Adaptive design for social-oriented healthcare: integrating MEP systems into SIPs structures for long-term temporary application

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Abstract—**This paper presents the development of a flexible, demountable, and fully equipped architectural system, conceived in response to insights from a previous study involving interviews with third-sector healthcare providers.**

The aim was to rethink meta-design strategies more adaptively and responsively. The research highlighted a growing demand for spatial solutions that address not only clinical needs but also the broader social dimensions of well-being, in line with the World Health Organization's framework of Social Determinants of Health (SDH).

This broader perspective calls for a shift in architectural practice—one where the built environment contributes proactively to both individual and community health, extending beyond conventional medical settings.

The proposed system reconfigures traditional Structural Insulated Panels (SIPs) through a Design for Disassembly (DfD) approach, enhancing them with pre-integrated service cavities capable of accommodating mechanical, electrical, and plumbing (MEP) systems. These upgraded panels are supported by a flexible design strategy that allows for context-specific configurations, ensuring optimal adaptability across different scenarios.

This approach significantly reduces construction time and enables immediate functionality without requiring additional installations or interior finishes. The system's feasibility is validated through a design matrix and the implementation of three theoretical case studies in the Emilia-Romagna region in Italy, as detailed in the second part of the paper.

Keywords—**Design for Disassembly, Construction Process, Healthcare Design.**

I. INTRODUCTION

The construction sector contributes to environmental degradation, resource depletion, energy consumption, and greenhouse gas emissions [1]. Construction activities account for approximately 32% of global resource use, including 12% of water and up to 40% of total energy consumption. Around 40% of all raw materials extracted and 25% of virgin timber are utilized in construction processes [2]. Furthermore, the construction and demolition (C&D) waste, defined as material produced during the processes of construction, renovation, or demolition of structures, poses severe environmental threats, contributing to waste accumulation, soil and air pollution, endangering ecosystems, and depletion of natural resources [2]. More than 80% of this waste comprises concrete, bricks, tiles, finishing materials, dust, and other construction materials debris [3].

The most critical phase for C&D waste generation is the end-of-life stage, responsible for approximately 50% of the total waste [4]. This is primarily because most construction materials are discarded rather than reused, lacking the inherent potential for recovery or repurposing [5].

A strategy to mitigate the environmental impact of construction is to adopt circular economy (CE) principles within the building industry [6]. In addition to minimizing material use and promoting recycling, the CE emphasizes the direct reuse of building components as a more sustainable solution [4],[5]. The European Parliament defines the CE as a production and consumption model aimed at extending the life cycles and generating added value through practices such as reuse, repair, refurbishment, and recycling [8].

Design for Adaptability (DfA) and Design for Disassembly (DfD), along with careful material selection and resource efficiency, are recognized as the key early-stage design strategies for transitioning towards a circular build environment [9]. In particular, this paper aligns with the definition of adaptability provided by Ross et al. [10], which describes it as the ability of buildings to be physically modified, deconstructed, refurbished, reconfigured, and/or expanded. Importantly, this definition acknowledges a temporal dimension:

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adaptability should not only anticipate future use but also accommodate changes during the building's operational lifespan.

Additionally, the principles of DfD, as defined by Tsoka et al. [11], refer to the capability of buildings to be easily disassembled into their constituent parts at the end of their lifecycle, facilitating efficient material recovery for reuse, recycling, or refurbishment. This paper emphasizes the importance of building demountable structures and the reuse of building structures to construct new buildings, aligning with urban challenges such as overdevelopment, increasing landfill use, and the destruction of soil ecosystems [12].

Consequently, governance and policy are necessary to prevent land misuse and promote urban sustainability. The integration of CE principles enables the development of reusable structures that directly support these goals.

Previous studies have explored the benefits of using reusable components and have highlighted the importance of material choices and connection types during the design phase [13]. However, despite growing interest in circular construction strategies, the integration of basic MEP (Mechanical, Electrical, and Plumbing) components into DfD (Design for Disassembly) panel systems remains largely unexplored in the existing literature. This strategy is likely to be capable of meeting the technological demands of long-term temporary structures. Notably, many buildings initially conceived as temporary often remain in place indefinitely, effectively becoming permanent structures [14]. The CE approach, by increasing reusability and adaptability, challenges the conventional boundaries between temporary and permanent architecture [15].

Therefore, the object of this study is to delineate a technological system suitable for long-term temporary buildings, specifically to avoid the deployment of provisional tent-based structures in third-sector healthcare contexts. This approach also seeks to reduce the on-site construction time through the pre-integration of MEP systems within Structural Insulated Panels (SIPs) technology, enabling the creation of demountable, easily stored facilities. These facilities would uphold the high standard of indoor air quality and user comfort, ultimately enhancing the patient experience. As in everyday environments, the quality of temporary shelters significantly affects both physical and mental health [16].

This is especially crucial in contexts where users have previously experienced violence of social exclusion, aligned, as well, with the imperative to protect ecosystems and urban surroundings, by promoting removability, reassembly, and repurposing structure, instead of occupying additional urban space unnecessarily.

