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High Performance and Optimum Design of Structures and Materials VI

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INTERNATIONAL CONFERENCE ON HIGH PERFORMANCE AND OPTIMUM DESIGN OF STRUCTURES AND MATERIALS

HPSM/OPTI 2025

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Conference Chairs

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High Performance and Optimum Design of Structures and Materials VI

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Preface

This volume contains a selection of the contributions presented at the International Conference on High Performance and Optimum Design of Structures and Materials (HPSM/OPTI) which took place from 10 to 12 June 2025. This edition of the scientific event follows the success of a number of meetings on structures and materials, and on optimum design, which originated in Southampton as long ago as 1989. As the meetings evolved, they gave rise to the current series, which started in Ostend (Belgium) in 2014 and continued in Siena (Italy) in 2016 and Ljubljana (Slovenia) in 2018. The health crisis created by the COVID-19, that reduced substantially people´s mobility, forced the transformation of the 2020 and 2022 conferences into online forums.

The 2025 edition of the conference was organised by the Wessex Institute and the University of A Coruña, Spain; the venue selected was Edinburgh, the beautiful capital city of Scotland.

This volume presents recent research initiatives on the development of materials with enhanced capabilities at micro, meso and macroscale, suitable for use in various scientific and technological applications. The focus is on characterisation and search for improved, mainly mechanical properties of different types of materials such as metals, plastics, composites and biomaterials. Bioengineering studies are also presented in the topic of molecular structural analysis.

Innovative structural typologies are also another area of interest in the book. There is more emphasis on sustainability rather than on innovations in large scale construction projects, such as high-rise buildings, large stadiums and sport halls, pedestrian bridges and long span bridges. Cardboard microarchitecture through scaled prototypes is proposed for internal space redevelopment leading to optimum life-cycles. Technological innovations contribute to meta-design of modular, energy-efficient, and flexible facilities for vulnerable populations' healthcare.

Both materials and structures can benefit from the advantages of optimisation techniques that guide the engineers and scientists in the search of the best solution for the problem they are working on. In that regard, numerical optimisation methods need to be seen as design tools that help engineering intuition, make better designers and speed up the learning curve of young practitioners. Currently these techniques are mature enough to be used in real design problems in mechanical, aerospace, construction or civil engineering. Several commercial codes have a variety of optimisation capabilities for various engineering fields. The application of various optimisation strategies is presented in this volume: structural, shape and topology and multi-objective optimisation as well as evolutionary methods.

The contributing authors are experts from many countries specialising in fields of materials definition and characterisation, structural designers, architects, mechanical, aircraft and civil engineers as well as experimentalists and computer analysts developing software for application to the fields covered in the book.

As with previous Wessex Institute HPSM/OPTI conference proceedings, this volume is part of the WIT Transactions on the Built Environment series and its papers are archived online in the WIT elibrary (www.witpress.com/elibrary), where they are freely available to the international scientific community.

It is expected this volume to be a valuable addition to the existing literature on the subject and will be of interest to any researcher working in this scientific field.

The editors are grateful to the authors for their contributions and to the members of the International Scientific Advisory Committee of the conference for reviewing the submitted abstracts and manuscripts thus ensuring the high quality of the contents of this book.

The Editors, 2025

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Section 9: Structural optimisation

RETHINKING HEALTHCARE ACCESS: META-DESIGN AND TECHNOLOGICAL INNOVATIONS FOR VULNERABLE POPULATIONS IN THIRD-SECTOR FACILITIES

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ABSTRACT

This paper addresses a critical issue both nationally and internationally: access to healthcare, a fundamental human right, as outlined in Article 25 of the Universal Declaration of Human Rights. This right includes medical care and the broader determinants of health, such as social, economic and physical environments, as well as individual characteristics and behaviours. While these determinants are widely acknowledged in other fields, healthcare design has lagged in addressing holistic well-being within healthcare settings. This issue is particularly significant for individuals who are not eligible for national healthcare systems, such as undocumented immigrants and impoverished populations, who often rely on third-sector organizations for assistance. This study proposes a meta-design framework aimed at improving both the spatial and service design of third-sector organizations that care for marginalized populations. The second part of the analysis explores the integration of appropriate technologies, where interventions often balance routine, temporary, humanitarian and emergency architecture. The goal is to design modular, energy-efficient and flexible clinics that can be assembled and disassembled as needed, while maintaining environmental sustainability – an essential consideration in contemporary construction practices, even for temporary structures. Finally, the implementation of the systems is presented to prove the efficiency and adaptability of the system.

