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The S.A.F.E. project: an interdisciplinary and intersectoral approach to innovation in Furniture Design

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Abstract

The S.A.F.E. project is an industrial research project whose objective was the design and prototyping of furniture for schools and offices capable of transforming themselves into intelligent systems of passive and "life-saving" protection of people during an earthquake, integrating technical-scientific knowledge and skills as those of Industrial Design, Structural Engineering, Computer Science and Chemistry and facilitating a process of cross-fertilization of the know-how of companies belonging to very different sectors, such as that of Wood-Furniture and that of ICT and IoT. During an earthquake, furniture and mobile equipment become obstacles that aggravate the dangerous conditions and often cause death, or, on the contrary, they behave, in a completely casual way, as a protection of life in the event of collapses. This different behavior of the furniture depends above all on how they are designed and built. The design of "anti-seismic" and intelligent furniture systems, developed for public contexts (schools and offices) in highly dangerous areas, could be an alternative and integrative solution, to the seismic adaptation of buildings, for the protection of people's lives during earthquakes. The challenge of the S.A.F.E. was to innovate the design of traditional furniture for schools and offices from a structural perspective, transforming them into intelligent systems for the protection of life, which facilitate detection, localization, and rescue of survivors under the rubble during an earthquake. The paper describes the main results of the S.A.F.E. project, focusing on the methodological relevance of a systemic, interdisciplinary and intersectoral approach to innovation to be able to manage both projects and complex research problems, and accelerate the processes of transfer and cross-fertilization of knowledge and know-how, in a collaborative model between universities and companies.

Keywords: design for safety, life-saving furniture, design thinking, design-driven innovation

1 Introduction

The seismic events that hit the regions of Central Italy in 2016 rekindled the debate on the safety of public and private buildings, with great attention to those in historic centers and the lack of an adequate anti-seismic prevention strategy, throughout the italian territory. At the same time, the toll of deaths and injuries to people in the latest earthquakes has again shown the substantial inadequacy and ineffectiveness of the usual domestic practices for survival in the event of an earthquake - such as sheltering under door lintels - for example, whose purpose is to give greater chances of survival in the event of subsidence and collapses, as now widely described by the theories of the "triangle of life" (Linn, 2013).

Furthermore, today we are more than ever aware of how Italy, at high seismic risk and with a predominantly historical architectural and building heritage, the process of securing and adaptation to the anti-seismic regulations of buildings will be long, slow, and complex. This awareness is causing the social demand for security to grow exponentially in the affected communities and territories in Italy and beyond. In fact, there are many countries in the world that have a geological, urban, and architectural conformation like Italy, and therefore express the same need. These assumptions led to the project "S.A.F.E. - Sustainable design of Anti-seismic Furniture as smart life-saving systems during an Earthquake" which began in June 2018 and was co-funded by the Italian Ministry of Education-Ministry of University and Research (MIUR), and involved a public-private partnership, of which the University of Camerino was the leader, consisting of three universities and eight companies, six from the wood-furniture sector and two in the ICT and IoT sector.

The guiding idea of the project is the result of the observation of a recurring phenomenon: during an earthquake, furniture and mobile equipment become obstacles that aggravate the dangerous conditions or, on the contrary, represent a casual protection of life in the event of collapses. This different and opposing behavior of the furniture depends on how they are conceived, designed, and built. Therefore, starting from this observation, the challenge was to innovate the design of traditional furniture, for schools and offices from a structural perspective, transforming them into intelligent systems for the protection of life, which facilitate - through the integration of specific sensors and a computer platform - the localization and rescue of survivors under the rubble during an earthquake.

Historically, seismic engineering has focused primarily on the structural response of buildings subject to the earthquake, and on how to mitigate the damage induced to building bodies. In the last ten years, the design vision of the safety concept of an architectural structure has greatly expanded, also recognizing non-structural elements - including furniture - a strategic role in an anti-seismic key (ENEA, 2006; Masatsuki et al., 2008; Meguro et al., 2008), i.e., considering that the latter can help protect people's lives and collaborate to mitigate the effects of the earthquake on the building. From the observation of this double and different behavior of the furniture and of the mobile and non-structural elements during an earthquake, the hypothesis and the guiding idea have been developed that it is possible to conceive and develop furniture systems and mobile equipment, which have a function "life-saving", and passive protection during an earthquake.

The furniture and mobile equipment of schools and offices are usually "product systems", coordinated and disseminated within the building. This characteristic can translate into a fundamental factor in the development of effective and innovative actions for the prevention and reduction of damage and victims in the event of partial or total collapses of the building.

