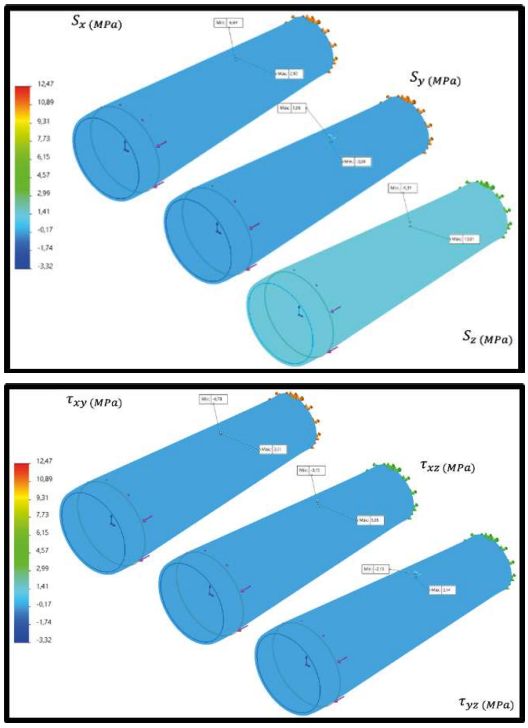

Figure 13. a) Plot of Maximum Tension Stresses S_x=2,92 MPa, S_y=1.06 MPa and S_z=13,81 MPa across all layers. b) Plot of Maximum Shear Stresses T_{xy}=3,01 MPa, T_{xz}=5,95 MPa and T_{yx}=2,14 MPa MPa across all layers [Own source].

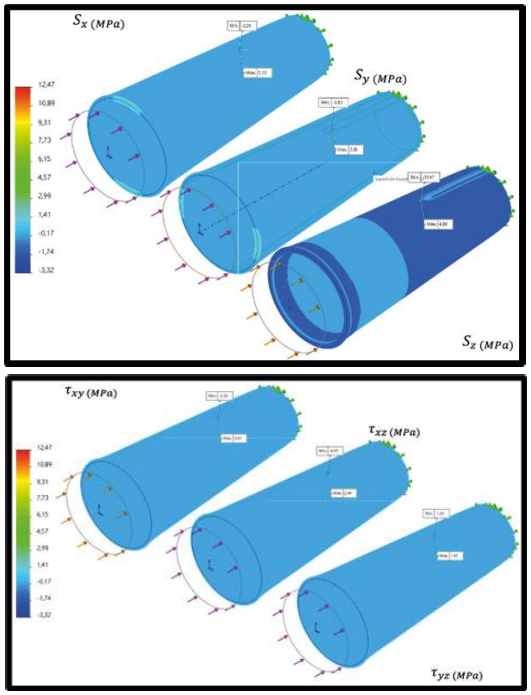

Figure 14. a) Plot of Maximum Tension Stresses S_x=5,13 MPa, S_y=2,35 MPa and S_z=4,83 MPa across all layers. b) Plot of Maximum Shear Stresses T_{xy}=2,33 MPa, T_{xz}=4,59 MPa and T_{yx}=1,65 MPa MPa across all layers [Own source].

Based on the comparison of the tensile simulation results (left side of the table) with the strength properties of our material (right side), it can be confirmed that the component will not fail due to the working stress level (Castro Sánchez, 2018). Additionally, obtaining the safety factor distribution yields a FS=25.56 for the worst case across all layers. Consequently, it can be concluded that the component will work properly under these loading conditions.

Static compression analysis: This test assesses the behavior of the component during a handstand or a push-up. Figure 14 displays the plot of maximum normal stresses and the maximum shear stresses generated by a compression force of 340 N.

Table 6. Evaluation of the maximum normal stress failure criterion (Rankine criterion) in compression.

CRITERIO DE FALLO DE TENSIÓN NORMAL MÁXIMA						
S_x=	5,13	MPa	<	Y_c=	86	MPa
S_y=	2,35	MPa				
S_z=	4,88	MPa	<	X_c=	900	MPa
τ_{xy}=	2,33	MPa	<	SC=	46	MPa
τ_{xz}=	4,59	MPa				MPa
τ_{yz}=	1,65	MPa				MPa

Similarly, comparing the compression simulation results (left side of the table) with the strength properties of our material (right side), it can be confirmed that the component will not fail due to the working stress level. Furthermore, the safety factor distribution yields an FS=36.17 for the worst case across all layers. Therefore, it can be concluded that the component will not fail under these loading conditions (Castro Sánchez, 2018).

Discussion of simplifications and limitations: It must be emphasized that:

- Dynamic effects during exercises were neglected, focusing only on static equivalent loads.
- Socket coupling and its mechanical integration were not analyzed.
- Possible stress concentrations near attachment points were not investigated in depth.

Additionally, the very high factors of safety obtained (>25) suggest that the structure is over-dimensioned for static loads. Future optimization work should aim to reduce material usage while ensuring safety under dynamic real-world conditions.

Conclusions

The design and development of a prosthetic device of this nature necessitates a collaborative effort involving various stakeholders. Active participation from patients, medical professionals, and orthopedists is paramount for accurately translating needs and capabilities into engineering design.

The proposed mechanism, while simple and familiar, offers the patient not only the ability to train but also to engage in the same activities as with her cosmetic and myoelectric prostheses. The practicality of achieving hand activation with a half-turn is emphasized, contributing to the versatility and usability of the prosthetic device. However, further work is required before manufacturing.

eLamX emerges as a valuable open-source software, greatly facilitating micromechanical analysis and the estimation of elastic and strength properties for composite material layers and laminates. Its use is underscored as a powerful tool for streamlining calculations and expediting product development processes.

While SolidWorks is a widely used and versatile tool for product design and conception, it encounters challenges in modeling textiles or non-rigid components. The limitations in modeling such components are highlighted, suggesting potential difficulties and delays in the product development process when dealing with these materials.

This project made significant simplifications to study the component's behavior. However, it's noted that SolidWorks' scope and simulation capabilities for composite materials are highly limited due to its inability to accommodate biaxial material sheets and limited capabilities for modeling complex orientations or structures. Challenges such as dealing with shell elements, meshing issues, and identifying

stress areas or singularities are highlighted as complicating factors in the simulation process.

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Research article

Packaging for the Medical Sector: A Systemic Design Perspective

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Abstract

The results provide a foundation for advancing sustainable coastal protection strategies, demonstrating the added value of bioinspired solutions in enhancing both shoreline resilience and ecological integration.

Packaging for medical products demands careful consideration due to the numerous implications and interactions that occur throughout its lifecycle. It must ensure product protection and integrity, enhance safety and usability, and comply with regulatory and environmental requirements. In managing this complexity, Systemic Design offers a valuable framework for research and development. However, its application remains limited among designers and decision-makers in the medical sector. This study investigates the potential impact of integrating Systemic Design principles into medical packaging at the university training level. Specifically, it aims (i) to explore the relevance and benefits of adopting the systemic approach in this field, and (ii) to assess the knowledge, misconceptions, and systemic approach adoption of postgraduate design students. To achieve this, a dedicated workshop was conducted in which participants were asked to analyze and map systems around specific medical packaging case studies. Initial observations indicated that participants struggled to recognize the complexity involved in redesigning medical packaging, and often lacked comprehensive evaluation criteria despite their background in design. The workshop activities revealed a limited understanding of stakeholder networks and lifecycle phenomena, highlighting the need for a broader, systems-oriented perspective in the field.