Keywords: third-sector facility, healthcare design, sustainable construction, adaptable construction, design for disassembly.

1 INTRODUCTION

Access to basic healthcare is globally recognized as a human right, as highlighted in Article 25 of the Universal Declaration of Human Rights. This has led more countries to adopt universal healthcare, ensuring medical care for everyone, regardless of income or insurance. However, in some cases, undocumented immigrants are excluded, requiring the third sector to step in to uphold this right and protect public health [1].

In Italy, universal healthcare for all individuals on national territory is guaranteed by Article 32 of the Italian Constitution. The third sector can operate within the National Health Service (NHS), which provides temporary health codes (STP/ENI) to facilitate access to outpatient clinics. Despite this, due to healthcare fatigue, the third sector often remains the primary access point for basic healthcare for these individuals [1]. Barriers to enrolment can arise from policies, systemic issues, and individual factors. In particular, bureaucracy, fear of deportation, communication barriers, and lack of information about the healthcare system play a crucial role in excluding this population [2].

The third sector typically assists in daily life, such as facilitating access to basic medical care, and during emergencies, offering support in the aftermath of crises, including natural disasters, health emergencies, and humanitarian crises.

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Similar to everyday life, the quality of temporary shelters significantly impacts both physical and mental health [3], [4]. Current evaluation indicators often fail to assess shelter adequacy fully, overlooking key aspects such as comfort, air quality, and overall well-being [5], [6]. As a result, temporary solutions are frequently used for extended periods, both in daily life and emergencies [7]. Enhancing adaptive design and technological requirements would significantly improve the sustainability of temporary structures [8], enabling a circular economy approach with greater reusability and blurring the lines between temporary and permanent housing [9].

Extensive research has been conducted on hospital architecture design [10], [11]. However, it is equally important to address local healthcare structures. Recent crises highlight the necessity for the proximity healthcare and hospitals to work together effectively in all situations [12].

One of the main challenges in healthcare facility design is its traditional perspective, which often neglects environmental, psychological, and socio-cultural factors in defining health [13]. In particular, the socio-cultural approach views health as a product of social and community structures [14]. A shift in perspective is needed, from rigid, stepwise representations of health outcomes to a more dynamic, multi-faceted model that better captures the complexity of health determinants [15].

The World Health Organization (WHO) has already taken a step in this direction by recognizing that healthcare is influenced by multiple determinants, encompassing not only medical treatments but also social and economic factors. Elements such as poverty and social exclusion are considered key social determinants of health [16] and particularly affect the population target of this study.

The object of this study is to propose a guideline to overlap the gap in the adaptability, reuse, and implementation of third-sector healthcare buildings by proposing an adaptable meta-design applicable to different facilities, aiming to provide a solution for healthcare spaces that need reorganisation or implementation of their spaces, especially in the third-sector. The study intends, also, to provide technological solutions – aiming to practical build the implementation for these facilities – suitable for both long-term and temporary applications in a circular economy perspective.

In the first part of the paper, the meta-design is analysed and explained by examining space characterization, including flow identification, macro-area descriptions, and the categorization of essential spaces required for an outpatient clinic based on accessibility and movement patterns. The meta-design serves as a guideline for organizing these identified spaces according to their function and flexibility, ensuring a replicable and adaptable model suitable for various scenarios, such as new constructions, expansions of existing services, and emergencies.

The second part defines the technological requirements – flexibility, transportability, and adaptability – leading to the development of a technological solution that aligns with the meta-design. The panels are described along with their guidelines.

Finally, the implementation of the system is presented, demonstrating its adaptability across different scenarios and its flexibility in meeting diverse needs.

2 SPACE CATEGORIZATION AND META-DESIGN

The space categorization (Table 2) aims to help reorganize healthcare facilities and serve as a valuable design guideline for broader implementation. Working with existing facilities – each with its own unique needs – requires a flexible meta-design. This approach ensures adaptability to various scenarios while maintaining the efficiency of every service.

The subsequent analyses in this study are grounded in a participatory approach (Table 1) and are informed by the findings emerging from these interviews.