2 An interdisciplinary and intersectoral approach to innovation

The results of the S.A.F.E. they are numerous. First, it was possible to define, through the critical analysis of the state of the art of projects, products, and prototypes of life-saving furniture, already developed at national and international level, of the guidelines for the design of innovative furniture, with passive protection in the event of an earthquake (Galloppo et al., 2019).Based on the guidelines identified, four new types of furniture have been developed and prototyped (desk, equipped wall, partition wall, automated storage module), which working as a system, offer timely and collective protection, to make the environments to study and work safer (Pietroni et al., 2021).
The new "anti-seismic" furniture system is characterized by a design developed from a structural perspective and by new technical-performance requirements, which enhance the specific characteristics of school and office furniture, with new performances in terms of operation, use, resistance, safety, healthiness, and environmental sustainability. The types of furniture were selected on the basis of four fundamental parameters: (i) furniture that had the greatest potential to contribute to the goal of passive protection in school and office contexts; (ii) furniture that could work synergistically within the environments; (iii) hybrid furniture that could be used in the two contexts using the same elaborate structural solutions; (iiii) furniture as coherent as possible with the production technologies of the partnership.
The project development activity, conducted in an integrated way by the different research teams and coordinated by the design team, through the methodology of design thinking, resulted in the development, prototyping and validation of: (i) a desk, characterized by a frame with high mechanical resistance, while maintaining standard materials and production processes; (ii) a dividing wall, able to withstand the stresses of the earthquake, and contribute to their dissipation; (iii) an equipped wall, designed to shelter adults, children and people in wheelchairs, and capable of preventing the weakest infills from overturning; (iiii) an automated filing system for the storage and distribution of teaching materials for teachers, which also acts as a hub for the collection and communication of data, coming from the sensors present on the other furniture, even in the event of a power failure.
All the furniture are equipped with an integrated sensor system (Fig. 1), which, in the event of an earthquake, is activated and allows to locate the survivors, to monitor the conditions of the people under the rubble and to communicate promptly, through an IT platform for processing the data, useful information for rescuers to make their complex rescue activities faster and safer.
A fundamental aspect of the S.A.F.E. project was the interdisciplinary and intersectoral approach to innovation guided by the methodology of design thinking. In fact, there has been both a strong integration of different and complementary technical-scientific knowledge and skills - such as those of Industrial Design, Structural Engineering, Information Technology and Chemistry -, and an intersection of technical know-how of companies very different from each other. Overall, the researchers involved in the project with different technical-scientific skills were more than fifty.
The project activity allowed to conceive and test a methodological-procedural approach, evolutionary and specific to the established design thinking methodology, specifically aimed at the conception, development and experimental verification of furniture with new life-saving performance in case of earthquake.