II. METHODOLOGY

This study builds upon a previous investigation that analysed third-sector facilities in Italy [17]. That research highlighted the importance of developing a design system for such facilities, focusing on enhancing indoor quality to support users' psychological and social well-being. Grounded in those findings, this paper explores the implementation of removable, prefabricated structures in three healthcare facilities located in the Emilia-Romagna region, in Italy. These additions make use of SIPs with pre-integrated basic MEP systems – specifically ventilation, electrical wiring, and plumbing.

The integration of MEP systems arises from the need to provide safe and high-quality indoor environments within temporary healthcare structures. While the solution is applicable to medical offices or other spaces as well, this paper focuses on the implementation of modular spaces aimed at psychological and social support. These efforts are aligned with the UN's definition of the Social Determinants of Health (SDH) [18], aiming to create a holistic view of people's health.

The aim is to create service-providing environments that avoid the need for conventional building processes or interior finishing, as illustrated in Figure1, in order to fasten the entry into operation of the service, since the SIPs panels arrive on-site with embedded MEP infrastructure.

To properly design the panels, a thorough understanding was required of how third-sector healthcare facilities operate, including user perception and indoor comfort, which subsequently informs the necessary technological and spatial requirements [17].

Special attention was given to panel-based systems, as utility connections must be embedded in both vertical and horizontal enclosures. This demands the development of

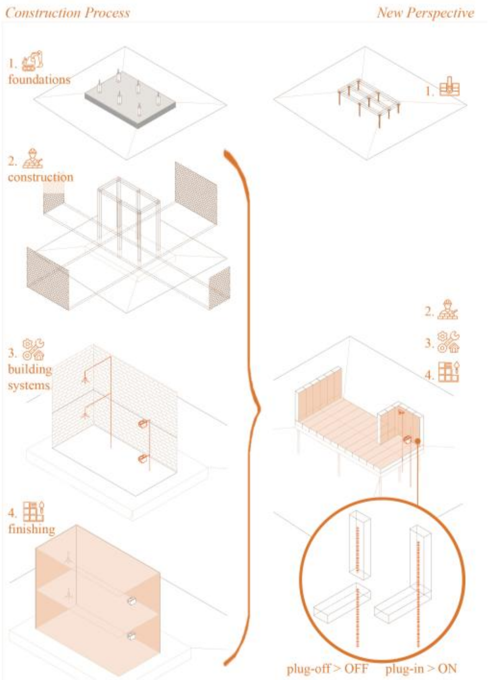


Fig. 1. Comparison and concept development of the new construction process proposed in the paper.

specialized panel types. The standard SIPs panel dimensions used in this study are: 0,6mx 2,1m (vertical); 0,6mx0,6m (vertical); 0,6mx1,8m (horizontal).

The energy balance was determined using equation (1):

$$\begin{cases} \dot{m}_{\iota n} = \dot{m}_{out} \\ \dot{Q}_{tot} - \dot{L} = \dot{m}\,[\,(h_2 - h_1) + \frac{1}{2}\,(w_2^2 - w_1^2) + g\,(z_2 - z_{1)})] \end{cases} \tag{1}$$

Where $\dot{Q}_{tot}$ is defined as:

$$\dot{Q}_{tot} = \dot{Q}_{tr} + \dot{Q}_{vent} - \dot{Q}_{rad} - \dot{Q}_{app} - \dot{Q}_{pers} \tag{2}$$

This equation assesses the energy demand required to operate the new building configuration, without initially addressing specific machine performance. For the purposes of this analysis, changes in kinetic and potential energy are assumed negligible, and the working fluid is considered incompressible with constant specific heat. Accordingly, the change in enthalpy simplifies to:

$$\begin{aligned} &\dot{Q}_{tr} = \sum_i U_i\,A_i\,\Delta T \;;\; \dot{Q}_{vent} = \dot{m}\,c_p\,\Delta T \\ &\dot{Q}_{rad} = GAg \qquad ;\; \dot{Q}_{app} = \mathrm{Pt} \quad ;\; \dot{Q}_{per} = \mathrm{n}\dot{q}_{per} \end{aligned} \tag{3}$$

The values used for the case studies correspond to SIPs panels constructed with Oriented Strand Board (OSB) and mineral wool insulation. The analysis was conducted under winter conditions – typical for northern Italy (Climate Zone E) – and constants were derived from applicable building regulations, as shown in Table 1.
For $\dot{Q}_{per}$ only sensible heat is considered, as the dimensioning pertains to winter operation.

System configuration and panel integration

During the system dimensioning phase, three case studies of varying sizes were evaluated to assess the scalability of a standardized panel-based system under different spatial requirements.

The objective was to maintain consistent MEP system sizing across all structures, both for structural reasons—larger systems may compromise panel structural integration—and production reasons, as it affects the ability to standardize and reuse panels across different projects.

TABLE I

VARIABLES AND UNITS

Symbol	Unit	Rif
T_{out}	-5°C	UNI 10349-1:2016
T_p	20°C*	D.P.R. 412/1993
λ_{OSB}	0,13 [W/mK]	Technical file
λ_{MWood}	0,033 [W/mK]	Technical file
ρ_{aria}	1,2 [kg/m^3]	[19]
c_{aria}	1005 [J/kgK]	[19]
r	0,5 [V/h]	UNI 10339; Italian regional NHS regulation
$\dot{q}_{per}$	60 [W/m^2]**	EN ISO 7730
G	150 [W/m^2]	Pick esteem
g	0,6	Technical file
P	20W***	Technical file
t	5h	Pick esteem

* 22°C if the intended use is the bathroom.