Results show that Systemic Design approaches are not yet widely understood when applied in Packaging Design, so the introduction of dedicated tools and methods in educational settings can significantly enhance students' ability to approach complex systems. Finally, a follow-up study could be conducted to determine whether the participants will internalize and adopt systemic approaches in their future design practice

Keywords: Systemic Design; Industrial Design; Product Design; Design Education

Introduction

Medical Packaging has become an extremely relevant area within the sector of healthcare administration, since it serves a variety of functions like ensuring safety, efficacy, and compliance of medical products and supplies. This type of packaging should prevent degradation and safeguard the integrity of products that mostly require high sterility and optimal functional standards (Starr, 1986), contribute to the adequate conservation, and keep a medical product's planned properties throughout its life cycle. To address this inherent complexity, a systemic approach should be adopted, since many existing solutions in this field seem to fail to balance the needs of all stakeholders involved, particularly when facing the current environmental challenges.

Designers, often recognized as horizontal professionals, contribute to a systemic approach to Packaging research and development. However, challenges related to satisfying all stakeholders and balancing environmental considerations within the field of Medical Packaging persist, revealing areas of improvement when adopting a systemic approach when operating in this specialized sector.

This phenomenon was also observed in a set of medical packaging case studies, collected by postgraduate students, in which they seemed to have difficulties in introducing evaluation criteria or setting parameters related to analyzing them with a systemic perspective. This scenario might suggest that the systemic design approach may be underemphasized at the undergraduate level in design education

In order to better understand the gaps that foster those issues, this study aims (i) to explore the relevance and benefits of adopting the systemic approach in this field, and (ii) to assess the knowledge, misconceptions, and systemic approach adoption of postgraduate design students.

For the didactic purpose of a Product & Service Design international Master's, course in a second year design studio on the topic of Packaging Design for the Medical Sector, three main sectors of packaging were identified for their functions and peculiarities: packaging for sampling and transportation of biological materials, packaging for disposable medical tools and supplies, and packaging for pharmaceutical products. These mentioned fields share many similarities in the stages of their life cycle as well as in the manufacturin processes, exposing their main differences in the final use and disposal stages according to the degree of specialization of the product they contain. The literature considered for this paper will focus primarily on pharmaceutical packaging, since it is the field that offers a more comprehensive body of research from the design perspective.

Theoretical Background

In recent years, User-Centred Design (UCD) has become a dominant framework within the design field. While this approach has contributed to more accessible and user-friendly products, it has also reinforced development models more focused on economic growth, sometimes at the expense of environmental sustainability. Although minimal and resource-conscious strategies in many design domains offer a viable path toward greater environmental and social responsibility, in highly-regulated sectors, such approaches are much more constrained. Indeed, Medical Packaging is subject to rigorous standards, regulations, and performance requirements that prioritize safety, sterility, and efficacy, obliging designers to make compromises. Given the essential role these systems play in human well-being, the main challenges lie in maximizing functionality and usability, rethinking logistics and supply chains, maintaining the high standards and compliance imposed by the field, while minimizing environmental impact.

The sector of medical packaging should not only be aligned with compliance and users' needs, even among newer patient-centric trends in the healthcare sector. It should also be suitable for the current

productive, distribution, and quality control processes, since increased manufacturing and commercialization costs could result in a higher economic burden for public or private systems, and therefore have an impact on the health access for the population.

The Pharmaceutical Packaging Sector

Within the domain of Medical Packaging, the Pharmaceutical Packaging is particularly relevant since it favours the maintenance of drugs in right conditions and allows them to be administered in the intended ways (Lorenzini & Olsson, 2018); it accompanies them throughout their life cycle and the numerous interactions that take place in it and therefore, requires careful consideration (Lorenzini & Hellström, 2016). Generally, the packaging of medications is reported to be focused on well-structured processes and standardized packages with few opportunities for innovation, along with a lack of a user-centered design focus (Lorenzini & Olsson, 2018). Traditionally, it prioritizes protection over user-friendliness (Lorenzini et al., 2022).

This indicates the tendency of decision-makers to prioritize aspects such as normative compliance and product protection over the user experience or the treatment adherence, even if approaching the balance between packaging functionality and its user experience with a systemic approach is crucial for reducing medication errors across diverse healthcare environments, particularly in high-stress situations (Estock et al., 2018).

Pharmaceutical packaging is an essential but often overlooked component of the healthcare system (Salmenperä et al., 2022). Although the public and even healthcare professionals rarely recognize its importance, packaging is fundamental for ensuring that products are delivered safely, effectively, and efficiently. Without appropriate packaging, the distribution and administration of life-saving drugs, vaccines, and medical devices would be impossible.

Packaging is becoming a sophisticated field where science, engineering, design, and marketing converge, more so in recent years, where user experience has gained prominence. During this time, the Pharmaceutical Packaging Sector has encountered a growing number of complex challenges, including regulatory compliance, waste reduction, counterfeit prevention, and issues around sustainability. Its role is complicated by economic and productive demands, medical technologies, increasingly personalized therapies, and diverse global distribution systems; the field is only becoming more intricate with time, with new technological and socioeconomic variables (Hertig et al., 2019). This increase in complexity requires a systemic design approach to manage interconnected factors.

Given this scenario and the growing awareness of the importance of psychosocial conditions and human factors (physical and cognitive), designers need to meet not only functional and regulatory demands but also societal expectations and ethical responsibility. The dynamic nature of scientific advancements related to the holistic definition of health — and its direct impact on patient outcomes — requires continuous innovation, interdisciplinary collaboration, and heightened attention to the new project requirements. Keeping up with its evolution, also from the educational front of design, it is necessary to continue adding value in the industry to support patient care.

Systemic Design

According to the Design Council, Systemic Design can be defined as “the acknowledgement of complexity and interconnectedness throughout the design thinking and doing process, considered as a mindset and a methodology” (Design Council, 2021). It serves as a strategic approach to tackle emerging challenges faced by designers in understanding the complexity, offering possible solutions to interconnected problems (Smith & Kalantidou, 2023). Its value lies in its

capacity to shift perspectives, allowing designers to tackle complex challenges more broadly, detecting new opportunities for intervention. It has emerged as an approach that many authors consider useful to describe systems by integrating knowledge from different disciplines.

In present times of interconnectedness between disciplines, its purpose remains not merely as a hybrid field born from design, but as an evolving framework to attend complex, real-world challenges (Systemic Design Association). Its adoption is particularly relevant considering the stakeholders in the system, including doctors, pharmacists, nursing staff, the drug industry, and patients. Design interventions should aim to incorporate prescriptive aspects into the drug's form, packaging, and information system, extending from the prescription to the package leaflet. (Salmenperä et al., 2022).