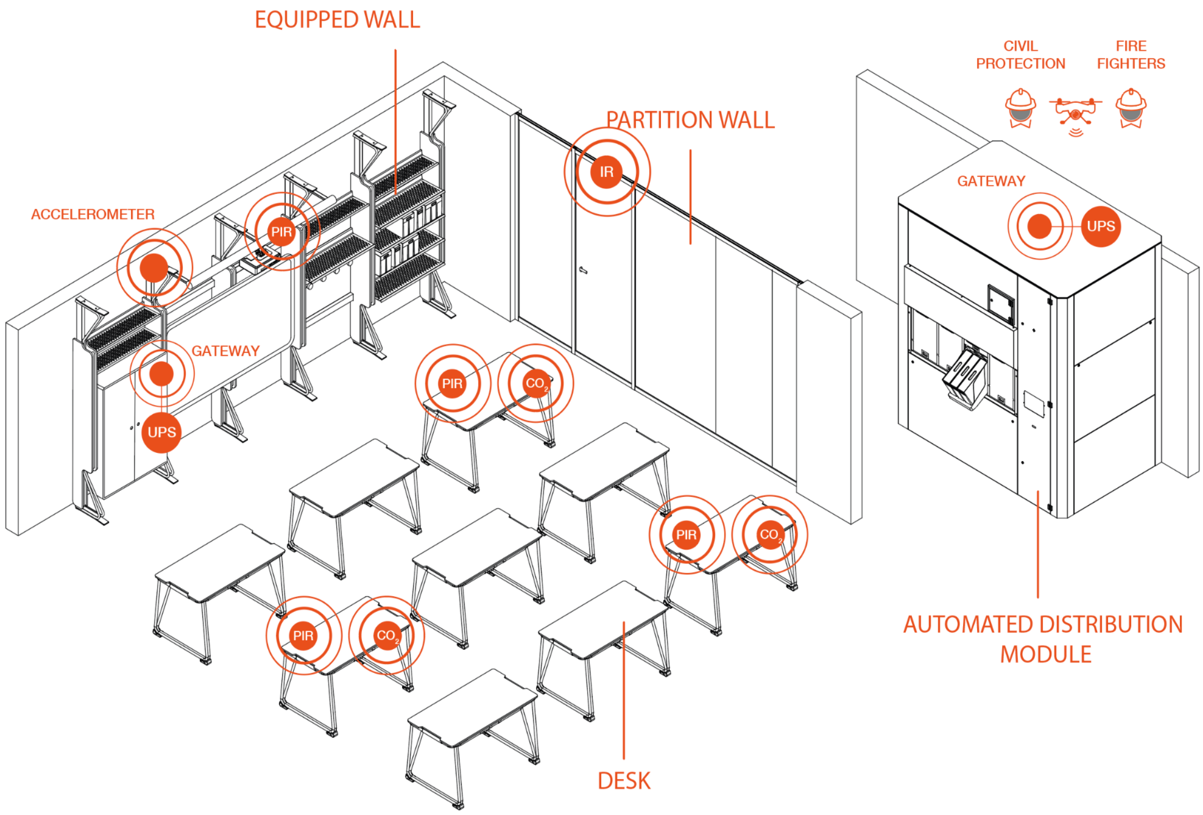

Figure 1. The four types of the Life-saving Furniture System with sensors able to communicate with the outside world through gateways (University of Camerino).

3 The methodology: the Design Thinking as a collaborative Design-driven innovation process

The methodology behind the development of the S.A.F.E. Project is Design Thinking (DT), aimed at open innovation of products, systems and services and effective management of complex interdisciplinary and cross-sectoral co-design processes. DT is a "user-centric," multi-stakeholder, participatory, pragmatic design approach that facilitates cross-fertilization between different disciplines and competencies, promotes an attitude of listening, collaboration, teamwork and knowledge transfer, and fosters the ability to focus on people's needs in solving complex problems.

In addition, DT allows for experimentation, learning from mistakes, modification and rectification for subsequent refinement of design choices, as it is a circular and iterative process, a continuous cycle of observation, reflection, implementation and verification of a new idea, project or product. Although creative thinking is the driver of DT, it is necessary to adopt a process within which creativity is stimulated, activated, and deciphered to produce innovation. In fact, the Design Thinking process consists of 5 main stages, according to the best-known model developed at Stanford University's Hasso Plattner Institute of Design (Fig. 2): (i) Empathize: empathize with users and learn about their needs; (ii) Define: define users' needs, problems and opportunities; (iii) Ideate: generate innovative ideas and solutions by continuously questioning the assumptions made; (iiii) Prototype: implement and concretize the identified solutions; (iiiii) Test: put the implemented solutions to the test.

DT thus enables the design and development of innovative solutions to complex problems by thoroughly understanding who the key players are and pragmatically experimenting with the usefulness and impacts of those solutions. Indeed, in experimental process testing, DT combines creativity and methodological rigor, imagination and concreteness, thus accelerating innovation processes focused on solutions and results.

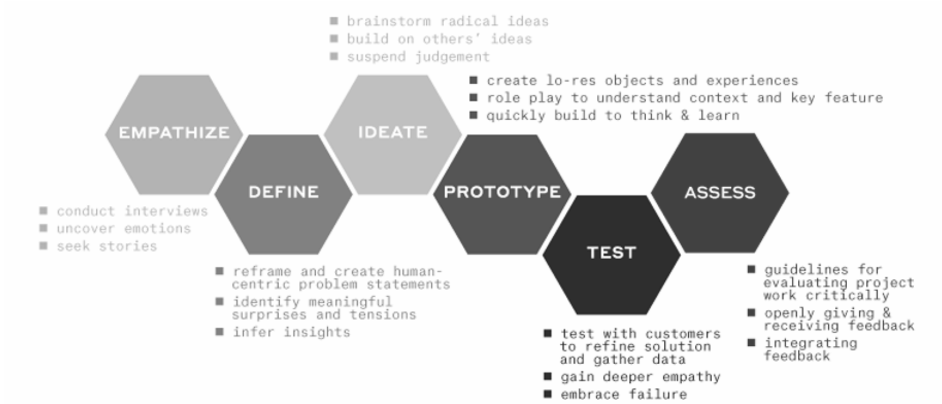

Figure 2. Design thinking process, graphic by d.school, (Hasso Plattner Institute of Design at Stanford).