**Refers to an average-size individual with a corporal surface estimated 1,8m^2 in resting condition – sitting down.

***Considered transformed into heat apport a 70%.

Three specialized panel types were developed, each corresponding to a key MEP function: electrical, plumbing, and mechanical ventilation. For each case study, appropriate components such as radiators, mechanical ventilation systems (MVS), electric boilers, and plumbing networks were pre-dimensioned.

An electric radiator with a thermal output of 200 W was selected for all case studies. This solution was preferred over hydraulic radiators, HVAC systems, or heat pumps due to its ease of installation and disassembly, which aligns with the project's goals of modularity, reusability, and adaptability. Electric radiators offer a simple plug-and-play mechanism that facilitates rapid deployment and future relocation without requiring complex plumbing or refrigerant infrastructure. Since the intervention focuses on extending existing facilities with limited additional space rather than servicing entire buildings, the energy demand and cost implications associated with this expansion were considered limited. This justified the use of simple, modular components such as electric radiators.

In contrast, the MVS presented more variability across the case studies. The system needed to accommodate different room sizes and functional programs, which introduced challenges in both structural and design terms.

To preserve reusability and modularity, each panel was designed to accommodate a ventilation duct with a diameter Ø_{pro} = 0,012 m per direction. The number of required panels was calculated based on the ratio of the total system area (A_{case} = calculated for each case study) to the area of the duct section:

$$n = \frac{A_{case}}{A_{prog}} \tag{4}$$

Plumbing systems used copper piping, and usage levels were estimated according to regulatory standards, as show in Table 2. For design consistency and modular replication, pipe dimensions were standardized and calculated as a single unit (sink, WC), allowing panels to be reused in different applications without major reconfiguration.

TABLE 2

VARIABLES AND UNITS

Symbol	Unit	Rif
T_{out}	60°C	UNI 10349-1:2016
T_p	15°C	D.P.R. 412/1993
λ_{COP}	0,025 [W/mK]	Technical file
ρ_{COP}	938 [kg/m^3]	[19]
$\dot{V}_{sink}$	15 [l/use]	CISBE Guide G; ASHRAE Applications Handbook
t	1,5 [min]	Pick esteem
w_{sink}	0,5 [m/s]	UNI EN 806-3
$\dot{V}_{WC}$	15 [l/s]	CISBE Guide G; ASHRAE Applications Handbook
w_{WC}	1,5 [m/s]	UNI EN 806-3
c_{aria}	4180 [J/kgK]	[19]
C_{boiler}	75 [l/kg]	Technical file
P_{boiler}	2 [kW]	Technical file

Cost-benefit analysis

Finally, a cost-benefit analysis was conducted for each of the three case studies under two different scenarios. The first one considers the initial construction costs, while the second focuses on the costs related to reuse.

In the first scenario, construction costs were calculated on the price perm^2 derived from technical data provided by companies producing panel structures with natural materials, and then multiplied by of each case study. In contrast, for the reuse scenario, construction costs were limited to labour for disassembly and transportation, calculated as a percentage on the original construction costs from the first scenario, excluding the repetition of material costs, as detailed in Table 3.

Table 3 also presents production costs, expressed as a percentage of construction costs for each scenario. Management costs- including utilities, administration, and volunteer reimbursements- are also reported. These were estimated according to the DEI price list and adjusted according to the size of each case. Utilities costs considered for all three case studies include lighting, potable water, cleaning and disinfection, administration, and heating.

Since no companies currently produce natural panels with the required features, the construction cost for the electric and plumbing systems were estimated separately, according to DEI price list and based to their applicability to each case study. Otherwise, the total esteem will be inaccurate, as it would only reflect the material costs of the panels itself, excluding the embedded system components.

Most third-sector facilities operate with volunteers based in the city; thus, a transport reimbursement of €20 per volunteer per opening week was included.

TABLE 3
VARIABLES AND UNITS

Item	Unit
Construction Costs (CC)	800 [€/m^2]*
Labour Cost- Reuse scenario	30% CC
Transport Cost-Reuse scenario	2% CC
Production Costs (PC)	
Area costs	-not applicable as the area is already considered as association property and in use-
Site remediation	
Adaptation costs	
Site preparation costs	
Demolition costs	
Urbanization charges	
Testing and commissioning	2% CC
Health and safety costs	5% CC
Overhead and insurance costs	2% CC
Amortizations	10% CC
Professional fees	8% CC
Management Costs (MC)	
Utilities costs	18.01 [€/m^2]*
Utilities costs- system construction electric	32.25 [€/m^2]*
Utilities costs- sys. constr. plumbing	78.01 [€/m^2]*
Volunteers' reimbursement	20 [€/week]*

*1st case = 17,64 m^2 ; 1 volunteer ; no plumbing construction.
2nd = 60,48 m^2 ; 2 volunteers ; no plumbing construction.
3rd = 11,52 m^2 ; 0 volunteers.