Designers who choose to adopt this framework are invited to engage with it at three "levels of awareness": method, methodology, and mindset. These layers represent, respectively, the tactical tools, the strategic approach, and the cognitive stance necessary for systemic inquiry (Systemic Design Association), but they should continue to be flexible enough to explore and reframe problems, to evaluate and refine proposals from different perspectives.

Despite the mentioned potential, there remains a gap between the academic concept of Systemic Design and its industrial applications, particularly in highly specialized fields such as the medical one. This disparity represents a missed opportunity for the medical sector, where the human experience and the economic factor are as important as the technological development and its environmental impact.

Methodology

In order to assess the participants' prior knowledge on the matter and to understand the utility of the proposed tools, a four hour workshop was conducted considering the three mentioned fields of packaging for the medical sector, chosen for each one of the groups according to the ones that students themselves had proposed as case studies during previous sessions of the course.

Sample

The workshop involved 50 international post-graduate students from a Product & Service Design international Master's course on the topic of Packaging Design for the Medical Sector. Participants were divided into pairs and assigned a specific case study of the following domains: packaging for sampling and transportation of biological materials (8 groups), packaging for disposable medical tools and supplies (9 groups), and packaging for pharmaceutical products (8 groups).

Tools adopted

Three tools have been employed to conduct the activities of the workshop and gather insights:

Questionnaires: They allowed a comparative analysis on the participants' understanding and perception of Systemic Design between the Pre-Workshop and Post-Workshop phases, with a focus on common patterns and misconceptions.

System-Building Tool: Accompanied by the Case Study Profile, an A4 sheet describing the specific case study, it served the participants as a tool for defining the system around the packaging in its phases and other entities. Its usage allowed a qualitative analysis of the main difficulties in specific areas and topics of the system mapping exercise.

Fill-In-The-Blanks Form: a text with fillable spaces presented to explore the participants' understanding of system dynamics and highlights from the activity of mapping their case studies' systems through a text with fillable spaces.

These tools have been used to gather insights at different levels: the System-Building Tool and the Fill-In-The-Blanks Form were useful to get qualitative insights

on the current knowledge and perspectives of the participants regarding the systemic approach around Medical Packaging on the other hand, the questionnaires allowed the collection of feedback on the understanding and comprehension of Systemic Design in this specific field, allowing a comparison between their previous knowledge and the acquired one thanks to the activities of this study that saw the participants involved.

System-Building Tool

The System-Building Tool (Fig. 1 and 2) had the purpose of guiding the system-building process, highlighting main concepts that should have been considered while conceptualizing the system around a certain solution in the field by filling a matrix that connected the stakeholders and their interactions with the life cycle of the packaging. For building this matrix, the authors took as a base the Design Council's Stakeholders Ecosystem, presented in their Systemic Design Toolkit, combining it with the main stages of the life cycle of products, from the development to the end-of-life phases (Llorach-Massana et al., 2015).

These two models were chosen as they represent valuable inputs to create the custom tool for the workshop, since they might help designers to visually construct systems around any kind of project, considering environmental and socio-economic issues while identifying critical points and opportunities for improvement.

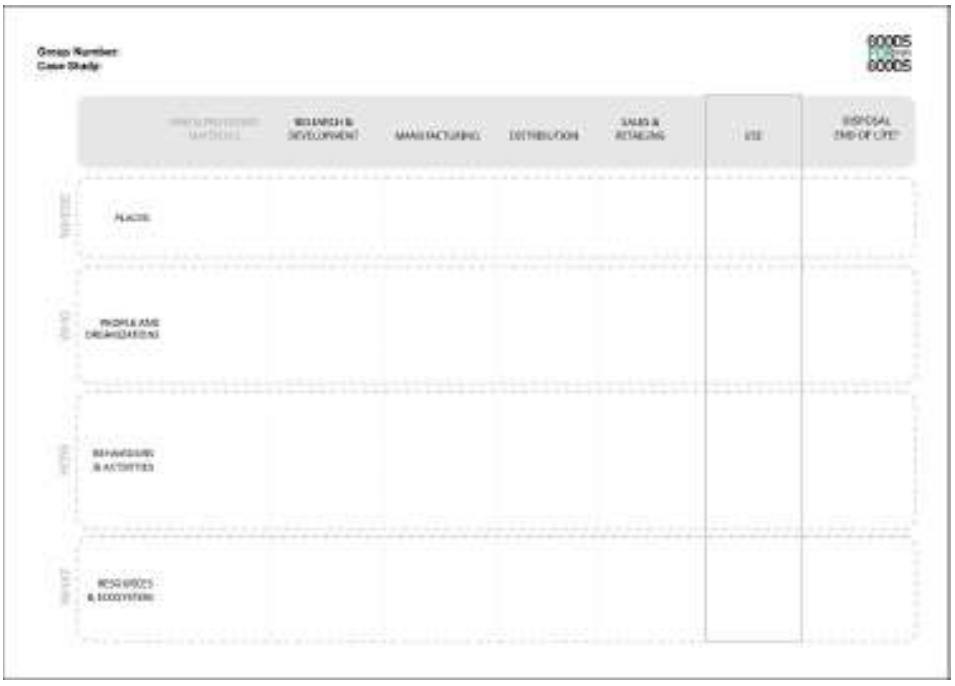

Figure 1. Fillable System-Building Tool, presented in an A3 format.

Questionnaires

To assess participants' knowledge and understanding of Systemic Design, two questionnaires were conducted: the Pre-Workshop Questionnaire and the Post-Workshop Questionnaire.

These questionnaires facilitated a comparative analysis of participants' understanding and perception of Systemic Design, enabling the identification of common patterns, misconceptions, and the extent of conceptual change between the pre-workshop and the post-workshop phase.

The answers to the questions in the questionnaires have been evaluated according to the following criteria:

Figure 2. Case Study Profile examples, assigned to students after the introduction.

Accurate (correct or almost correct): If the response correctly describes systemic design as a holistic approach that involves systems thinking. It recognizes the importance of complexity, relationships, user interactions, sustainability, life cycles, and broader system dynamics.

Partially Correct (close, but some confusion): If the response shows good understanding of the main concepts but is either incomplete or overly focused on just one element, without fully capturing the holistic nature of systemic design.

Confused (confusing Systemic with other concepts): If the response is not entirely wrong, but the emphasis is misplaced. It might confuse systemic design with related concepts, such as sustainability, without addressing the full systems perspective.

Incorrect, Incomplete, or out of scope: If the response does not describe systemic design, is too vague, or fundamentally misunderstands the concept.

Other (self-reported uncertainty and invalid answers): If the respondent admits to not knowing, expresses uncertainty, or leaves the answer blank. The questionnaires were presented to the participants digitally, through the Google Forms platform.

FIll-In-The-Blanks Form

The Form shown in Fig. 3 was developed as a complementary tool, specifically designed to facilitate the students' reflection on their work, carried out during the workshop. The form was structured to guide participants through a series of unfinished statements to help them articulate their understanding of systemic design principles and organize their takeaways. This tool aimed to encourage a critical and systemic analysis, nudging a deeper engagement with key concepts from the workshop.

In addition, the form served as a valuable instrument for assessing students' knowledge and conclusions following the workshop. It was provided on an A4 format paper sheet.