Compared to the past, in which design was mainly considered a tool for the aesthetic qualification of the product, DT has placed design at the helm of innovation, making it the engine of collaborative processes for generating innovative ideas for products, services and business models. In addition, DT makes it possible to go beyond the traditional "problem solving" method, which is not sufficient to provide answers to complex contemporary problems that need to be addressed by different actors, with the involvement of different disciplines and skills and diversified entrepreneurial abilities, without preconceptions and simplifications. In other words, design becomes a transversal process and the connector that transforms creativity into innovation.

In fact, according to Donald Norman, it is inherent in designers to arrive at innovative solutions through extensive analysis, research and definition of real problems: “Designers resist the temptation to jump immediately to a solution to the stated problem. Instead, they first spend time determining what the basic, fundamental (root) issue is that needs to be addressed. They don’t try to search for a solution until they have determined the real problem, and even then, instead of solving that problem, they stop to consider a wide range of potential solutions. Only then will they finally converge upon their proposal. This process is called “Design Thinking.” (Norman D.A., 2013). Moreover, in business contexts that pursue innovation, DT is particularly effective. As Tim Brown, CEO of IDEO and promoter of DT in organizational, managerial, and strategic business processes, states, the DT is "an approach to innovation aimed at integrating the needs of people with the possibilities offered by technologies and business objectives" (Brown, T., 2009), an approach that combines together what is desirable from a human perspective (human-centered), what is feasible from a technological perspective, and what is sustainable from an economic perspective. At the meeting of these three elements lies innovation (Fig. 3).

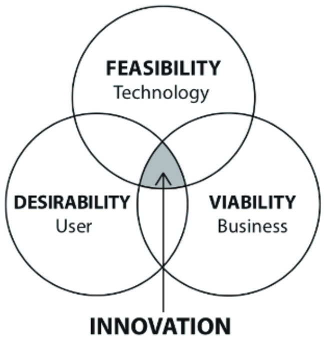

Figura 3. Design Thinking framework by Tim Brown.

Finally, DT is even more useful and effective in industrial research projects aimed at innovation and solving complex problems and developed by interdisciplinary teams and companies from different production sectors in collaboration with researchers from different universities. This is the case with the S.A.F.E. project, in which the traditional DT model was reworked and adapted to the specific scientific, technological and design challenge: to make furniture for schools and offices that could behave as life-saving protection systems in the event of an earthquake.
In fact, the metaproject model developed and defined in the S.A.F.E. project, as one of the main achievements, is a three-stage methodological process (A-P-V) that has made it possible to effectively and efficiently generate innovative solutions to concrete problems, accelerating the integration of different competencies and knowledge transfer processes from universities to enterprises. The S.A.F.E. metaproject model supported a collaborative and collective process of design-driven innovation, generating value for all project partners. This model, like the DT model, is recursive and circular, focusing on the people, communities, cultural and physical contexts of the earthquake-affected territories and their needs, for extensive "problem setting" activities, facilitating and supporting a fruitful cross-fertilization process between the expertise of researchers from different disciplines and the know-how of business technicians, between the experiences of relief workers and the safety demands of students and teachers in earthquake-affected schools.
This model made it possible to find innovative product solutions, prototype them, test them, refine them, scale them up, until the correct combination of what was socially desirable, technologically feasible, and economically sustainable was found. Finally, such a methodological-procedural model will enable replicability of the results of the S.A.F.E. project in other contexts of use.

4 Replicating the results of the S.A.F.E project: a metaproject model for the development of life-saving furniture

The experience gained in the research and development process of the S.A.F.E. project, strongly characterized by a multidisciplinary and intersectoral approach, has allowed the development of a methodological-procedural model, aimed at replicating the results, in other contexts with a high seismic risk.
The objective of the S.A.F.E. Metaproject Model is to guide the different areas of expertise, from time to time involved in the design, in a step-by-step process aimed at the conception, development and verification of new life-saving furniture in the event of an earthquake; also proposing a set of tools for the collection and systemization of data necessary for the generation of design guidelines. Therefore, this tool is mainly aimed at companies, planners and designers who intend to start a complex and multistackeholers process, aimed at the generation of new furniture solutions, for the safety of indoor environments particularly exposed to the danger of the earthquake.
The architecture of the metaproject model is divided into three macro-phases that relate in a continuous and iterative manner: macro-phase A, Analysis and Organization of the collected data; macro-phase P, Life-Saving Furniture system design; macro-phase V, Verification, and Optimization test of the developed models.