It is important to note that there is no payback on this investment, as the system is a free public service with no revenue generation. Therefore, the nominal cash flow reflects the expenditure responsibility borne by the associations– amortization and management costs in the first scenario, and management costs only in the reuse scenario, since production costs are assumed to be paid in the first year for both cases. Management costs for the first year are excluded due to bureaucratic delays and ongoing construction activities.

III. PANEL DESIGN

The system integrates prefabricated panels not only with standard construction functions but also with basic MEP services. Due to the need for grid connectivity, MEP integration involves both vertical enclosures (walls) and horizontal ones (floor and ceiling).

These panels require specific design adaptations to accommodate utilities that must enter and exit the structure through the ground or roof, such as electrical cables, water supply, and ventilation ducts. Each panel is constructed with a structural OSB layer, s= 30 mm, covering the outer surfaces and an internal core of mineral wool insulation s= 240 mm, for a total panel thickness of 300 mm. Since panels are connected to utility grids via floor modules, their orientation during installation is fixed and must follow a defined layout, as shown in Figure 2.

Plumbing System

The plumbing system is designed to meet the basic needs of outpatient clinics, including the installation of sinks for doctor's offices, bathroom sinks, and toilets. Figure 3 illustrates the layout of the plumbing systems, showing the placement of electrical conduits, hot and cold-water pipes, and wastewater discharge routes. The upper diagram (Figure 3a) indicates the origin and destination of each utility (e.g., cold water from the main grid, hot water from the electric boiler), while the lower diagram (Figure 3b) details how the infrastructure is embedded within wall and floor modules. This approach aims to minimize on-site work and optimize prefabrication efficiency.

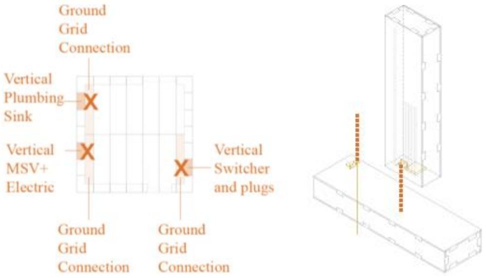
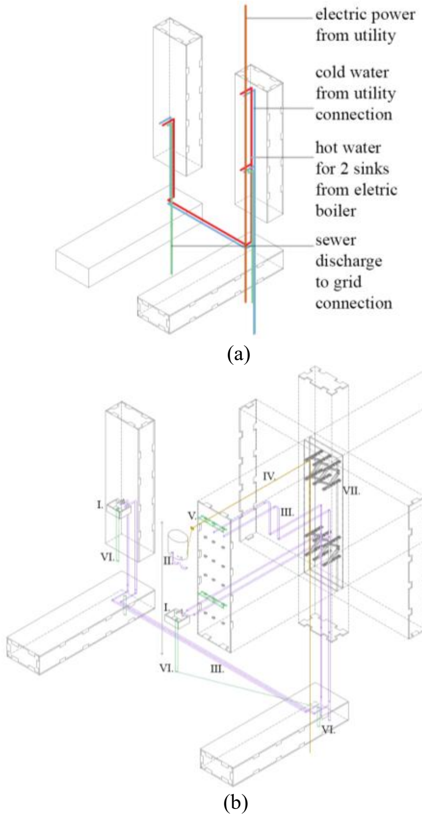


Fig.2.Design grid: correct direction of installation for MEP panels.

Cold water and electricity are supplied from the grid. The electric boiler, powered by the electrical connection, heats the water for the sinks. For logistical and safety reasons, the boiler is not installed in every room, especially not in those freely accessible to patients. Due to the number of integrated components, a reinforced wall panel is required (Figure 3b.VII). Special floor panels are also used to route sewer discharge (Figure 3b.VI) and hot water supply pipes (Figure 3b.III), based on market-standard dimensions.



(a)

(b)

Fig.3a. Flow chart of essential grid systems incorporated in the panels.

Fig.3b. 3D of the panel's connections and components. I) sinks, II) electric boiler, III) pipes $\emptyset = 5cm$, IV) electric cables and plugs, V) anchorage (DfD), VI) sewer discharge, VII) panel's reinforced structure (DfD).

The electrical system (Figure 3b.IV) is embedded only in the panels containing the boiler.

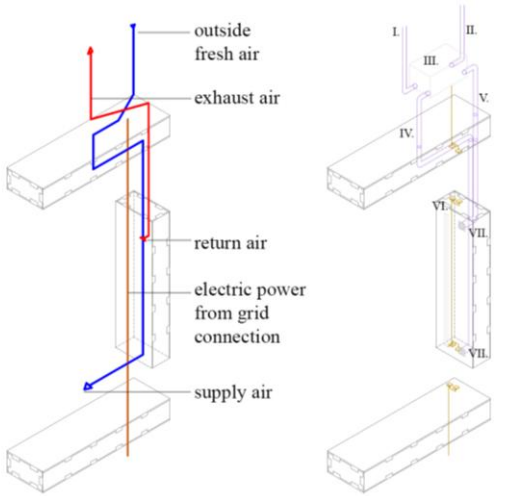
Both the sinks (Figure 3b.I) and the boiler (Figure 3b.II) are installed using demountable anchoring systems (Figure 3b.V), enabling adaptation to the specific needs of each facility.