Figure 3. Fill-In-The-Blanks Form

Workshop articulation

The workshop presented in this study required each group to outline the life cycle of an assigned case study of medical packaging in the aforementioned fields with a systemic approach, identifying and describing in a schematic way the involvement of stakeholders, places, activities, and resources along the process. Based on the completion of this task, insights have been gathered on the approaches and comprehension of systemic design-related concepts and practices by this target. Before the beginning of the workshop, the participants were told that these activities, along with their outcomes, did not impact the final evaluation of the course.

The workshop began with an assessment of the participants' prior knowledge of Systemic Design through a five-question initial questionnaire, built using Google Forms. The questions aimed to gather the following information: the participants' specific bachelor's area, their prior knowledge about the concept of systems and Systemic Design, and the features they valued as most relevant to evaluate the quality of a medical packaging solution.

Then, the participants have been provided with the rudiments of Systemic Design through a dedicated lesson, to make sure that all of them possessed the fundamental notions required to take part in this workshop. The topics covered in this briefing comprised an overview of Systemic Design, taking as a reference the educational resources made available by The Design Council, and the general definition of the key concepts in the System-Building Tool.

In the hour that followed, the groups explored their case study through the Case Study Profile and filled in the System-Building Tool to outline the entities that characterize the system of the packaging they have been assigned, i.e. stakeholders, places, activities, and resources, throughout the entire packaging life cycle. The participants were then provided with the Fill-In-The-Blanks Form, which functioned as a supportive tool to summarize the main takeaways and other key information on the case studies and their systems. This phase was followed by the recollection of the material. Right after, the participants were asked to fill in a second questionnaire, built using Google Forms, the aim of which was to explore the shifts in perspective after the previous phases. To do so, some of the initial questions were presented again, e.g. the one regarding what a system means and how they would describe Systemic Design, to allow a comparison with the answers of the previous questionnaire. The completion of this phase marked the end of the workshop. After the workshop, the authors of this study analyzed the material to uncover common patterns and unique characteristics in the participants' approaches and biases on Systemic Design in the field of Medical Packaging

In addition, the form served as a valuable instrument for assessing students' knowledge and conclusions following the workshop. It was provided on an A4 format paper sheet.

Results

Insights from the System-Building Tool and the Fill-In-The-Blanks Form

In this section, a comprehensive analysis of the main patterns, misconceptions, and critical insights that emerged from the use of the System-Building Tools and the Fill-In-The-Blanks Form is presented.

The analysis of the participants' work highlighted several recurring patterns and critical gaps in their understanding of the systemic approach around Medical Packaging Design. The first aspect worth discussing concerns the raw materials and end-of-life being the most problematic phases of the life cycle to address, i.e. the initial and the final phases of the life cycle. For instance, many considered the final user "throwing the packaging in the bin" as the end of the life cycle, ignoring crucial steps connected to the packaging disposal. Additional overlookings of necessary

resources and activities have also been frequent in other steps, such as distribution and retail, often leading to incomplete life cycle mapping.Moreover, the packaging journey was often linearly and sequentially mapped, instead of posing the attention on systemic or circular interactions. Moreover, the work of many participants often lacked internal coherence: within a given phase, they introduced elements (e.g., the pharmacist in the "Who" section) without mentioning connected instances (e.g., the pharmacy in the "Where" section). Their understanding of stakeholders was also limited: although patients and manufacturers were properly mentioned across all groups, other key actors such as regulators, healthcare institutions, and waste managers were not mentioned. Connected to this, it is worth mentioning that many groups tended to refer to stakeholders as organizations and groups of people, rather than individuals. When the participants were asked to provide suggestions for improvement of their case study packaging, the participants mostly prioritized material features to improve sustainability, mentioning solutions like adopting recyclable, biodegradable, or mono-material options (even if some of them had slight confusion between recyclable and recycled materials). However, these proposals largely focused on material improvements, ignoring major factors like increased emissions, resource use, or non-compliance with regulatory means. Indeed, only a few participants demonstrated awareness regarding medical packaging design choices being dependent on stringent pharmaceutical regulations (e.g., sterility, contamination prevention, and quality standards). Other valid strategies throughout the life cycle, such as reducing packaging dimensions, reuse possibilities, system redesigns, user behaviors, or policy interventions (such as take-back programs), were rarely proposed. Although challenges connected to the disposal of packaging (dispersion in landfills, incineration, and non-recyclability) were mentioned, only a few groups considered how other systemic factors (like user behavior, infrastructure, and regulation) can also impact the environmental dimension after disposal.

Insights from the Questionnaires

The following section summarizes the insights gathered from the questionnaires before and after the workshop, which focused on investigating the participants' knowledge shift regarding the systemic approach.

Table 1. Pre-Workshop questionnaire results (50 answers)

CATEGORY	TYPE OF ANSWERS	EXAMPLES	NUMBER OF ANSWERS
Accurate	Holistic, complex systems, connections, users, environment	"Combines systems thinking and design"	11
Partially Correct	Good ideas, but incomplete/specific focus	"Comprehensive design process"	14
Confused	Misplaced focus	"Better service feeling for customers"	10
Incorrect, Incomplete, or out of scope	Wrong ideas, misunderstandings	"Design with some rules"	13
Other (self-reported uncertainty and invalid answers)	Admitted uncertainty	"Turns out I didn't know"	2

Table 2. Post-Workshop questionnaire results (50 answers)

CATEGORY	TYPE OF ANSWERS	EXAMPLES	NUMBER OF ANSWERS
Accurate	Holistic, complex systems, connections, users, environment	"A broader approach to product design, including its entire life cycle for example."	20
Partially Correct	Good ideas, but incomplete/specific focus	"It means system thinking and design methodology together focused on human-center solutions."	15
Confused	Misplaced focus	"Organizing all components and processing to achieve the final goal"	5
Incorrect, Incomplete, or out of scope	Wrong ideas, misunderstandings	"Design from 0 to 100"	7
Other (self-reported uncertainty and invalid answers)	Admitted uncertainty	"Still don't know"	3

In the pre-workshop phase, many participants demonstrated limited or unclear understanding of Systemic Design. Based on inferred responses, common misconceptions and design assumptions arose. Participants predominantly approached design from a linear perspective, often conceptualizing it in terms of "product–user" without acknowledging the broader system involved. The focus was primarily on functionality and aesthetics, with little consideration for the life cycle of products or the interconnectedness of design elements across various stages. Additionally, many participants confused "systemic" with "systematic", using that word to refer to step-by-step processes rather than a holistic and interconnected approach. There was also a limited recognition of stakeholder mapping or life cycle thinking, which are core principles of Systemic Design.

The Post-Workshop Questionnaire revealed a notable shift in participants' understanding of Systemic Design. The majority of the responses now referenced concepts such as networks, life cycle, stakeholders, and connections. This shift in vocabulary signified a higher awareness that Systemic Design is not merely about the object or product, but rather about the broader context and relationships in which that object exists. One participant described it as "a way of thinking in a holistic approach for optimizing processes and services from their beginning to the end of the life cycle", while another noted it as a "design that considers the broader context, relationships, and long-term effects".

