Design research for the development of a Medical Emergency Ambulance. Design as a symbolic qualifier in the design of complex systems/products

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Abstract: This research made it possible to launch a cooperation program between the University, the Industry and the National Institute of Medical Emergency of Portugal (INEM), to design a new medical emergency ambulance. The study has built a conceptual reference framework of an Ambulance Type B, focused on the sanitary cell, i.e. the area of a vehicle in which the assistance to the patient, stabilization and transport take place, as well as the interaction between the main medical equipment, medical personnel and patients occurs. This type of ambulance is used by the INEM to attend more than 91% of emergency calls. This project has developed a holistic participative design approach to the user’s needs, qualifying space with the conditions to improve the medical staff and patient experience. The research results have emphasized design as one of the main factors for the development of Prehospital emergency and patient transport vehicles.

Keywords: Medical Emergency; Project-based Research; Participative Design; Product Design;

1. Context

Prehospital care “deals with acute events which, by their nature, are unpredictable regarding to place, time and type of event. There is an almost endless variety of acute incidents, most of which have a low frequency of occurrence” (Anantharaman Venkataraman, et al, 2014, p.9).

According to Büscher “most studies of emergency work focus on control centres, where emergency calls are received and response teams are dispatched,” (Büscher, 2005, p.3). The previous studies also focus on the response time of services and clinical and medical practices, forgetting the ambulance as one of the most important elements within the emergency response system. The process of transformation of ambulances failed to follow sufficiently the advances in other areas
related to rescue and emergency. “The interior of a present-day ambulance looks in many ways much as it did when I first started working in the NHS over two decades ago. " (Lord Ara Darzi of Denham, 2011, p.3)

According to National Institute of Medical Emergency of Portugal - INEM Annual Report 2015, the “ambulances accounted for 91,49% of the total calls, and more than 81% of these ambulances are Medical Emergency Ambulance- MEA”, with 891,223 annual calls representing on average 1.7 ambulances activated per minute, Figure 1.

How can its design qualify the experience of a system / hospital emergency product, which combines the clinical practice and the technical dimension associated with medical equipment?

2. Design Research Framework (DRF)

The design and development of a new sanitary cell (Figure 2), is a complex project, it has to fulfill different types of requirements: technical, legislative, medical, clinic and constructive. To construct a comprehensive and accurate concept of the ambulance Type B, in particular, the INEM Type B EMS Ambulance (Figure 3), it was essential to draw a Design Research Framework (DRF), based on those requirements as they have implications in ambulance space, emergency practices as well as safety of crew members and patients. The DRF evolved from three kind of activities: analytical, interpretative and project.
2.1 Analytical activities

The approach to this problem was based on an ethnographic research with participant observation, working with users, groups of specialists and also surveys. The work carried out had the following tasks: identification and characterization of the service provided by INEM, equipment identification and characterization that supports the Prehospital medical emergency service, bibliographic review, selection of methods to be used, fieldwork, analysis of precedents and the participatory design observation.

A study was carried out to understand the structure and procedure approved by the National Emergency Medical Institute, which analysed sequences of actions, type of service provided and also means involved and the intrinsic characteristics that define Prehospital emergency in Portugal.

At the same time, research was carried out on the equipment to be studied, the national manufacturers, the reference companies in Europe and North America and the methods and construction techniques currently used. In Europe’s and North America’s study, a questionnaire was made addressed the types of technologies used in vehicle transformation, materials used and their functions, as well as methods of selecting them for functions they had to perform - aesthetic functions, censorial, mechanical resistance, structural, etc.
According to the methodology adopted and the methods employed, of direct / participated observation, the questionnaire to INEM collaborators at national level, focused its work with a group of ambulance technicians, instruments that supported the research / action cycles necessary to consolidate a feasible solution. This participation component and group involvement allowed not only a better understanding of the problem but also the incorporation of the contributions of specialists (doctors, nurses and ambulance technicians), that goes beyond the questionnaire assumptions and unstructured interviews, made over the contact time.

ambulance in europe and u.s.a. Most of the companies on the same continent rely on the same assembly procedures and materials used, differing little from each other. The main differences are pronounced in shape and functionality (number of drawers in a cabinet) than on the materials used, Figure 4.