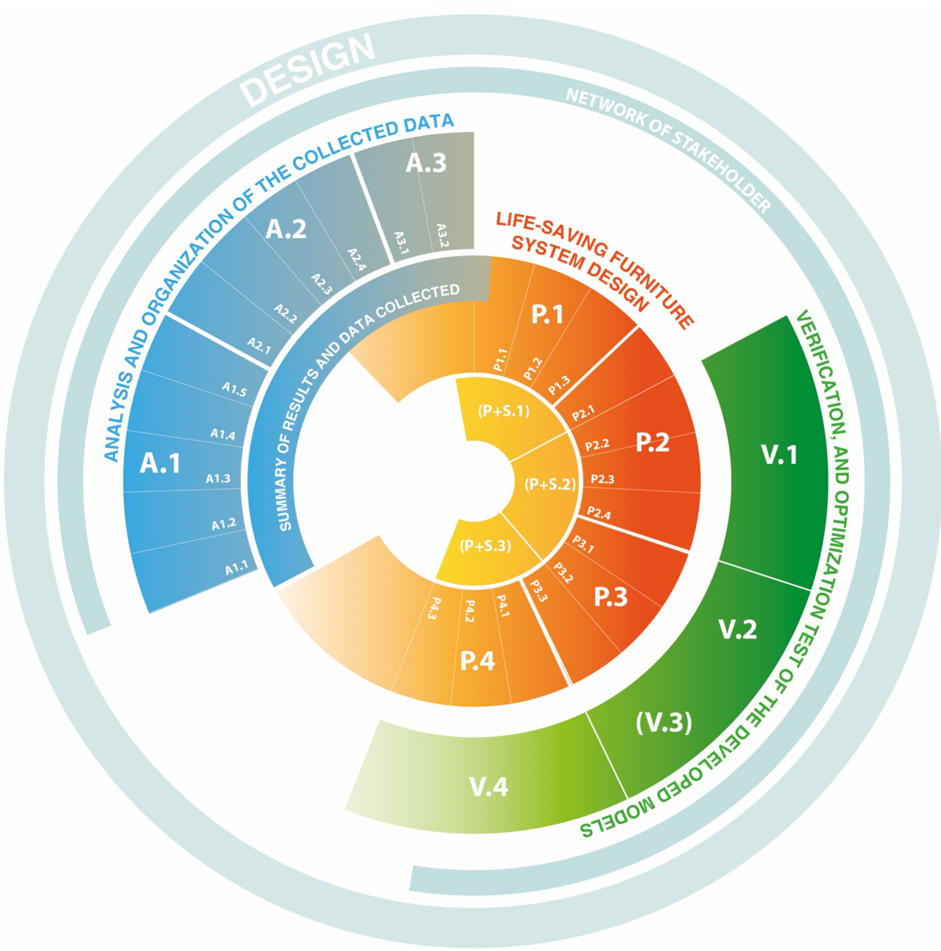

Figure 4. S.A.F.E. Metaproject Model for the development of new life-saving furniture in other contexts with high seismic risk (University of Camerino).