This notable shift can be noticed in Fig. 4. The participants' responses indicate a deeper understanding of the importance of life cycle thinking, interconnectedness, and environmental and stakeholder-related factors in the design process. However, despite these improvements, there were still instances of uncertainty, with few participants answering "Still don't know" or offering vague descriptions such as "assemble" or "design with rules". These patterns suggest that while awareness has increased, full internalization of systemic thinking requires more effort.

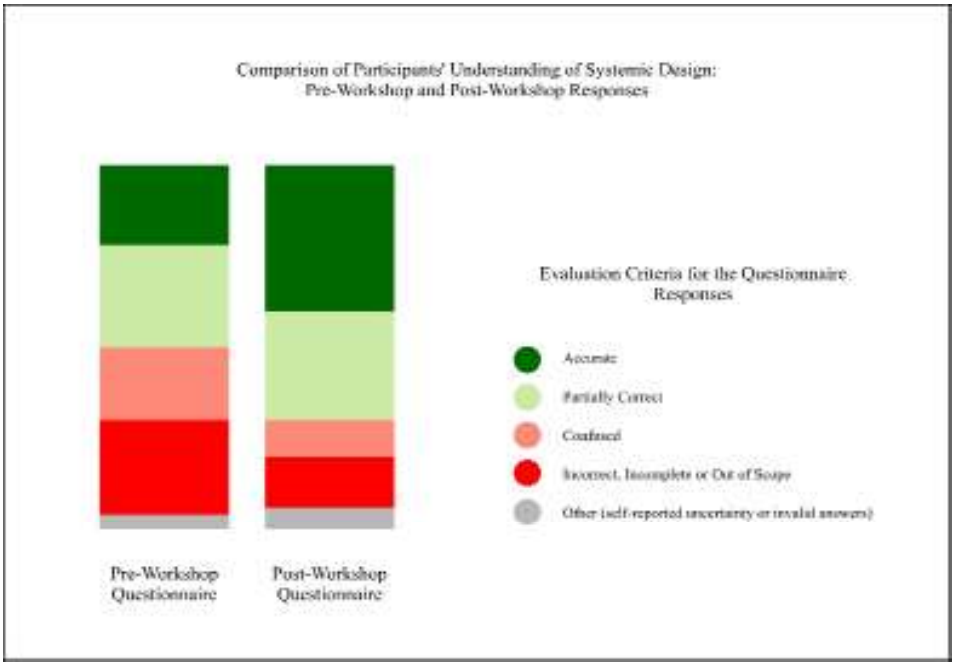

Figure 4. These bar charts illustrate the evaluation of responses to the questionnaires. A noticeable positive shift in participants' understanding of Systemic Design is evident between the Pre-Workshop and Post-Workshop Questionnaire results

A major difficulty that emerged in this study is that participants lacked knowledge on specific topics that are usually not addressed in design courses, still relevant to the adoption of systemic thinking for Pharmaceutical Packaging. For instance, many participants neglected the issue of energy and resources connected to the phases of transportation and disposal. Dominici (2017) highlights that the most important aims of a systemic paradigm are the education of ecoliterate people and the awareness development, which is focused on the network between systems and subsystems. In this regard, multiple strategies, such as project-based learning and holistic analysis and evaluation, could be adopted to overcome this challenge in design education. In particular, Peer-to-Peer learning was reported as a valid method to achieve this objective, which is the case of the workshop carried out in this study. A more profound comprehension of systemic design could ultimately bring future benefits in industrial settings, once students integrate this knowledge into their professional practice.

Observation of Systemic Analysis on Pharmaceutical Packaging Projects

Systemic analysis provided participants with a more holistic framework for reimagining medical packaging design, not simply as a physical product, but as an active component that interacts with and influences the surrounding ecosystem. In this project, for example, the team considered multiple interconnected factors, including manufacturing processes, logistics, environmental sustainability, and patient usability. Through this lens, the designers identified several inefficiencies in both the primary and secondary packaging, particularly concerning the accurate dispensing of doses for children and the environmental risks posed by the disposal of unused antibiotics.

The project was developed within the context of the aforementioned Master's course and promoted in collaboration with a local pharmaceutical packaging manufacturer. The example focused on amoxicillin, a commonly prescribed antibiotic for children, typically available in powder form in a bottle (Figure 5) that

must be turned into a liquid solution before use. Preparing the solution requires adding a precise amount of clean water to the powder to create a liquid suspension, which must be shaken thoroughly before each dose is administered.

Figure 5. The typical amoxicillin packaging that this project aims to innovate.

Figure 6. The prototype developed by participants after implementing a Systemic Design approach.

During their investigation, the participants identified a critical issue in the usage stage related to dosing precision. While this was a primary concern, through systemic analysis the designers could unveil additional issues that needed to be tackled. One major issue concerned the standard practice of preparing the full suspension at once, which must then be consumed within 14 days. Often, the prescribed volume exceeds what is actually needed, leading to significant waste as unused portions expire.

Dosing errors were another common problem, as caregivers frequently used spoons rather than calibrated tools like syringes or dosing cups, resulting in inaccurate administration. Another important aspect regards the fact that shaking the bottle before each use is often an overlooked action, useful to provide consistent dosing uniformity. Storage also presents challenges, as the need to preserve the solution in a refrigerated environment is sometimes overlooked, especially when instructions are unclear or refrigeration is unavailable. Finally, Contamination constitutes an additional risk if the bottle or dosing instruments are not kept clean. If the medication is not consumed within the specified period, it may degrade, and improper disposal of unused antibiotics poses an environmental hazard.

To address all these challenges, the team proposed a solution involving single-dose

powder sachets (Figure 6), designed to be mixed with water at home just before use. This approach could improve accuracy in pediatric dosing and maintain the stability of the medication, as the components would not degrade over time. Additionally, the design would allow for more compact secondary packaging and more precise distribution, reducing waste and environmental impact while utilizing similar material resources. Unveiling and tackling many of the described issues could be possible mostly because the systemic approach was adopted along the phases of the project.

Conclusions

As the healthcare sector continues to evolve through new social dynamics, emerging technologies, and shifting methodologies, designers must be equipped to respond to complex and rapidly changing challenges with a systemic approach to problem-solving. This evolving landscape requires expanding the focus beyond users to include multiple perspectives, accounting not only for human and societal needs, but also for non-human and non-present stakeholders, such as the environment and future generations. The Systemic Design approach for Medical Packaging helps to embrace a more inclusive mindset that acknowledges interdependencies, ethical responsibilities, and the broader impact of design decisions across time and different stakeholders and contexts. A lack of attention from companies and decision-makers could have repercussions for the sustainability of the entire health sector. professional development of students, and thus on the future of the industry. As well as, the approach of educators in the packaging sector only focused on product innovation could have repercussions for the professional opportunities of young designers.