![Diagram of ambulance model](https://via.placeholder.com/150)

*Figure 4 Architecture of the ambulance model. Copyright © 2015 ARBox Project*

participant observation The follow-up of health professionals lasted 150 hours and was divided between the Ambulance Type B, where its crew is formed by Emergency Ambulance Technicians (EATs), Figure 5, and the Medical Emergency and Resuscitation Vehicle, intended for fast transport to the patient’s site - the team involves a doctor and a nurse. This experience allowed to identify and understand on the ground the equipment in use; interactions and complementarities between the two kinds of ambulance and between the EATs; and record data that help to better understand this reality, Figure 6.
Design research for the development of a Medical Emergency Ambulance. Design as a symbolic qualifier in the design of complex systems/products.

focus group, National Emergency Medical Institute Specialists In order to obtain qualitative data on the current configurations of the INEM ambulances and to collect information on future ambulances, a working group was set up with the participation of emergency ambulance technicians. The first exercise proposed to this group consisted in sanitary cell arrangement without changing vehicle size.
and consequently the cell, changing only its position, furniture location and ambulance components. Based on a scale model: 1:10, solutions were developed to configure the ambulance interior that best fit the needs of its users, Figure 7.

The second proposed exercise consisted in stimulating the group’s creativity to identify and characterize requirements, needs, ambitions and desires, from a prospective perspective - an ambulance of the future. Participants used a variety of printed graphics - images and drawings - and constructed collage and overlay techniques that expressed their own ambitions. New forms were designed using A3 sheets with an ambulance print that served as a reference element in terms of volumetry and scale of form, allowing exploratory and speculative interaction on futuristic concepts of the equipment, Figure 8.
Design research for the development of a Medical Emergency Ambulance. Design as a symbolic qualifier in the design of complex systems/products.

**National Emergency Medical Institute, national survey** The information obtained helped to elaborate a questionnaire on the last model of the National Emergency Medical Institute’s Ambulance in circulation, in order to test the degree of satisfaction that emergency ambulance technicians, doctors and nurses had on the overall performance. This activity counted on the dissemination and execution, with the support of INEM, which provided the means to send the document to its collaborators, resulting in a response rate of around 10% (130 Answers) of the whole universe to be surveyed. The questionnaire was constructed using a scale of 5 values, with questions grouped around the following themes:

- sanitary cell (dimension, geometry, volumetric);
- mobile equipment (medical and emergency equipment used inside and outside the ambulance);
- usability and ergonomics of the equipment (fixed structures and mobile);
- exterior of the vehicle (location and quantity of doors, access ladders);
- electrical and communication infrastructure (quantity and location of light points and electrical outlets, intercom);
- materials used in the construction of the ambulance (robustness, texture, color, cleaning).

The questionnaire allowed to obtain quantitative data as well as a general picture of the current ambulance, and it is now necessary to interpret and extrapolate this data. It is intended to extract information that can contribute to the work’s main objective - the design of a new solution, viable and recognized as advantageous, for the various beneficiaries in the construction, maintenance and use of this type of equipment. The data was compiled into a graph, which represents synthetically, the evaluation of the existing equipment, Figure 9.

![Figure 9 Evaluation graph of the National Emergency Medical Institute Medical Emergency Ambulance. Copyright © 2012 Augusto de Sousa Coelho](image-url)

The participation of specialists, who use this system / product on a daily basis, proved to be extremely important because it allowed identifying the areas that need intervention in the health cell
and obtaining a set of information that has contributed to the outline of the project’s design strategy.

2.2 Interpretive activities

The development of a Conceptual Reference Framework (CRF), for design and development of a National Emergency Medical Institute Ambulance aimed at redefining attributes of the equipment / system at the level of product design and development - functionality, ergonomics, safety, usability - promoting also the symbolic re-qualification of this equipment / system.

The CRF development process was thought of as a space-overlapping system, rather than a sequence of steps, with iteration being preferred among promoters in order to obtain a mapping, capable of reflecting the project territory, allowing an approach to definition and understanding of the problem. The CRF results from the critical analysis of the current equipment, starting from both the field experience and the bibliographic review, where standards applicable to the incorporated sector, which determine factors in the design of this type of equipment/system. This task made it possible to recognize and characterize the deficits and expectations about the equipment/system and to rethink the symbolic dimension: so, that users (medical staff and patients) not only act on the physical qualities of things, but on the meaning that they assign or recognize. It allowed a set of guidelines on comfort, safety, dedicated technical systems, accessibility, occupant accommodation, materials and communication and information systems.