Mechanical Ventilation System (MVS)

Given the healthcare-related use of spaces, indoor air quality is essential for both physical and psychological well-being [20], as well as in temporary shelters [16]. Although mechanical ventilation is not mandatory in the absence of surgical procedures, the study considers its application for a comprehensive analysis.

As illustrated in Figure 4a, the MVS requires only an electrical connection to function. However, specific floor and ceiling panels are necessary.

The floor panel connects the ventilation system to the ground grid while the roof one routing air ducts around the unit. For plant dimensioning analysis, the unusable space between the room and the roof is not considered; therefore, the analysis only refers to the liveable part of the project, considering that horizontal enclosure as the one facing the outside. In particular, Figure 4b shows the system configuration, which includes air intake (Figure 4b.I) and exhaust (Figure 4b.II) points, both connected to a heat recovery unit (Figure 4b.III) mounted at the top of the panel. This unit is accessible for inspection, and the modular nature of the panels allows components to be separated and maintained without disrupting adjacent elements.



(a) (b)

Fig.4a. Flow chart of essential grid systems incorporated in the panels

Fig.4b. 3D of the panel's connections and components. I) exhaust air $\emptyset = 12cm$, II) intake air$\emptyset = 12cm$, III) heat exchanger, IV) supply air pipe, V) return air pipe, VI) electric cables and junctions, VII) tabs.

The heat recovery unit connects to supply (Figure 4b.IV) and return (Figure 4b.V) air ducts serving indoor areas. Protective caps (Figure 4b.VII) shield exposed ductwork, and electrical connections (Figure 4b.VI) enable the integration of power outlets, lighting, or auxiliary heating elements within the same panel.

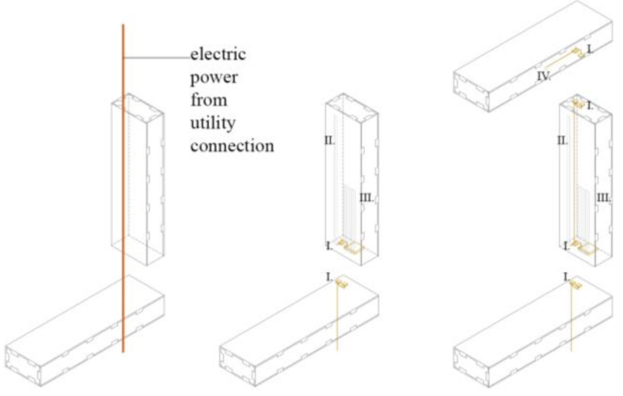
Electric System

While electrical wiring is included in all MEP panels, a dedicated electrical panel was also designed to accommodate situations where only electrical connections are required (Figure 5a). This is the least structurally demanding component and does not require reinforcement.

Cables are routed horizontally through floor panels (Figure 5b/c.I) and vertically within the wall panels. Ceiling panels may be either non-MEP or include electrical wiring (Figure 5c), depending on the intended use—for example, ceiling panels might be useful for installing smoke detectors or other sensors or light sources (Figure 5c.IV).

Light fixtures are integrated into the panel finish, with LED lamps connected directly to pre-installed electrical junctions via embedded recesses (Figure 5b/c.II).

This design supports energy-efficient illumination, essential in medical offices, which require high levels of brightness.



(a) (b) (c)

Fig.5a. Flow chart of essential grid systems incorporated in the panels

Fig.5b/c. 3D of the panel's connections and components. I) exhaust air, II) intake air, III) heat exchanger, IV) supply air pipe, V) return air pipe, VI) electric cables and junctions, VII) tabs.

Similarly, electric heaters (Figure 5b/c.III) can be embedded within the panel finish using the same infrastructure, enhancing thermal comfort while maintaining reusability.

The electrical system also supports safety devices and sensors, making each panel highly adaptable. However, it is recommended to pre-install all essential services so that, in line with circular design principles, panels can be reused without requiring significant disassembly or modifications during subsequent applications.

IV. CASE STUDY APPLICATIONS

The system was applied in three different settings within third-sector outpatient clinics located in the Emilia-Romagna region, Italy. These pilot projects enabled a critical evaluation of the system's limitations and potential, helping to refine the design and improve technical integration.

The same design process was adopted in all three cases, aim to expand the existing facilities with a common purpose—improving outpatient services. Nonetheless, the modules were adapted for different functions based on local needs. In the third case, for instance, the unit included a toilet, addressing a lack of sanitary services within the existing structure.

In each case, the modular structure was positioned in adjacent outdoor spaces with direct or easily accessible connections to utility grids, minimizing invasive infrastructure work.

To ensure that each intervention met the specific functional needs of the facility, a predefined intended use was selected for every space. Consequently, both the number of users and the size of the new building were determined based on the standard dimensions of the panels and the available site conditions. By comparing these spatial requirements with the technical calculations, it was possible to define the number and type of MEP panels needed. In line with the design principles and panels grid outlined above, each structure was then assembled accordingly.

While the following case studies represent specific applications, the system remains highly adaptable—alternative configurations are feasible, provided that indoor environmental quality standards are met.