Table 1: Qualitative analysis approach.

Method	No.	Localisation	Data collection		
			Tool	**Analysis criteria**	**Output**
Direct survey	10	Emilia-Romagna (6), Marche (1), Piemonte (1), Lazio (1)	Analysis of services and spaces Data collection of access for each structure	Descriptive statistical analysis Comparative analysis among the structures	Services list (Table 2) Macro-areas and flows (2.1/2.2)
Indirect survey	2	Campania (1), Lazio (1)	Analysis of services and spaces	Thematic qualitative analysis	Importance of flexibility (3.1)
Semi-structured interview	15	Emilia-Romagna (11), Marche (1), Piemonte (1), Lazio (2)	Interview guide	Thematic qualitative analysis	Implementation of services and lack of social space in the services (Table 2: 2.1/2.2/3.1)

2.1 Flows

Some areas must be restricted to professionals due to the presence of sensitive materials or confidential information, for this reason also the flows are classified and associated with every space, to regulate the entrance. Five types of movement flow have been identified: F01.1 Public: everyone can access at any time; F01.2 Public after check-in: accessible only to those who have completed the triage process; F01.3 Public under supervision: users are allowed in this area but must always be supervised; F02.1 Private: restricted to staff only; F02.2 Private with public selective access: typically, a private area, but under specific conditions approved by triage or medical staff, users may enter while supervised.

2.2 Macro-areas

In the development of this project, the spaces are divided into four categories, primarily to classify functions, monitor user and professional fluxes, and optimize the strategic layout of services for better efficiency and future adaptability. Additionally, the social area is designed to bridge gaps by creating a new community space focused on the social determinants of health.

2.2.1 Complementary area/A01

The complementary area includes essential services that support the overall healthcare system. It encompasses waiting areas, including a covered external waiting area to protect against weather. Since the service cannot open 24/7, healthcare professionals highlight the need for these shelters, as long queues often form before services open.

2.2.2 Administration area/A02

Directly connected with triage, the administrative area is a staff-restricted access only. However, the administration office is often used by some associations as a reserved space to host users with special needs or to help users with financial support. Ideally, the administration office should also collaborate with local health authorities to activate STP/ENI codes for undocumented migrants, helping to prevent miscommunications that lead the patients to give up on the enrolment and resort to emergency rooms for conditions that could be treated in primary care.

2.2.3 Medical area/A03

The access to the medical area is restricted to those who have completed the triage process. A crucial but often missing feature in outpatient clinics is a dedicated infirmary. The interviewed professionals stress its importance, especially for patients needing frequent medical dressings due to their living conditions.

The peculiarity of the third-sector outpatient clinic is the flexible doctor's office, which hosts a general practitioner but is also equipped to provide other specialized care classified as basic healthcare, such as gynaecology, orthopaedics, and dermatology. Other essential specialist services, which may not always be available in existing structures, include dentistry and psychiatric support/listening centres.

2.2.4 Social area/A04

The interviewed professionals and the literature report that patients often face not only medical challenges but also social issues such as isolation and poor living conditions [13], [14], [16]. To address this, this project developed a new approach incorporating a social area within outpatient clinics. A dedicated daytime space for socializing, combined with a multifunctional room, could host prevention and education programs in collaboration with schools or associations, fostering a more inclusive and effective healthcare system.

2.3 Meta-design development guideline

Once the spaces are classified, a meta-design is proposed to guide the optimal organization and interconnection among spaces (Fig. 1). This configuration includes the essential spaces required to optimize the model and their relationship.

The entrance should lead to a covered waiting area (Fig. 1, Table 2: 01.1.1), which shelters users before triage (Fig. 1, Table 2: 04.1.1). Triage directs users to one of the clinic's three main services (A02/03/04) and grants access to the internal waiting area (Fig. 1, Table 2: 01.1.2) and its services (Fig. 1, Table 2: 01.1.3) for those screened. It also provides access to the infirmary (Fig. 1, Table 2: 02.1).

The administration office (Fig. 1, Table 2: 04.1.2) is the only space accessible to the public under selective access (F02.2), ideally, to offer NHS enrolment support and financial services. Other administrative spaces, like the pharmacy (Fig. 1, Table 2: 04.2.1), storage (Fig. 1, Table 2: 04.2.2/3), and staff changing rooms (Fig. 1, Table 2: 04.3), are restricted to staff.