The CRF provided information to the National Emergency Medical Institute and to the industrial partner, regarding the ambulance requirements, users’ needs and design guidelines, strategically positioning the symbolic dimension as anchor:

- Symbolic qualification of the equipment – patient and staff experience;
- Patient and staff safety and comfort: security and comfort of sanitary cell in movement;
- Interior ergonomics and interior work layout- interaction between people and equipment;
- Sterilize and sanitation - hygiene and cleaning daily/routine;

The guiding capacity of the CRF was also verified, removing incompatible possibilities and making possible the viable variants and solutions to be explored in the process of design and development of new products. These actions allowed to identify and describe possible solutions in terms of comfort, safety, dedicated technical systems, accessibility, accommodation of occupants, materials and communication and information systems to be incorporated into a coherent mobile medical emergency unit.

2.3 Project activities

The CRF application was done through the development of medical emergency, medical mobile concepts, sketches and drawings, 3D models and prototypes based on the developed CRF. The applied development process went through the contextualization phases, in which the main market and technological constraints were identified, through the development of concepts and three-dimensional CAD modelling, including the recognition of photo-realistic images and the execution of mock-ups and Prototypes.
sanitary cell architecture and proposals for design concepts. Functional schemes were generated allowing the generation of architectural proposals for the different sanitary cell typologies. The generation of architectural proposals for the sanitary cell was carried out with a Mercedes Sprinter Van and allowed to identify and select solutions, which served as design guidelines in the development of the new concepts and models, Figure 10.

Figure 10 Functional identification and physical elements in the sanitary cell; functional schemes and physical elements of sanitary cell. Copyright © 2015 Augusto de Sousa Coelho.

mock-ups The selected concepts were tested in the 1:1 scale to obtain a more detailed evaluation and to identify with more precision the most viable solutions, Figure 11.

Figure 11 Testing the concepts at scale 1:1, using a Mercedes Sprinter VAN. Copyright © 2015 ARBox Project

conceptual design Proposals were developed for the sanitary cell, materialized through drawings, aimed at the development of new spatial organization solutions of the sanitary cell, and assembly
process, synchronized with syntactic and symbolic requirements that were identified by users during design research, Figure 12.

new ambulance design Taking into account previous studies, concepts were developed for an A1-Type ambulance, to test and validate the CRF. Through CAD modelling the selected concept has built a new prototype ambulance by the partner, applied to a Renault Trafic van, Figure 13.
Design research for the development of a Medical Emergency Ambulance. Design as a symbolic qualifier in the design of complex systems/products.

Figure 13 New concept for an ambulance Type A1. Copyright © 2015 ARBox Project

**ambulance prototype** It was possible to test different solutions in terms of usability, functionality, form and constructive viability. This prototype was also used to perform destructive tests (g10), necessary for the validation and homologation (legislative requirements) of future systems/equipment, Figure 14.
medical emergency type B and C Ambulance product design; architecture solutions were performed, built and mounted on a Mercedes Sprinter van. An analysis of flexibility, technical geometry and productive solutions, and also assembly processes were made, Figure 15.
Design research for the development of a Medical Emergency Ambulance. Design as a symbolic qualifier in the design of complex systems/products.

**real-scale prototype** A mock-up scale 1:1 was executed and mounted in a Mercedes Sprinter van, allowing the project partners to evaluate various prototype elements and equipment. This permitted the CRF validation, Figure 16.

*Figure 16 Real-scale prototype (Mock-up scale 1:1) of Medical Emergency Ambulance, mounted in a Mercedes Sprinter van. Copyright © 2015 ARBox Project*
The concepts CAD modelling also allowed us to detail solutions created during development phase and was not only an important step in scale refining but also in making some changes in the final health cell proposal. Real-scale prototype (Mock-up scale 1:1) was executed and mounted in a Mercedes Sprinter van, allowing the project partners to evaluate various prototype elements and equipment; the final solution of the whole health cell, Figure 17.