Case Study 1 - Ferrara

The first case involved the extension of an existing third-sector facility, adding a psychology consultation room to a complex that already included medical offices, a canteen, dormitories, and a language school.

As illustrated in Figure 6, the existing clinic can be accessed via two private courtyards. Although the one is closer to the direct entrance of the outpatient clinic, it is historically protected. The unit was therefore installed in the second courtyard, enabling shared access to both the clinic and the canteen through a single entrance.

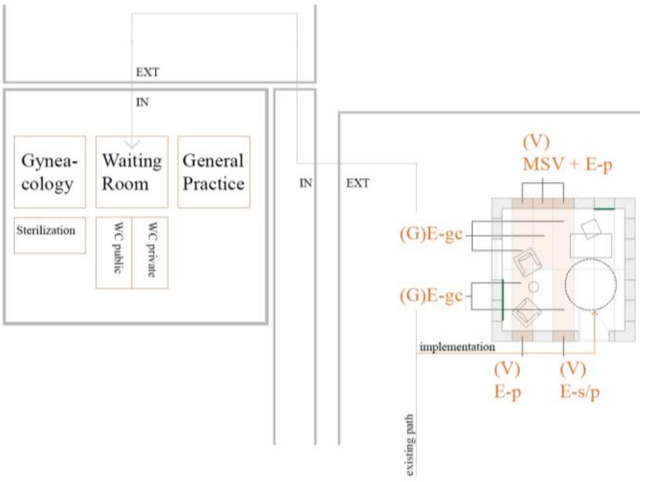


Fig.6. Implementation of the existing facilities: addition of listening centre in the external area using: 3 x vertical MSV panels (V) MSV combined with electric panels with plugs (E-p); one electric panel with switcher and plug (V) E-s/p and one with plug only (V) E-p. All panels are connected to their respective ground panels with electric grid connection (G)E-gc.

The psychology office was built using 7 panels per side, measuring 0.6 m x 2.1 m, plus an additional layer of wall panels, 0,6 m x 0,6 m to reach the required interior height of 2.7 m. Openings include two windows (0.9 m² each) and one door (0.9 m × 2.1 m), all aligned to the 0.6 m panel grid for modular consistency.

The ventilation requirements were met using three MVS panels, ensuring 0.5 air changes per hour as per regulations shown in Table 1. These panels were connected to floor modules that provided access to the grid. Two additional electrical panels were integrated, one with switches and plugs for general use, and one with a built-in electric radiator, as detailed in Figure 5b. The cost-benefit analysis indicates that a total amount of €16,522.85 is required as the initial investment to cover all CC and PC, with an amortization of €1,408 over 11 years. Including MC of €1,546.35 the total cost of implementation over the first 11 years amounts to €2995.50 per year. In the reuse scenario, these costs are significantly reduced. The investment required to reassemble the system is €5,257.53 the first year (covering CC and PC), while the nominal cash flow of -€1,546.35, demonstrate that reusing the building system provide a clear economic advantage.

Case Study 2 - Reggio Emilia

The second project focused on a larger outdoor area repurposed as a multifunctional community space. In addition to supporting outpatient care, the new unit was intended to host community engagement activities, informational sessions, and collaborations with local associations. The goal was to address SDH not only from a healthcare perspective but also through social interaction and public participation.

Figure 7 shows that the unit was built using 12 × 7 panels per wall, with the same panel dimensions and assembly method as in Case Study 1. To meet the air quality demands of a larger volume, four MVS panels were installed, each incorporating electrical outlets.

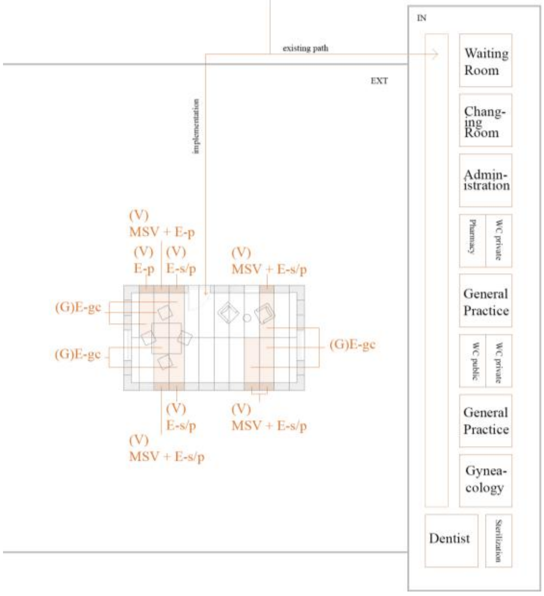


Fig.7. Implementation of the existing facilities: addition of a social area in the external yard using: 4x vertical MSV panels combined with electric panels with switcher and plugs (V)MSV + E-s/p; two vertical electric panels, one with switcher and plug (V) E-s/p and one vertical electrical with plug (V) E-p. All connecting to their respective ground panels with 8x electric grid connection (G)E-gc.