The medical area should have direct access to the waiting room (Fig. 1, Table 2: 01.1.2) and include various healthcare services, like flexible doctor's offices (Fig. 1, Table 2: 02.2.2), dental offices (Fig. 1, Table 2: 02.2.3), and listening centres (Fig. 1, Table 2: 02.2.4). It is recommended to include two flexible consultation rooms, accommodating both specialist (e.g. gynaecology) and general doctor consultations simultaneously.

The triage should allow access as well to the social area composed of a daily space (Fig. 1, Table 2: 03.1.1) for sociality and a multifunctional room (Fig. 1, Table 2: 03.1.2) for health education, prevention programs, and community collaborations, enhancing inclusivity.

Fig. 1 shows the relationship among the above-mentioned spaces and works as a guideline for design purposes.

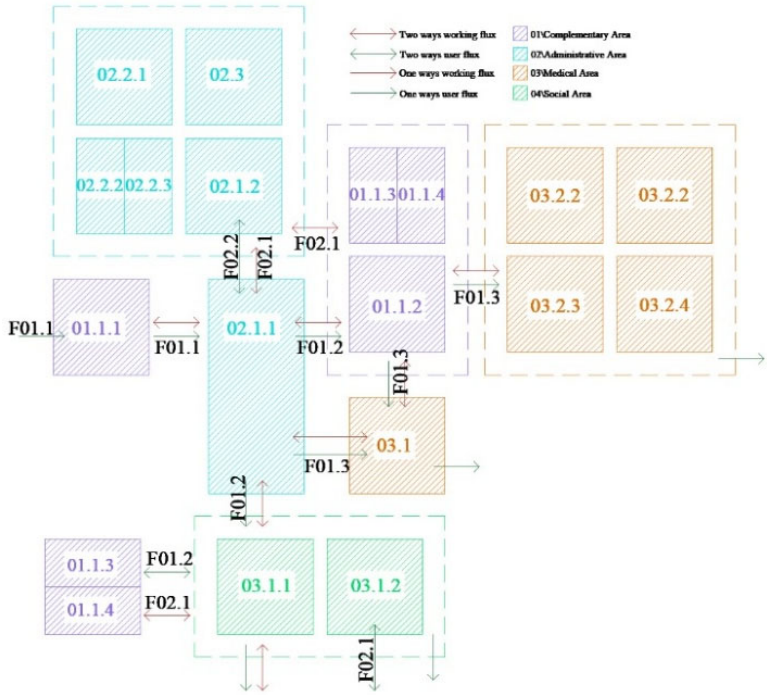


Figure 1: Schematisation of meta-design and relationship (flows) among essential spaces. Purple = A01/complementary area; Blue = A02/administration area; Orange = A03/medical area; Green = A04/social area; Red arrow = professional flow; Green arrow = user flow.

Table 2: Space categorization and allowed accesses.

Category code	Code	Space	Flow
A01: Complementary area	01.1.1	External cover area	F01.1
	01.1.2	Internal waiting area	F01.2
	01.1.3	User toilet	F01.1
	01.1.4	Staff toilet	F02.1
A02: Administration area	02.1.1	Triage	F01.1
	02.1.2	Administrative office	F02.2
	02.2.1	Pharmacy	F02.1
	02.2.2	Clean deposit	F02.1
	02.2.3	Waste deposit	F02.1
	02.3	Staff changing room	F02.1
A03: Medical area	03.1	Nursing	F01.3
	03.2.2	Flexible doctoral office	F01.3
	03.2.3	Dentist	F01.3
	03.2.4	Listening centre/psychiatrist	F01.3
A04: Social area	04.1.1	Daily space	F01.3
	04.1.2	Multifunctional lab	F01.3

3 REQUIREMENTS AND TECHNOLOGICAL DEVELOPMENT

This section presents the technological design of the modular system, focusing on the needs identified in the meta-design and offering a technical solution for project development and implementation. Specifically, these needs were defined through key requirements that the technology must address to achieve the study's objectives. Additionally, the panels were categorized to ensure flexible applications within the meta-design and implementation process.