3. Evaluation Process

2015 TYPE A1 AMBULANCE EVALUATION

Type A1 Ambulance, was built to test the CRF and to validate ongoing work in a less complex product. The new product corresponded to the design’s first result and project research which allowed the evaluation and validation of the carried-out research. It was intended to evaluate a set of perceptions and the overall product value based on the quality perceived through three dimensions: Pragmatic Dimension associated with Program (Product Function), Syntactic Dimension associated with Technology (Product Structure) and Symbolic Dimension associated with Authorship (Meaning of Product). The ambulance Type A1 was presented in Securex 2015 Tradeshow and during the event’s four days, it was analysed and assessed by the consortium and also by a large group of users and emergency experts, Figure 18.
Design research for the development of a Medical Emergency Ambulance. Design as a symbolic qualifier in the design of complex systems/products.

Figure 18 Ambulance Type A1 presented in Segurex 2015 Tradeshow. Copyright © 2015 ARBox Project

2016 TYPE B AMBULANCE EVALUATION

The prototype evaluation of the type B ambulance, was carried out during the First European Congress of Medical Transport, held Aveiro in 2016, and organized by the Portuguese Ambulance League and by ANEA - Federación Nacional de Empresarios de Ambulancias, from Spain. The evaluation was made through a survey that was developed based on AtrackDiff adaptation which allowed collecting the hedonic and pragmatic quality dimensions as well as ambulance attractiveness. A set of perceptions was also evaluated based on the pragmatic dimension (product function), syntactical dimension (product structure), and symbolic dimension (product signification). The prototype was presented during the event and was valued by medical staff, emergency technicians, ambulance manufacturers, competition and one vehicle manufacturing company, Figure 19.

Figure 19 Outside view from the closed space where the prototype was and where the evaluation was performed. Copyright © 2016 ARBox Project
Before assessed to prototype, people passed by a hall where they were briefed about the design research and Co-promotion project through a synthetic show that explained the principal research phases and findings for the next sanitary cells of Ambulance Type B and Type C, and also the new design of the ambulance container Type C (Box), Figure 20.

The prototype evaluation was performed in small groups of two to three people, but in most cases, individually. The evaluation was accompanied by the design researcher, who provided an initial framework for the prototype, and its brief analytical description so that the conditions for the assessment could be created without interference. At the same time, complementary information was given on materials, finishes, colours, functions, possibility of modularity, among others, Figure 21.
Design research for the development of a Medical Emergency Ambulance. Design as a symbolic qualifier in the design of complex systems/products.

In this way, it was possible to help the evaluator to be given the opportunity to complete their own mental image of the product. The users’ impression of the prototype’s utility was reinforced by the information given on materials, finishes, colours, functions and modularity.

It was also possible to help give the evaluator the opportunity to complete their own mental image of the product, during the evaluation. The questionnaire evaluated the Pragmatic Quality associated to product usability, the Hedonic Quality / Stimulus, associated with the product's ability to stimulate the user in terms of novelty, interest and interaction, the Hedonic Quality / Identity associated with product capability allows the user to identify the attractiveness, which describes the overall value of the product experience based on the quality perceived, by the respondents - emergency staff.

The two types of evaluation reported above provide qualitatively and quantitatively different pictures of prototype evaluation. These differences may be explained by two major factors related to the design and the evaluation approaches chosen in the case study. The two types of evaluation were done with real users, which knew the business.

This fact could explain the richness of data because the users were motivated to contribute to the design of a new emergency ambulance, and they applied their knowledge used in daily work in order to provide suggestions and some small/particular prototype improvement. The results of the assessment are displayed graphically below, Figure 22.
The evaluation result shows that the new equipment design is now seen from an entire new perspective. In the questionnaire carried out to National Emergency Medical Institute professionals, the result obtained revealed relative equipment satisfaction, classifying it in a generic way, as enough or good. The evaluation results made to new ambulance design showed that the enough and the good have now become desirable, Figure 23.
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Figure 23 Results of the evaluation made through a survey that was developed based on an adaptation of AtrackDiff. Copyright © 2016 Augusto de Sousa Coelho

This confirmed the perception we had in the first evaluation results obtained through the survey and, after the four days of the Segurex 2015 Tradeshow, Figure 24.