Many gaps and misconceptions were observed during the workshop activities presented in this study, and a meaningful shift in perspective emerged after the use of the tested tools. Participants increasingly internalized concepts such as networks, life cycle stages, connections, and stakeholder relationships. These changes in vocabulary and framing capability suggest an increased adoption of systemic thinking. Participants' responses indicate a growing awareness that Systemic Design is not limited to the service level but must account for its embeddedness in complex, multi-actor systems. Subsequent feedback suggested that while awareness has increased, full internalization of systemic thinking still requires a deeper study of the Medical Packaging Sector according to the approach of Systemic Design.

Future research could contribute to a more comprehensive understanding of how systemic thinking is adopted and applied within the Medical Packaging Sector. To deepen this perspective, similar studies could involve a broader range of stakeholders, including pharmacists, regulators, experienced designers, healthcare professionals, and waste management experts, whose insights are essential for acquiring a more complete and integrated view of the system as a whole. Additionally, a follow-up study could be conducted to assess whether the participants of this workshop eventually internalize and implement systemic approaches in their future design practice.

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Resumen / Abstract

Inma Bermúdez es una mujer y diseñadora industrial pionera cuya filosofía de vida ha reflejado en sus proyectos desde sus inicios creativos. Inma Bermúdez estudio, ha destacado desde su creación gracias a la innovación aplicada en la ideación y desarrollo de productos de uso cotidiano. Productos en los que la diseñadora hace especial énfasis en el “user experience” y su sostenibilidad global, a través del diseño estratégico. Filosofía creativa que le ha dado paso a ser una de las pocas mujeres galardonadas con un Premio Nacional de Diseño en la categoría de profesionales, siendo la primera en el marco del diseño de producto. Lo cual además de convertirla en un referente del diseño nacional, le ha dado a la diseñadora un potente altavoz mediante el que transmitir el valor del diseño a nuestra sociedad.

Inma Bermúdez is a trailblazing woman and industrial designer whose life philosophy has been reflected in her projects since her creative beginnings. Since its inception, Inma Bermúdez Studio has stood out thanks to its applied innovation in the conception and development of everyday products. Products in which the designer places special emphasis on the “user experience” and their overall sustainability through strategic design. This creative philosophy has led her to become one of the few women to win a Premio Nacional de Diseño in the professional category, the first in the product design category. This, in addition to making her a leading figure in national design, has given the designer a powerful platform through which to convey the value of design to our society.

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INMA BERMÚDEZ, Solucionadora de problemas sostenibles

"Si bien resulta evidente que siguen existiendo mujeres en el diseño industrial y que siguen cursando su disciplina, ¿dónde están las mujeres profesionales del sector? Con el objetivo de dar respuesta a esta pregunta, el pasado octubre de 2022 se presentó en el II Congreso Internacional de Mujeres Creadoras organizado por la Universidad de Sevilla, la ponencia dedicada a La mujer diseñadora de producto en el XXI. En su texto se puede leer un exhaustivo análisis con el objetivo de demostrar la evolución de la mujer en los estudios profesionales de Diseño Industrial, para más tarde terminar con entrevistas personales a diversas egresadas académicas las cuales permitieron concluir. Asimismo, se puede apreciar que, si bien el número de mujeres en el diseño industrial profesional es significativamente reducido en comparación al hombre, éste va en aumento con la consecuente aparición de referentes como Clara del Portillo, Silvia Ceñal o la protagonista de nuestro análisis Inma Bermúdez. (Mellado & Jonathan, 2022).

El estudio de Inma Bermúdez fue galardonado con el Premio Nacional de Diseño el mismo año de la ponencia citada, en 2022. Desde entonces son varias y diferentes las entrevistas que ha concedido la diseñadora a diversos medios de difusión. Sin embargo, la presente propuesta busca ir un poco más allá poniendo el foco su condición de mujer profesional del diseño industrial galardonada con un Premio Nacional, gracias a su dedicación al User Experience, así como su importante aportación al Diseño Sostenible. En cada uno de los proyectos de Inma, se aprecia la belleza que requiere todo producto de uso cotidiano, y no explícitamente por su estética, sino por su destacada capacidad funcional mejorando la experiencia del propio usuario. Para la diseñadora, los profesionales del diseño somos solucionadores de problemas, por lo que ella misma se define como "solucionadora de problemas" (Redacción CC/Magazine, 2024). Definición que, por pura curiosidad creativa y emocional, nos invita a investigar en sus orígenes para conocer las bases creativas de la diseñadora, así como a poner de manifiesto su filosofía proyectual centrada en la usabilidad de los productos y también su afán por evidenciar la sostenibilidad productiva de los mismos.

Inma, diseñadora por vocación.

Para poder comenzar a hablar sobre Inma Bermúdez, así como de su labor en el Diseño de Producto, debemos antes planearnos las siguientes preguntas; ¿Quién es Inma Bermúdez? ¿Cuáles son sus bases creativas? ¿Cuáles son sus expectativas de futuro en el diseño?. Preguntas que también, los jóvenes diseñadores o estudiantes de la disciplina se pueden hacer al escuchar el nombre de la diseñadora por primera vez y a las que se busca dar respuesta a través de este texto, apoyadas de un análisis exhaustivo de diversas entrevistas realizadas a la protagonista.

Seguramente la amplia mayoría de los lectores conozcan a Inma Bermúdez por ser la única diseñadora española que idea y desarrolla nuevos productos para la archiconocida firma nórdica IKEA. Otros la conocerán desde el año 2022 cuando fue galardonada con el mencionado Premio Nacional de Diseño e Innovación en la categoría de Profesionales.

se generan, "el premio por su labor de innovación a través de procesos y materiales más respetuosos con el medio ambiente y la sociedad en un momento en el que materialidad de los objetos cotidianos ha de estar en plena sintonía con los objetivos de desarrollo sostenible" (Carlos Garsan, 2023).

Figura 1: Inma Bermúdez estudio, Imagen extraída de la página web Inma Bermúdez estudio,2025.

Inma es una mujer que siempre ha pensado en dar solución a los problemas con los que convivimos, con el objetivo que nos define como diseñadores, mejorar la vida que nos rodea. Objetivos en los que nuestra protagonista lleva trabajando desde la creación de su estudio en 2007, al que tan solo dos años después, en 2009, se sumó Moritz Krefler, arquitecto y pareja de la diseñadora. En su haber podemos encontrar desde lámparas a accesorios para animales domésticos o utensilios de limpieza, el estudio Inma Bermúdez adivina en todo tipo de producto una oportunidad de mejora basada en la experiencia del usuario y la tan necesaria sostenibilidad, a través de la estrategia y la innovación.

Por todo ello, el Premio pone de manifiesto la eminente aportación de este tándem de diseñadores al campo del diseño sostenible de la mano de su persistencia en incidir en el ciclo de vida de los productos que

Inma, mujer premiada.

Desde la primera edición de los Premios Nacionales de Diseño celebrada en 1989, hasta la edición de 2022, el mencionado galardón tan solo ha sido concedido a tres mujeres, siendo Inma Bermúdez la tercera de ellas en conseguirlo. Sin embargo, si hacemos números según la especialidad creativa de cada una de ellas, podemos decir que las dos primeras, trabajan más el ámbito del diseño gráfico como Patty Nuñez premiada en 2007 y Marisa Gallén en 2019. (Anónimo, s.f.). Por lo que se podría considerar a Inma como la primera mujer en conseguir dicho galardón, en la especialidad profesional del diseño industrial en los 33 años de historia de estos Premios Nacionales, hasta el momento del reconocimiento de la diseñadora. A ello sumar el paso de los años, y el presente 2025, un pequeño y casi inapreciable porcentaje que desde 2022 no se ha visto incrementado.