3.1 Technological requirements

To develop a flexible and adaptable structure, a panel-based system was chosen, meeting three key service requirements: modularity, construction efficiency, and ease of dismantling. This approach aligns with design for disassembly principles and the circular economy, emphasizing sustainability through technological solutions and natural materials that offer environmental benefits while complementing the overall system.

By utilizing a predefined panel catalogue, the system supports customizable layouts tailored to the specific needs of each outpatient facility, which may vary over time. The integration of these panels with building finishes and systems simplifies the construction process, reducing overall build time and promoting a holistic approach to temporary structures with a focus on wellbeing. This ensures that temporary healthcare facilities maintain high-quality standards, reducing the risk of short-term solutions becoming permanent fixtures that lack durability or comfort. Once no longer needed, the structure can be removed, allowing for the restoration of urban space without additional land consumption.

The design also prioritizes the use of natural materials, reinforcing sustainability, and supports a biophilic approach, enhancing energy efficiency and off-grid performance, and ensuring the long-term viability of the building.

3.2 Panels categorization

The panels are designed to be flexibly paired, thus adapting to the needs of various situations. To achieve this while optimizing the production process, a matrix of different solutions has been developed (Table 3), each tailored to meet the main service requirements: modular structure, rapid construction, easy assembly and disassembly, easy maintenance, and well-being over the required period.

The panels are categorized based on the technology used in their design. To streamline both design and production, panels with similar functions typically share the same technological structure and differ only for finishing or additional components.

3.2.1 Standard panels/P01

The standard panels (Fig. 2(a)) are available in two dimensions: 01.1.a (0.6×2.1 m) and 01.1.b (0.6×0.6 m), (Table 3: 01.1). Both dimensions are essential for constructing the system. Specifically, the 01.1.b (0.6×0.6 m) panels are required to achieve the standard height for habitability and are used above the feature panels that do not need a smaller version. Standard panels are utilized when no special features are needed, and they can be used as vertical and horizontal closures.

3.2.2 Systems panels/P02

The system panels (Fig. 2(b)) include one panel combining both electrical and heating systems (Table 3: 02.1), and another panel dedicated solely to the electrical system (Table 3:

Table 3: Panel categorization. a and b define the dimensions applicable to the panel; V, vertical; F, floor; and C, ceiling; specify whether a panel requires slight modifications to connect with others in one of these specific units. When nothing is specified, a standard panel can be used.

Category code	Code	Panel	a	b	V	F	C
P01: Standard panels	01.1	Standard	0.6×2.1	0.6×0.6	–	–	–
P02: System panels	02.1	Electric + Heating	0.6×2.1	–	02.1.1	02.1.2	–
	02.2	Electric	0.6×2.1	–	02.2.1	02.2.2	–
P03: Integrated panels	03.1	Equipment	0.6×2.1	–	–	–	–
	03.2	Mycelium	0.6×2.1	–	–	–	–
	03.3	Biophilic	0.6×2.1	–	–	–	–
P04: Aperture panels	04.1	Door	0.6×2.1	0.6×0.6	–	–	–
	04.2.1	Window: one	0.6×2.1	–	–	–	–
	04.2.2	Window: two	0.6×2.1	–	–	–	–
P05: Structural panels	05.1	Structural	0.6×2.1	0.6×0.6	05.1	05.1	05.1
	05.2	Corner structural	0.6×2.1	0.6×0.6	05.2	05.1	05.1
P06: Hydraulic panels	06.1	Sink	0.6×2.1	–	06.1.1	06.1.2	–
	06.2	WC	0.6×2.1	–	06.2.1	06.2.2	–

02.2). To ensure proper earth connection, a specific configuration is required for floor panels. In particular, the vertical panel (Table 3: 02.1.1) must be connected to the floor panel (Table 3: 02.1.2) to minimize on-site labour and simplify the installation process.

3.2.3 Integrated panels/P03

The integrated panels (Fig. 2(c)) serve different functions, but the proposed technological system remains consistent. It features an internal structure designed to support external loads, such as shelf panels for pharmaceuticals or equipment (Table 3: 03.1). Additionally, the panels incorporate green elements (Table 3: 03.2/3) aimed at creating a biophilic environment for users. One such element is the potential use of mycelium (Table 3: 03.3) in panel construction, which is hypothesized to offer promising capabilities in enhancing air quality [17].

For these panels, no specific adjustments for vertical and horizontal closures are required.