Figure 24 The ambulance that was on the market vs the new ambulance design. Copyright © 2015 ARBox Project
Comparing the evaluation between current equipment and the new one, is clearly that there was a significant change in functional and symbolic of its dimensions and that was widely recognized and valued by users. In this sense, our results do support the hypothesis that design can be a symbolic qualifier in the design of a complex system/product such as an emergency ambulance.

4. Outcomes & impacts

This project has developed a holistic participative design approach to the user’s needs and created a new and innovative ambulance interior, which improves functionality, safety, hygiene, and comfort while enhancing the patient and medical staff experience.

The new ambulance Type A1 is currently in circulation, mainly on the French market, Figure 25. The ambulances Type B and C are in the process of industrialization and will be presented to the market in 2017.

The research results have emphasized design as a key player in the field of Prehospital emergency and patient transport and it changed the way either the medical partner or the industrial partner valued design. The company's attitude has changed in relation to design and began the process of creating a new department - design research, trends and concepts. Design awareness contribution is being extended to the company's partners, having at the moment renowned vehicles brand interested in this project results, allowing the company to change from a vehicle transformer into a major emergency healthcare.

Figure 25 New Type A1 Ambulance. Copyright © 2015 ARBox Project
Remarks

As a first observation, we highlight that Prehospital Medical Emergency requires the involvement and the work of several specialists, as well as integration of multidisciplinary competences, which jointly define the strategy, and design the way to operate it.

As a second observation, we highlight the difficulty of implementation of complex products and systems, associated with the design of this typology of products (political, economic, technical, productive, technological, organizational, logistical, etc.).

As a third observation, we highlight the lengthy continuity of the design process, with repeated revisions. The design process never ends.

As a fourth observation, we highlight the relevance of the design, especially in the project’s strategic definition and in the construction of the objectives and goals to be achieved.

5. Conclusions

The consulted bibliography and investigations that served as the starting point for this work, allowed to conclude that knowledge in the area of Design of Ambulance of Pre-Hospital Medical Emergency is still reduced. Research on this typology of systems is found mainly in the areas of service, patient care and guidance, also medical practices and procedures.

The assignments for academic design that have been already finished in this area, and from what has been known so far, have had a lot of difficulty in overcoming the concept definition or prototyping phase.

In order to overcome these difficulties, this research had as objective adding the contribution and the involvement of all main stakeholders - groups that define and provide service (eg: INEM) and ambulance manufacturers (eg: AutoRibeiro Lda).

This approach was essential to obtain a multifocal and simultaneously integrated vision of reality, which allowed the Design to configure a new paradigm of action in this field, provoking the generated transfer of knowledge and its consequent application in the product / equipment destined to the medical emergency market users, and therefore to patients / persons.

The Conceptual Framework, created the appropriate environment by identifying and integrating the different expectations of the partners into a coordinating methodological tool, in which partners were able to jointly map key issues and challenges, set priorities and also were able to clearly indicate the goals and expected benefits of the project.

The participatory approach to this research, in which design functioned as a pivot of action and dialogue between these various actors, required that this environment was previously observed and mapped, so that it generated the conditions for hosting a project / research of this nature.

The achieved results - an ambulance in commercialization and one in the process of industrialization - were the effort result of this network, created by research in design. It reflects the expressions of an action-research culture that has been extended to organizational, business and academic levels.

It is essential for Design to re-imagine and construct new and meaningful work models, transversal to all its fields, in order to change the impact paradigm of its action. This change requires the
construction of cooperative networks with the government, academia, industry and all those interested in the process, so that design can take on its own nature, generating a more informed, multidisciplinary and systematic type of thinking and in order to ensure positive results and the long-term sustainability of action.

This type of research in design, based on a cooperative source and configured through an action / research network, has multiple benefits:
- as a mechanism to generate a strong commitment, involvement and stakeholders’ contribution, which leads to the progressive integration of knowledge and allows to take design to the implementation phase;
- is a consistent process able to adapt to changing circumstances throughout the project;
- is a highly creative approach to problem solving that leads to suitable and applicable solutions in many contexts, therefore, it is a highly transferable process.

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