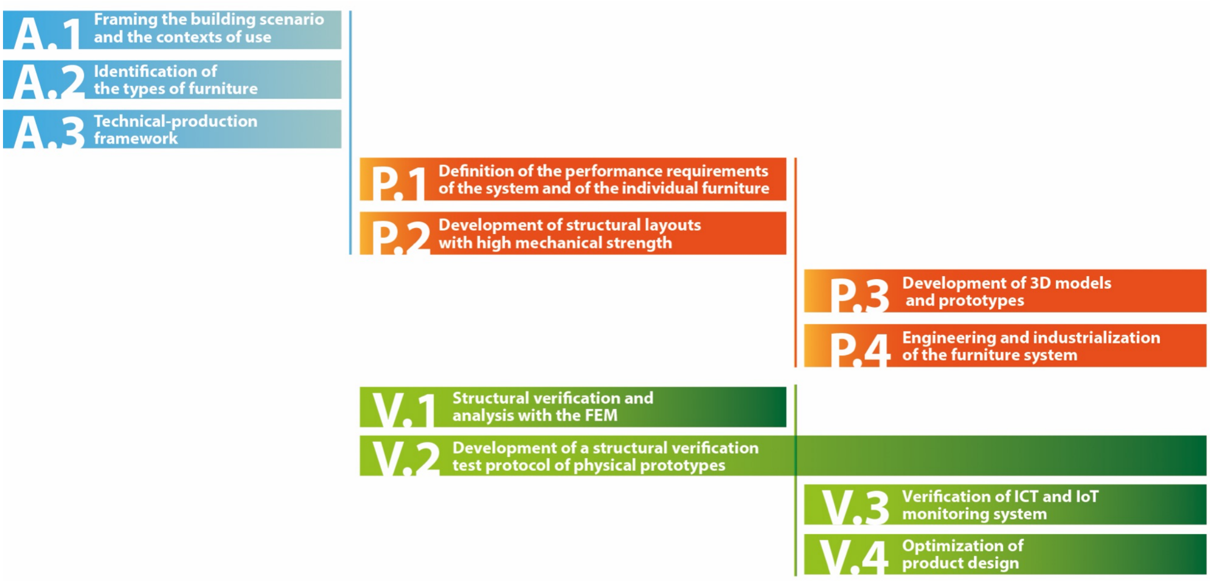

Figure 5. Workflow of the macro-phases of the S.A.F.E. Metaproject Model (University of Camerino).

Design, represented by an external circle, which encompasses the entire model, governs and guides all phases through the methodological approach of design thinking and user-centered design, systemizing the contributions developed by the individual disciplines and stakeholders involved in the development process. Each phase of the metaproject model is in turn divided into macro-activities and sub-activities, characterized by the development of tools and guidelines to simplify the operations of data collection, interpretation, development, and finally, the definition of the expected results (Figg. 4-5).
The macro-phase "A" has the main objective of framing the reference context, with particular attention to three areas of design interest: (i) macro-activity "Framing the building scenario and the contexts of use" (A.1): in this phase, the structural and building scenario and its users (the target) are described, and is divided into five sub-activities (A1.1, A1.2, A1.3, A1.4, A1.5); (ii) macro-activity "Identification of the types of furniture" (A.2): a wide-ranging activity is envisaged, aimed at recognizing the types of furniture, which characterize the identified scenario and is divided into four sub-activities (A2.1, A2.2, A2.3, A2.4); (iii) macro-activity "Technical-production framework" (A.3): the regulatory aspects and production technologies relating to the furniture considered most promising for the development phase are examined in depth. This phase is characterized by two sub-activities (A3.1, A3.2).

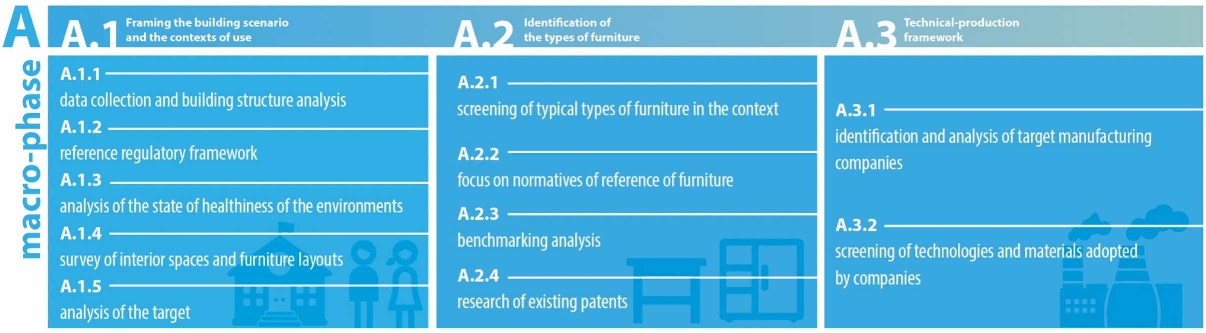

Figure 6. Macro-phase "Analysis and Organization of the collected data" (A) with macro-activities (A.1, A.2, A.3) and sub-activities (University of Camerino).

In macro-phase "A," each activity (Fig. 6) is conducted in parallel, and data collection takes place both in the field, through interviews, meetings and company visits, and on desk, through consultation of specific sites and databases.
The main tools used are: (1) survey sheet and structural assessment of the identified building; (2) questionnaire on earthquake emergency procedures; (3) interviews with emergency responders (fire brigade, civil defense); (4) measuring devices and CAD software; (5) ergonomics manual; (6) check-list for data collection of identified furniture; (7) ISO and UNI databases for identifying reference standards (www.uni.com, www.iso.org); (8) product sheets and catalogs of identified furniture companies; (9) patent databases (Google Patents, Espacenet, etc.) for identifying life-saving devices and furniture in case of earthquake; (10) check-lists for surveying materials and technologies of furniture companies.
The main expected outcomes of this macro-phase are: (A) structural assessment reports of the identified building and rooms (tool 1); (B) drawings 2D of the layouts of the furniture and indoor spaces (tools 1,2,3,4); (C) target anthropometric sheets (tool 5); (D) summary sheet of relevant regulations (tool 7); (E) data sheets for the design development of the identified furniture (tool 6, 8); (F) benchmarking and patent report (tool 8, 9); (G) material and technology sheets of the production chain involved in the project (tool 10).