3.2.4 Aperture panels/P04

Due to the specific requirements above the door panel (Fig. 2(d), Table 3: 04.1.a), a dedicated panel (Table 3: 04.1.b) is necessary in place of the standard one (Table 3: 01.1.b). However, for window openings (Fig. 2(e), Table 3: 04.2.1/2), no above panel modification is required, as the standard panels suffice. It is possible to design one or two casement windows.

No specific adjustments for horizontal closures are required.

3.2.5 Structural panels/P05

The structural panels, linear (Fig. 2(h)) and angular (Fig. 2(i)), must be positioned at regular intervals, with no more than three non-structural panels between two structural panels. Each structural panel (Table 3: 05.1/2) must be paired with a smaller version above it (Table 3: 05.1/2.b) and combined with a structural horizontal panel. However, for both vertical and horizontal enclosures, no modifications are required, meaning the same structural panels (Table 3: 05.1 or 05.2) can be used for all the versions.

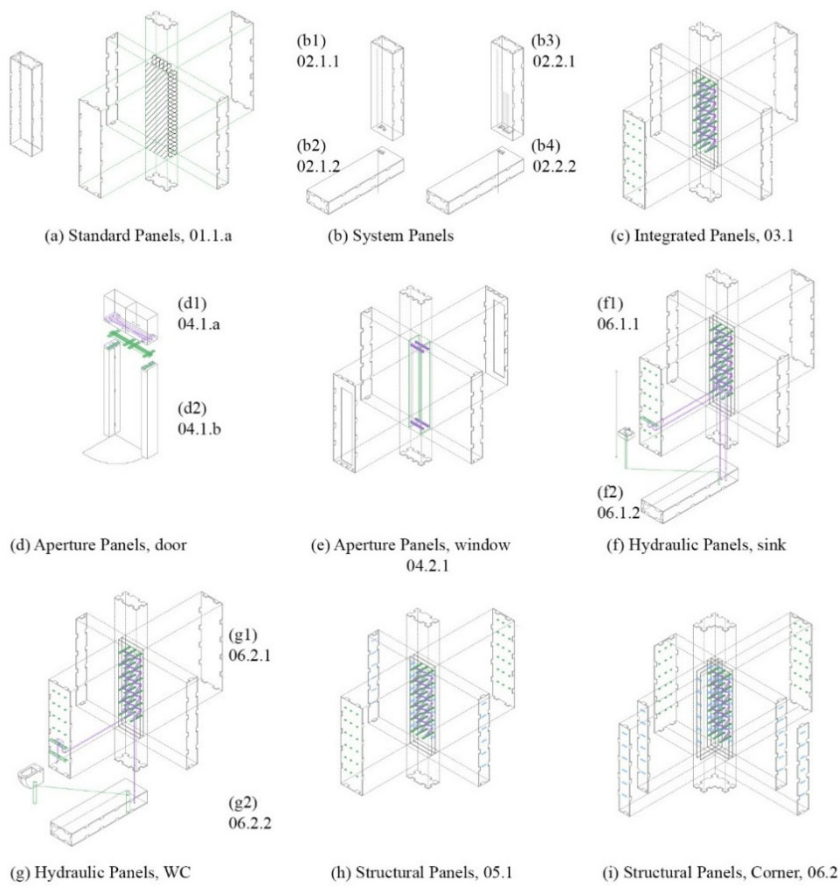


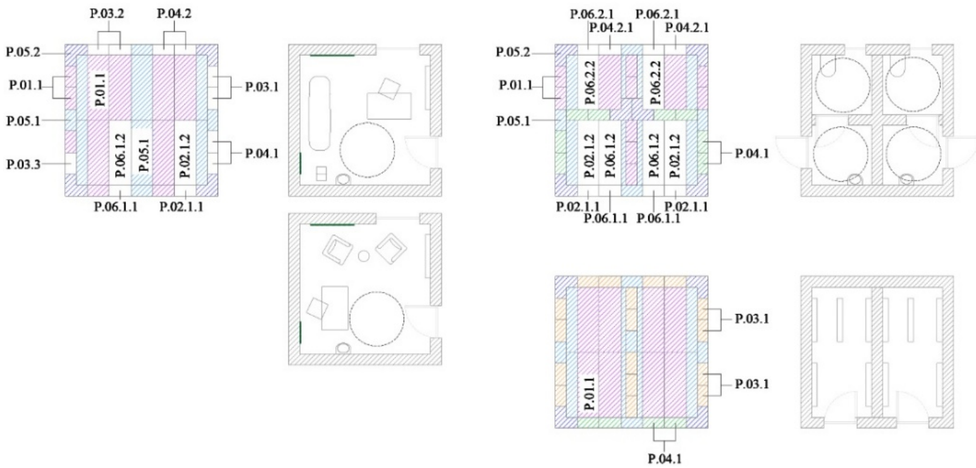
Figure 2: Panel matrix in reference to Table 3. (a) Standard panels; (b) System panels; (c) Integrated panels; (d) Aperture panels, door; (e) Aperture panel, window; (f) Hydraulic panel, sink; (g) Hydraulic panel, WC; (h) Structural panels, linear; and (i) Structural panel, angular.

3.2.6 Hydraulic panels/P06

The hydraulic panels are designed to ensure the proper functioning of bathrooms (Fig. 2(g)) and consultation rooms, each requiring at least one sink (Fig. 2(f)) according to regulations. As happened for the system panels, a specific configuration is needed for the floor panels (Table 3: 06.1.2, 06.2.2) to ensure proper installation and minimize on-site labour. No specific adjustments for vertical and horizontal closures are required.

3.3 Minimal cell and standard designs

The minimal cell was designed to provide a flexible space solution for urgent situations (Fig. 3(a)), offering a standardized approach, which can include all the services indicated in the meta-design. It consists of 6×6 panels, with the first layer made of 0.6×2.1 m panels, and a second layer of overlapping 0.6×0.6 m panels, to meet the minimum room height requirements of 2.70 m.