Two standard electrical panels were also added: one equipped with a heater and switch, and another for general plug access. A total of five windows were integrated, each with the same size and placement logic as in the first case. For case 2, the analysis reveals that an initial investment of €56,684.81 is necessary to cover all CC and PC, with an amortization of €4,838.40 over 11 years. Adding the MC of €3,819.99 bring the total annual maintenance cost of €8,658.39 for the first 11 years. When considering the reuse scenario, costs are notably reduced; the first-year investment to rebuild the system is €17,050.52, with a nominal cash flow of -€3,786.76.

Case Study 3 -Bologna

The third case highlights the importance of a holistic design approach that addresses not only medical care but also the comfort of users during their experience of the space. In this case, a toilet unit was added near the outpatient clinic, reducing the need for users to cross administrative areas to access sanitary facilities. As Figure 8 shows, space availability was more limited in this context. The unit was constructed using 8x4 panels per side, with the same dimensions and layers as the other two case studies.

The system requires one radiator to guarantee adequate conditions in winter, but unlike the other two cases, the internal temperature design target (Tp) was set at 22°C—slightly higher than the 20°C standard, as suggested by the D.P.R. 412/1993. The configuration included: two plumbing panels, one for a sink and one for a toilet; two MVS panels, one in the sink area and one in the WC area, ensuring adequate ventilation; one electric radiator, installed near the entrance, with associated electrical switch. An additional switch is placed within the toilet space for independent control. In case 3, the initial investment required to cover CC and PC is €10,856.25, with an amortization of €921.60 over 11 years. Adding MC of €331.43 results in an annual cost of €1,253.03 for the first 11 years. Under the reuse scenario, the first-year investment decrease to €3,247.72, with a nominal cash flow of -€325.10.

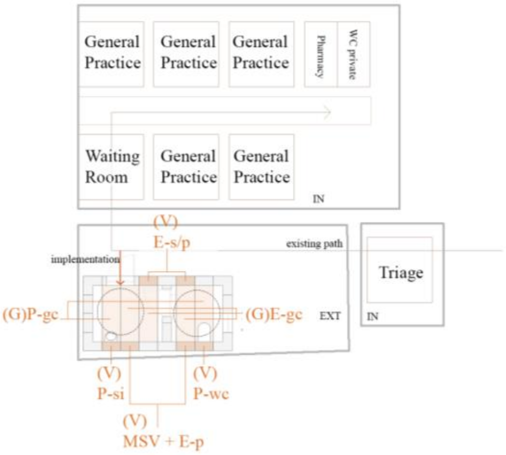


Fig.8. Implementation of the existing facilities: addition of a public toilet in the external yard using: 2x vertical MSV panels combined with electric panels with plugs (V)MSV+E-s/p; one electric panels with switcher and plug (V) E-s/p; one vertical plumbing with sink panel (V) P-si; and one vertical plumbing panels with WC (V)P-wc. All connecting to their respective ground panels with 3x electric grid connection (G)E-gc and 2x plumbing grid connection (G)P-gc.

V. DISCUSSION AND FURTHER IMPLEMENTATION

This research explored the design, integration, and application of a modular, prefabricated panel system aimed at improving healthcare infrastructure in third-sector outpatient clinics. By embedding essential MEP services—electrical, heating, ventilation, and plumbing—directly within SIPs panels, the system enables rapid deployment, reusability, and efficient connection to existing utilities. Although originally conceived for third-sector outpatient clinics, the proposed system shows potential for broader application, including public healthcare infrastructures such as NHS facilities, pending further refinement and testing.

The three case studies demonstrated the system's adaptability across varying spatial and functional scenarios, providing evidence of its potential for integration into diverse healthcare contexts. The ability to extend services without invasive construction and with minimal disruption to existing facilities offers a valuable solution for underserved or transitional care environments. Moreover, the cost-benefits analysis undelights the economic viability of the system and enhance the economic advantage of using a reusable system.

This study aimed to perform a preliminary feasibility assessment of a prefabricated construction system capable of ensuring adequate indoor environmental quality in temporary and demountable structures, integrating the essential MEP components—electrical wiring, heating, mechanical ventilation, and plumbing for both sinks (with hot water) and WCs (with cold water)—within a modular SIPs panel configuration.

While a full structural assessment is required prior to real-world implementation, the findings emphasize the system's capacity to enhance existing facilities flexibly, especially in underutilized outdoor spaces with accessible utility grids. However, despite this operational flexibility, the system's reusability is conditioned by the directional nature of its assembly: both the panels and embedded MEP elements are interconnected in a way that necessitates a specific installation orientation.

Future studies should investigate the system's performance under summer conditions and explore alternative materials or insulation strategies to optimize energy efficiency and comfort throughout the year. Furthermore, a comprehensive performance analysis will assess the maintenance requirements and system durability, while addressing risk of performance degradation. In conclusion for a holistic evaluation, the cost-benefits investigation would benefit from integration in with Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) analysis, allowing a more parametric and comprehensive analysis across the entire life cycle.

REFERENCES

[1] A. N. Meshref and A. Ibrahim, 'A dynamic approach for investigating design approaches to reducing construction waste in healthcare projects', *J. Build. Eng.*, vol. 95, p. 110092, Oct. 2024, doi: 10.1016/j.jobe.2024.110092.