This preliminary research is always followed by a phase of synthesis of the main results and of the data collected, which has the aim of making the contents and information identified, usable and immediate for the development and design phases. In fact, the work of synthesis and systemising the data will be useful for defining a set of performance requirements, for the design and generation of new types of life-saving furniture in the event of an earthquake.

The macro-phase "P" together with the verification and optimization activities, represents the heart of the model, and its main objective is to develop, design and optimize new furniture systems, capable of protecting people from the earthquake. The design phase is divided into seven macro-activities: four main phases dedicated to the development of earthquake-proof furniture (P.1, P.2, P.3, P.4), and three supplementary activities dedicated to the development of the ICT and IoT system (P+S.1, P+S.2, P+S.4), for the localization and monitoring of people missing under the rubble but will not covered within this paper.

The four important project activities are: (i) macro-activity "Definition of the performance requirements of the system and of the individual furniture" (P.1) aims to identify the basic functional, ergonomic and performance requirements of individual products. This phase involves the execution of three subtasks: (P.1.1, P1.2, P1.3); (ii) macro-activity "Development of structural layouts with high mechanical strength" (P.2) aims to define and develop the structural parts of all identified life-saving product types and is divided into four sub-activities (P.2.1, P.2.2, P.2.3, P.2.4); (iii) macro-activity "Development of three-dimensional models and prototypes" (P.3) involves the realization of the mathematical models and the first physical prototypes to be developed and validated with the verification and optimization activities (macro-phase "V"). Three sub-activities (P.3.1, P.3.2, P.3.3) are planned to achieve these objectives; (iiii) macro-activity "Engineering and industrialization of the furniture system" (P.4) focuses on the production and commercial aspects of the life-saving products developed, and has the aim of optimizing, in terms of product design, the components for the industrial production, assembly and maintainability of the new life-saving furniture. This phase is divided into three sub-activities (P.4.1, P.4.2, P.4.3, P.4.4).

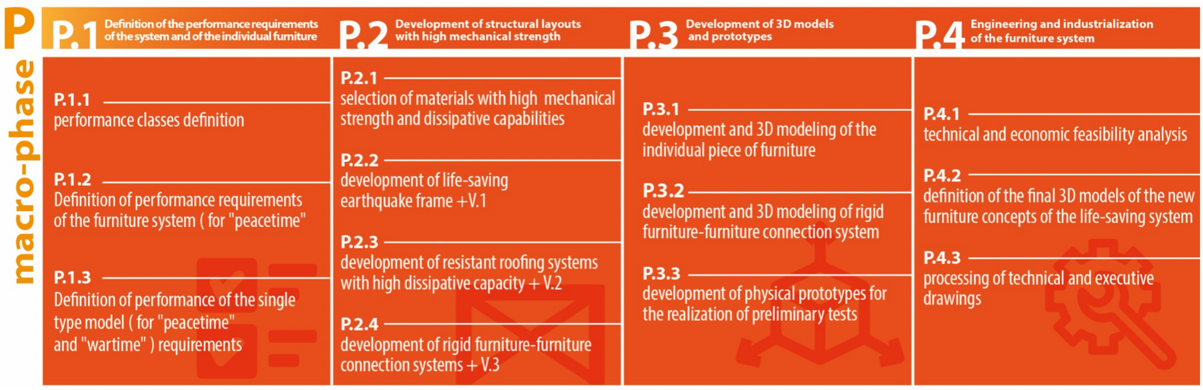

Figure 7. Macro-phase "Life-saving furniture system design" (P) with macro-activities (P.1, P.2, P.3, P.4) and sub-activities (University of Camerino).

In the "P" macro-phase, the first two macro-activities are conducted in parallel, the others in a "cascade" approach (Fig. 7), i.e., specific deliverables are needed in order to proceed with the next stages of design development. The design of the new life-saving furniture is carried out with an initial ideation process, characterized by brainstorming and problem solving activities, followed by a series of CAD development phases and prototyping activities through the technologies of the identified production sector. Each phase is punctuated by reporting and review activities with manufacturing companies through telematic meetings or by exchanging and sharing data through cloud computing services.