(a) (b)

Figure 3: Minimal cell in standard designs with reference to Table 3. (a) Adaptation of the minimal cell design to categorized spaces: a. up flexible doctor's office, a. down listening centre; and (b) Optimization of the minimal cell design for space efficiency: b. up bathroom, b. down storage areas.

This adaptable design serves as a functional solution, accommodating other essential services such as bathrooms and storage areas (Fig. 3(b)), making it an effective model for emergency and flexible use. The selected panels are a suggestion and can be combined as desired.

4 IMPLEMENTATION OF THE SYSTEM

The system is designed for adaptability, making it suitable not only for third-sector settings but also for a broader range of applications. It can be customized to address varying needs over time, such as fluctuating demands, seasonal changes, or emergencies. Specifically, the outpatient clinic design can be implemented in four different ways.

4.1 Implementation of the meta-design

The meta-design framework allows for flexible implementation, accommodating the integration of individual modules or entire functional areas according to site-specific requirements. This approach is particularly advantageous in new-build scenarios, where it provides scalability and adaptability to dynamic needs. The example shown (Fig. 4) illustrates the addition of an entirely new medical area.

4.1.1 Implementation of the existing facilities

The meta-design has been developed to meet specific needs without requiring all areas to be available for full functionality. By following the provided guidelines for spatial consolidation and flow, existing services can be integrated with missing, substituted, or additional spaces as needed. For example, as shown in Fig. 5, the triage service of an existing facility is enhanced by adding an external canopy, an infirmary, a multifunctional laboratory, and a temporary restroom.