[2] M. Yeheyis, K. Hewage, M. S. Alam, C. Eskicioglu, and R. Sadiq, 'An overview of construction and demolition waste management in Canada: a lifecycle analysis approach to sustainability', *Clean Technol. Environ. Policy*, vol. 15, no. 1, pp. 81–91, Feb. 2013, doi: 10.1007/s10098-012-0481-6.

[3] L. Kong and B. Ma, 'Evaluation of environmental impact of construction waste disposal based on fuzzy set analysis', *Environ. Technol. Innov.*, vol. 19, p. 100877, Aug. 2020, doi: 10.1016/j.eti.2020.100877.

[4] C. J. Kibert, *Sustainable Construction: Green Building Design and Delivery*. John Wiley & Sons, 2016.

[5] L. A. Akanbi *et al.*, 'Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator', *Resour. Conserv. Recycl.*, vol. 129, pp. 175–186, Feb. 2018, doi: 10.1016/j.resconrec.2017.10.026.

[6] J. M. Allwood, 'Chapter 30 - Squaring the Circular Economy: The Role of Recycling within a Hierarchy of Material Management Strategies', in *Handbook of Recycling*, E. Worrell and M. A. Reuter, Eds., Boston: Elsevier, 2014, pp. 445–477. doi: 10.1016/B978-0-12-396459-5.00030-1.

[7] R. Minunno, T. O'Grady, G. M. Morrison, R. L. Gruner, and M. Colling, 'Strategies for Applying the Circular Economy to Prefabricated Buildings', *Buildings*, vol. 8, no. 9, p. 14, 2018, doi: 10.3390/buildings8090125.

[8] 'Circular economy: definition, importance and benefits', Topics | European Parliament. Accessed: May 21, 2025. [Online]. Available: https://www.europarl.europa.eu/topics/en/article/20151201STO05603/circular-economy-definition-importance-and-benefits

[9] G. L. F. Benachio, M. do C. D. Freitas, and S. F. Tavares, 'Circular economy in the construction industry: A systematic literature review', *J. Clean. Prod.*, vol. 260, p. 121046, Jul. 2020, doi: 10.1016/j.jclepro.2020.121046.

[10] B. E. Ross, D. A. Chen, S. Conejos, and A. Khademi, 'Enabling Adaptable Buildings: Results of a Preliminary Expert Survey', *Procedia Eng.*, vol. 145, pp. 420–427, Jan. 2016, doi: 10.1016/j.proeng.2016.04.009.

[11] S. Tsoka and K. Tsikaloudaki, 'Design for Circularity, Design for Adaptability, Design for Disassembly', in *Circular Economy Design and Management in the Built Environment: A Critical Review of the State of the Art*, L. Bragança, P. Griffiths, R. Askar, A. Salles, V. Ungureanu, K. Tsikaloudaki, D. Bajare, G. Zsembinszki, and M. Cvetkovska, Eds., Cham: Springer Nature Switzerland, 2025, pp. 257–272. doi: 10.1007/978-3-031-73490-8_9.

[12] C. Ouyang *et al.*, 'Dynamic analysis and numerical modeling of the 2015 catastrophic landslide of the construction waste landfill at Guangming, Shenzhen, China', *Landslides*, vol. 14, no. 2, pp. 705–718, Apr. 2017, doi: 10.1007/s10346-016-0764-9.

[13] M. J. Eckelman, C. Brown, L. N. Troup, L. Wang, M. D. Webster, and J. F. Hajjar, 'Life cycle energy and environmental benefits of novel design-for-deconstruction structural systems in steel buildings', *Build. Environ.*, vol. 143, pp. 421–430, Oct. 2018, doi: 10.1016/j.buildenv.2018.07.017.

[14] R. Askar, A. L. Rodrigues, L. Bragança, and D. Pinheiro, 'From Temporary to Permanent; A Circular Approach for Post-disaster Housing Reconstruction', *IOP Conf. Ser. Earth Environ. Sci.*, vol. 225, p. 012032, 2019, doi: 10.1088/1755-1315/225/1/012032.

[15] B. Leupen, R. Heijne, and J. van Zwol, *Time-based Architecture*. 010 Publishers, 2005.

[16] K. Bhui *et al.*, 'Air quality and mental health: evidence, challenges and future directions', *BJPsych Open*, vol. 9, no. 4, p. e120, Jul. 2023, doi: 10.1192/bjo.2023.507.

[17] Mensi L., Brunoro S. 'Rethinking Healthcare Access: meta-design and technological innovations for vulnerable populations in third-sector facilities', presented at the *12th International Conference on High Performance and Optimum Design of Structures and Materials, 2025*.

[18] WHO, 'Social determinants of health', Social determinants of health. Accessed: Apr. 29, 2025. [Online]. Available: https://www.who.int/health-topics/social-determinants-of-health

[19] Y. A. Çengel, *Termodinamica e trasmissione del calore*. McGraw-Hill, 2013. Accessed: May 30, 2025. [Online]. Available: https://www.mheducation.it/termodinamica-e-trasmissione-del-calore-5-ed-con-connect-9788838655630-italy

[20] A. P. Jones, 'Indoor air quality and health', *Atmos. Environ.*, vol. 33, no. 28, pp. 4535–4564, Dec. 1999, doi: 10.1016/S1352-2310(99)00272-1.