A raíz de ello surgen nuevas preguntas, ¿Por qué se ha tardado tanto tiempo en otorgar un Premio Nacional de Diseño a una mujer del diseño industrial? ¿será porque no hay mujeres en dicho sector? ¿será porque falta visibilidad? Es aquí donde podemos entender cuando Inma comenta que, "Las mujeres tenemos el ego bastante enterrado", (Bermúdez, Entrevista a Inma Bermúdez, 2024) es decir, que no tenemos una necesidad existencial de ser vistas y recompensadas por la sociedad en general, que nosotras con obtener un óptimo resultado de nuestro proyecto consideramos que es suficiente reconocimiento.

Frase y pensamiento que recuerda a las palabras de Isabel Campi, a quien también sorprendía que, en pleno boom de las comunicaciones durante los años 90, las mujeres diseñadoras industriales prefirieran ser invisibles a exóticas. (Campi, Diseño y Género. 39 años en busca de la explicación, 2023). Un hecho que quizás hoy, en pleno siglo XXI todavía no ha sido superado, y quizás sea por ello que siguen siendo más ellos que ellas, los profesionales en primera linea del diseño industrial.

Tal y como estamos viendo, la mujer y el diseño industrial, es un tándem de conceptos cuya unión ha sido investigada y analizada por reconocidas teóricas del diseño como Isabel Campi, quien de manera vehemente realza el valor del diseño de producto ideado para su propio contexto, independientemente de quién sea su creador o creadora, dejando así de lado las históricas relaciones entre estética y mujer, lo que en su momento dio origen al bautizado como "toque femenino". Concepto sobre el que Campi reafirma su inexistencia racional, vinculándolo intrínsicamente a requerimientos particulares del sector publicitario o los medios de comunicación. (Campi, 4to coloquio internacionales Bauen, Construir, Habitar, Pensar y Diseñar, 2018). Sin embargo, se trata de un concepto erróneamente extendido en el ámbito profesional, que incluso hoy en día nos lleva a leer comentarios como el dedicado a Inma Bermúdez tras conseguir el Premio Nacional, en el que, si bien por un lado se elogia su trayectoria profesional y labor por la sostenibilidad, de algún modo, por otro lado, cae en el error de vincular el hecho de ser mujer con su particular filosofía creativa.

> "un nuevo referente del diseño español en el panorama internacional, preservando la impronta de su mirada femenina y de su identidad mediterránea, así como por su labor de innovación a través de procesos y materiales más respetuosos con el medio ambiente y la sociedad en un momento en el que materialidad de los objetos cotidianos ha de estar en plena sintonía con los objetivos de desarrollo sostenible" (Carlos Garsan, 2023)

A pesar de la historia y de los hechos más recientes, el reconocimiento a una larga etapa de trabajo duro y constante, llegó. Tiempo en el que la diseñadora ha sabido poner el foco en dar solución a problemas cotidianos de la manera más sencilla y sostenible posible, manteniendo en todo momento el valor en la usabilidad del producto. Aspecto en el que Inma encontró un impulso para seguir en el camino del diseño tras una mala experiencia profesional durante sus prácticas en una empresa alemana, (Bermúdez, Entrevista a Inma Bermúdez, 2024). Fue a partir de entonces cuando el concepto la UX entró en su haber creativo. Un ejemplo de ello es LILLÄNGEN su primer proyecto creado en 2009 para la gigante sueca IKEA, "un lavabo pequeño que cabía en cualquier baño y llevaba un toallero y espacio para los cepillos de dientes y el jabón. Todo por pocos euros. Pensé que debía facilitar la vida de las familias con prisas" (Zabalsbeacoa, 2024). A raíz de este proyecto, los suecos bautizaron a Inma Bermúdez con el sobrenombre de Inma Smart (lista). Persona capaz de dar solución con lo mínimo para conseguir resultados máximos.

Pero las soluciones innovadoras no surgen de la nada, un día una no se levanta de la cama con la solución ideal para su cliente en mente. La solución no surge si previamente no se ha llevado a cabo de manera

voluntaria, o quizás involuntaria, toda una investigación de campo que permite a todo profesional del diseño tomar referencias y ejemplos de posibles soluciones, capaces de resolver la problemática inicialmente planteada.

"Yo también me inspiro, al final mi cabeza es un baúl lleno de imágenes de cosas que voy viendo a lo largo de mi vida, y seguro que muchas de mis piezas están bañadas de este imaginario que tengo." (Bermúdez, Las entrevistas de Aimar - Cadena Ser, 2023) Problemas de envergadura, morfología o funcionalidad diversa y diferente, que requieren de una solución para mejorar su rendimiento y usabilidad siempre desde la perspectiva de la sostenibilidad. "Yo creo que el diseño es el resultado de nosotros como personas, yo siempre me he querido definir como un estudio que da solución a un problema, no tenemos un estilo que nos defina, nos ceñimos a los requerimientos del cliente. Pero sí que es cierto que últimamente nos centramos mucho en el diseño sostenible, si la empresa no lo tiene, intentamos convencerle de su valor y la importancia de ello". (Bermúdez, Las entrevistas de Aimar - Cadena Ser, 2023)

Evolución hacia la Sostenibilidad

"lo más sostenible, es lo que no se tira a la basura, reparar es una cosa maravillosa". (Takaroumt, 2022)

Lo de Inma con la sostenibilidad viene de lejos, más bien, lo lleva en la piel desde sus inicios creativos. No obstante, ha sido con su evolución profesional cuando ha encontrado el nicho en el que aplicar este lado de su ser. Un aspecto de su vida que aplica en su día a día y del que hizo gala en la entrega de los Premios Nacionales de Diseño, desde el altavoz que este escaparate le concedió. Inma no se cansa de reivindicar el valor que tenemos los diseñadores, lo capaces que somos si nos dejan, pero, sobre todo, si se nos da la oportunidad.

"A mí me gustaría que a los diseñadores se nos diera una oportunidad y nos colocarais en estos lugares donde de normal no estamos, en esas mesas redondas donde se deciden las cosas para las personas el medio ambiente" (Bermudez, 2022).

Resulta complicado saber o proponer cómo los diseñadores podríamos encajar en aquellos espacios donde se toman decisiones estratégicas o políticas, ámbitos técnicos y burocráticos en los que quizás nuestras mentes creativas se pudieran no encontrar demasiado cómodas, pero que, a su vez, tanta falta hace. Nuestro objetivo es aportar soluciones a problemáticas de total actualidad, pero sobre todo a problemáticas futuras, relativas a la evolución social y al inminente cambio medioambiental. Tal y como la propia Inma reconoce, es difícil saber de qué manera podríamos encajar, pero sí que es cierto que poseemos una mente privilegiada que nos permite ver las cosas desde otro punto de vista, como dicen en inglés out of the box, "sabemos mirar las cosas desde otro punto de vista y somos super rápidos e ingeniosos para aportar soluciones que a muchas otras personas no se les ocurren" (Bermudez, 2022).