The main tools developed and used are: (1) excel tables for defining performance classes; (2) checklists for detecting critical design issues; (3) datasheets of materials with high mechanical strength and dissipative capacity; (4) materials selection software (e.g., Ansys CES GRANTA Selector); (5) CAD software for 2D and 3D parametric modeling; (6) software for FEM analysis; (7) software for rendering; (8) data exchange service in cloud computing environment (for example: Google drive); (9) material processing machinery and technology (for example: milling machine, laser cutting, etc.); (10) management software.

The main outputs expected from this phase are: (A) summary sheets of the technical and performance requirements of individual furniture (tools 1,2); (B) sheets of the materials identified (tools 3,4); (C) 3D models of the components, subcomponents and 3D assembly (tools 5,6,7,8); (D) technical drawings (tool 5); (E) physical prototypes (tool 9); (F) executive drawings (tool 5); (G) bill of materials (BOM) and economic impact tables (tool 10).

The design phases of development of the ICT and IoT sensor platform ("P+S" macro-phase "ICT and IoT system design" in the general model scheme), capable of giving intelligence to the entire furniture system, are not mandatory, but represent an additional part to be implemented when a specific request is made. This specific phase is not covered in this paper.

The third macro-phase “V” of Verification and Optimization, aims to validate the effectiveness of the models developed in terms of mechanical strength and the ability to protect both personal and collective from possible collapses.

The four main macro-activities are conducted in parallel with the project phases (P.2, P.3, P.4) and are divided into: (i) macro-activity “Structural verification and analysis with the FEM” (V.1): this activity is aimed at verifying the mechanical resistance of the structural layouts through the FEM calculation (finite element method); (ii) macro-activities “Development of a structural verification test protocol of physical prototypes”: this activity includes a series of laboratory tests to analyze the resistance to static and dynamic loads of the physical prototypes, developed for each type of furniture (type A, B+...+Z); (iii) macro-activity "Verification of ICT and IoT monitoring system" (V.3) involves verifying the functioning of the sensor system implemented in the furniture, when developed in the "P+S" macro-phase; (iiii) macro-activity “Optimization of product design” (V.4): the activity is conducted simultaneously with all the verification processes and has the aim of updating and optimizing the components to facilitate the industrialization and marketing of new furniture.

Figure 8. Macro-phase "Test verification and optimization of developed models" (V) with macro-activities (V.1, V.2, V.3, V.4) and sub-activities (University of Camerino).

In macro-phase "V" each macro-activity is conducted in parallel with the design activities and according to a "cascade" approach (Fig. 8), so the design progress is a function of the results of the validation tests that characterize all "V" activities. Once the reference seismic scenario and the main static and dynamic actions to be borne by the furniture system have been defined, preliminary FEM structural analyses will be initiated and then validated on the physical models, through laboratory tests.
The main tools developed and used are: (1) verification protocol with the order and type of tests (static and dynamic) for each developed furniture; (2) software for FEM analysis; (3) CAD software for 2D and 3D parametric modeling; (4) set of sensors and machinery for static (Universal compression and tension testing machine) and dynamic (Earthquake shaking table) testing; (5) text and image editing software; (6) static and dynamic analysis software (laboratory); (7) set of video cameras for video documentation of tests.
The main expected results from this phase are: (A) graphs of static and dynamic analyses (tools 1,2,6); (B) videos of the mechanical behavior of the furniture (tool 7); (C) summary report of results with structural optimization options for each developed furniture type (type A+B+...+Z) (tool 5); (D) final 3D models (tool 3); (E) final 2D drawings (tool 3); (F) testing of the integrated life-saving furniture system (tool 1,4).

5 Conclusion and outlook

The S.A.F.E. Metaproject Model represents one of the major results achieved in the S.A.F.E. project, and it is expected to continue the experimental process through its verification and validation, applying it to new potentially critical contexts such as tourist accommodation, home environment, health and religious places.
Of the model, generated through a reinterpretation of traditional procedural models of design thinking, the relationships to the objectives, requirements and tools to be considered in the development of earthquake-capable furniture were described. For easy access to its use and experimentation, the model has been ideogrammed into its macro-phases, while the macro-activities and sub-activities have been tabulated and represented on a gantt diagram that further explicates their operational relationships. This will enable universities and earthquake life-saving products companies to access a method that effectively supports their work with an interdisciplinary and cross-sectoral approach.
As a further development, digitization of the model on a web platform is underway, with the aim of supporting the actors involved in the project process by making available the tools already developed within the S.A.F.E. project (checklists, datasheets, protocols, etc.) and allowing others to be shared that will be developed in the future.

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