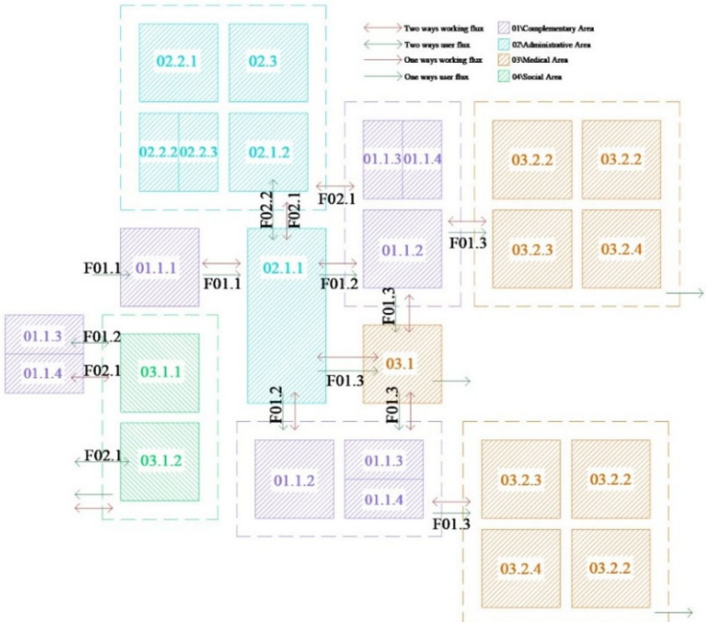


Figure 4: Implementation of the meta-design. This solution illustrates the addition of an entire medical area, based on the hypothesis of increased demand for medical spaces. Similarly, other areas can be expanded using the same approach, following the meta-design approach outlined in Section 2.3.

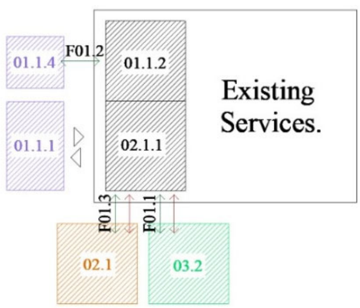
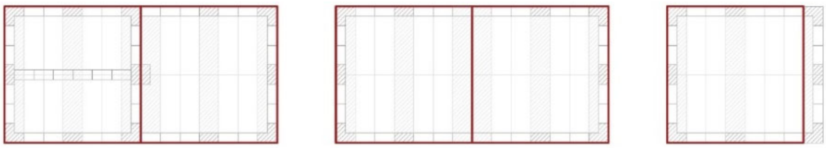


Figure 5: Implementation of existing facilities. In this case, only a few additional spaces are needed to complement the existing services. The same guidelines outlined for the meta-design development (Section 2.3) can be applied to integrate these new spaces.

4.1.2 Implementation of the minimal cell

The spaces are not designed with a fixed layout; rather, the entire system is intended to be customized based on the specific needs and patient flow of the healthcare facility, with the option for temporary implementation. The structure can be easily expanded, for example to accommodate waiting areas or to directly connect a bathroom to a medical consultation room.

This can be achieved in two ways: by adding a minimal additional cell (Fig. 6(a)) or by simply incorporating the necessary panels (Fig. 6(b))



(a) (b)

Figure 6: Implementation of the minimal cell. (a) Two examples of the addition of a minimal cell; (b) Addition of single panels.

4.1.3 Implementation of the existing cell

It is also feasible to retrofit an existing structure by replacing panels that require maintenance, or by exchanging standard panels for those equipped with additional functionalities, such as integrated electrical and heating systems (Fig. 7). This approach is particularly relevant when expanding spaces, such as enlarging a waiting area. These adaptabilities make this solution especially suitable for emergency structures, as it allows for seamless modifications in response to evolving operational requirements.

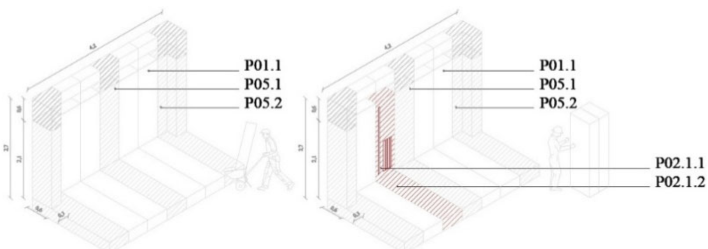


Figure 7: Implementation of the existing cell by replacing one standard panel.

5 DISCUSSION AND CONCLUSION

This study presents a new strategy based on hands-on knowledge for implementing outpatient clinics in the third sector. The proposed system can be used in both everyday services and emergencies to ensure easy access to basic healthcare. It introduces a meta-designed, adaptable solution that meets different needs, along with a technological approach that enables quick assembly, disassembly, and an all-in-one system, eliminating the need for additional on-site construction work. Moreover, the adopted technological strategy ensures easy transportability and zero waste, aligning with the principles of Design for Disassembly and the Circular Economy.

Potential challenges include the cost implications of the project, the available space for the implementation of the existing facilities, and the overall performance of the solution. To address these, further implementation should include testing full-scale panels and evaluating their functionality. Additionally, performance analysis would provide deeper insights into the system's energy efficiency and air quality.

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