Es desde el punto de vista mencionado desde el que el estudio Inma Bermúdez se adentra en el conocido como diseño estratégico, un concepto de diseño basado en la visión a futuro con el objetivo de aumentar la capacidad de innovación y, en consecuencia, la competencia de la propia empresa productora. Es bajo esta particular metodología creativa, bajo la que la diseñadora busca dar soluciones a las empresas que se interesan en su visión, en detrimento de la creación y producción de nuevos objetos, en demasiadas ocasiones, innecesarios. Se trata de una estrategia orientada a aumentar o facilitar la aplicación de la sostenibilidad en los procesos creativos y productivos ya existentes en las propies empresas.

Los Proyectos

Un ejemplo de ello es el proyecto para la bodega Dominio de la Vega basado tanto en la sostenibilidad como en el cuidado y mimo que la propia bodega dedica a su producto principal , el vino.

"Elaboramos vinos auténticos y expresivos elaborados en calma y que transmiten la esencia de nuestros viñedos" (Redacción, Dominio de la Vega, 2025)

El proyecto de Dominio de la Vega supuso todo un reto profesional para el estudio de Inma Bermudez, dado que se centraba en generar la evolución de su identidad corporativa, tomando como referencia la sostenibilidad instaurada en cada fase de la producción. Este proyecto fue trabajado en colaboración con la diseñadora Silvia Martínez, a fin de poder presentar una propuesta real, completa y eficiente al cliente. Para ello Inma y Moritz dedicaron un análisis completo y concienzudo "con el objetivo de minimizar los procesos y materiales utilizados en los envases y otros aspectos de esta evolución natural." (Redacción, Inma Bermúdez, 2025)

El trabajo que conlleva idear y desarrollar la nueva identidad corporativa de una marca, puede quedar algo distanciado del territorio habitual para la diseñadora, sin embargo, decidió sumergirse en la ideación de la propuesta dado el eminente interés por la sostenibilidad de la empresa. "Yo no quería trabajar con ellos por motivos de no ser intrusiva, ... pero es una bodega con un proyecto sostenible que ha hecho que me enamorara de su labor, y decidí dar un paso hacia delante, a probar otras cosas." (Bermúdez, Entrevista a Inma Bermúdez, 2024).

Con este concepto de probar nuevos retos, el estudio de Inma Bermudez ha conseguido formar parte de la vida de Dominio de la Vega, junto a su potente equipo de enógolos, para materilizar el objetivo de la sostenibilidad a través del rediseño de la fase de producción y el etiquetado de cada botella, lo que incluye la decisión de cambiar materiales de producción e impresión.

Por otro lado, siguiendo el camino de la sostenibilidad y con la mirada puesta en la experiencia de usuario, el estudio de Inma Bermúdez se encontró con la icónica firma de sanitarios ROCA, así como con su nuevo director de Marketing y diseño corporativo, Marc Viardot.

Desde su incursión en la marca, Viardot tenía por objetivo hacer que Roca diera un paso hacia delante en este imparable mundo cambiante, motivo por el que la firma lanzó en 2020 un concurso a nivel nacional, cuyo briefing solicitaba el rediseño de su clásica colección de grifería Targa.

Figura 2: Identidad corporativa de Dominio de La Vega, 2021, Imagen extraída de la página web Inma Bermúdez estudio,2025.

De entre las diferentes propuestas presentadas, NU, ideada por Inma y Moritz, resaltó. Resaltó porque no encajaba en el briefing dado, sino porque iba un poco más allá. En su propuesta el estudio de Inma presentaba una colección de grifería estéticamente innovadora y con una importante eficiencia sostenible. Si bien, es realmente complicado innovar en la estética de una colección de grifos, Inma y Moritz lo lograron reduciendo los componentes a su mínima expresión. Para ello basaron todo su atractivo en la sencillez de sus líneas, su versatilidad compositiva y atractivo cromático. A ello sumar, la atención al peculiar carácter funcional de la colección al mismo tiempo que se centraban en la experiencia del usuario y en hacer del momento de abrir un grifo un acto simpático a la par que consciente con el medio ambiente, "lo mejor es que cuando abres el agua te sonríe el grifo. Detalles que no siempre puedes aplicar, pero conseguir esa sonrisa y bienestar del usuario, es genial" (Bermúdez, Las entrevistas de Aimar - Cadena Ser, 2023). Conjunto de aspectos que, si bien es cierto que han logrado reducir al máximo el proceso productivo de este tipo de producto, también han logrado poner de manifiesto la capacidad de dotar de cierto dinamismo un entorno habitualmente frio y en exceso estandarizado como lo son las griferías. Proyecto con el que se suman a propuestas como la presentada en 2019 por la diseñadora Teresa Sapey para Griferías Galindo, bautizada como Chip&Chap y LuckyMe. Ambas, piezas con una destacada estética y un particular carácter emocional.

No obstante, aunque la estética y la funcionalidad de NU resulta innovadora a la par que divertida y funcional, de ella cabe destacar su carácter sostenible. Desde el proceso de producción y acabado de cada uno de sus componentes a su usabilidad diaria. Cada grifo ha sido ideado para que pueda ser abierto y cerrado más de un millón de veces, aumentado con ello su vida útil. A ello, cabe sumar un sistema de reducción de salida de agua a traves de un filtro regulador, así como el denominado sistema Cold Stard propio de la empresa. Aspectos cuya unión permite que la presente colección de grifos pueda reducir de manera sustancial el caudal del agua sin perder eficiencia y minimizando emisiones de CO2.

> "En la nueva generación de griferías Cold Start de Roca la apertura frontal queda reservada exclusivamente para el agua fría, evitando así un consumo innecesario de energía y agua". (Redacción, ROCA, 2024)

Figura 3: Grifería NU, para ROCA, 2023. Imagen extraída de la página web de Inma Bermúdez, 2025.

CONCLUSIONES

Desde sus inicios en el camino profesional del diseño industrial, a nivel personal Inma Bermúdez ha tenido por objetivo solucionar los problemas de las personas de esta sociedad tan cambiante. Este objetivo toma como base la UX, un concepto que ha permitido a la diseñadora trabajar en proyectos de sencillez constructiva y funcionales. A ello cabe sumar la consideración por trabajar en proyectos de carácter sostenible que tanto motivan al estudio Inma Bermúdez, dado la situación actual y conocida evolución del medio ambiente. Conjunto de hechos, cuya unión la hicieron merecedora de ser reconocida con un galardón nacional, gracias al cual ha podido dar a conocer su labor hasta el día de hoy, y a su vez difundir el valor de trabajar por un diseño estratégico capaz de mejorar la rentabilidad tanto de la empresa como el propio producto.

El estudio de Inma Bermúdez ha sido el primer estudio de diseño industrial liderado por una mujer que ha conseguido un premio nacional de diseño, gracias a su capacidad de dar soluciones innovadoras a problemas de la sociedad contemporánea, apostando por un futuro profesional basado en el diseño estratégico.

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