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*Published in:*
Human Interaction, Emerging Technologies and Future Systems V

*DOI:*
10.1007/978-3-030-85540-6_130

Published: 01/01/2022

*Document Version*
Peer-reviewed accepted author manuscript, also known as Final accepted manuscript or Post-print

*Please cite the original version:*
Ahola, M., Uusitalo, S., Palva, L., & Sepponen, R. (2022). Scaling the Magnetic Resonance Imaging Through Design Research. In T. Ahram, & R. Taiar (Eds.), *Human Interaction, Emerging Technologies and Future Systems V: Proceedings of the 5th International Virtual Conference on Human Interaction and Emerging Technologies, IHIET 2021, August 27-29, 2021 and the 6th IHIET: Future Systems (IHIET-FS 2021), October 28-30, 2021, France* (pp. 1018-1025). (Lecture Notes in Networks and Systems; Vol. 319). Springer. https://doi.org/10.1007/978-3-030-85540-6_130

# Scaling the Magnetic Resonance Imaging Through Design Research

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**Abstract.** The superior soft-tissue contrast and sensitivity for pathologies have made magnetic resonance imaging (MRI) a primary modality in medical imaging. At present, the high initial and running costs, and demanding requirements for siting and operating personnel limit its availability to large hospitals and imaging clinics. Improved accessibility of MRI technology can lead into new healthcare services. To study this, we set up the Accessible Magnetic Resonance Imaging (AMRI) research platform, including a multidisciplinary research team and a very low field MRI device for evaluation of new service solutions. We explored the expected value of accessibility in point-of-care contexts, achieving validation and improved focus for initial need-descriptions for the solution. Our design research points towards the potential of a more accessible MRI in improving healthcare provision, and that ever-prevalent medical imaging healthcare services could cause systemic changes to the healthcare processes, technologies, and operating environments.

**Keywords:** Magnetic Resonance Imaging · Accessibility · Healthcare Service Design · Medical Device Design

## 1 Introduction

Accessible Magnetic Resonance Imaging (AMRI) is a research project between Aalto University's School of Electrical Engineering, and School of Arts, Design and Architecture. The project aims to bring Magnetic Resonance Imaging (MRI) out of the conventional hospital environment, enabling new transformational point-of-need services in healthcare and wellness. The technology solution in question potentially decreases local and global inequalities by bringing quality healthcare in the form of accessible medical imaging to areas and uses not addressed before, in line with the United Nations Sustainable Development Goals 3 and 10 [1]. The goal is reached by designing a research platform of a very low field MRI (VLF MRI) scanner. The collected information about the possibilities and limitations enables the development of MRI scanners and services for different applications. The medical community strives for more ubiquitous and accessible MRI systems, and lowering magnetic field strength can increase adaptability [2]. AMRI scanner upscales the accessibility of imaging in terms of e.g. safety, mobility, and user experience, making it a compelling solution to many domains. In parallel with the technology development track, a design research effort gathers information about selected potential application domains (e.g., healthcare and wellness), application areas (e.g., mobile and hospital), and use cases (e.g., pulmonary imaging and cerebrovascular emergency). The aim is to validate and prioritize these to inform the development of the technology.

The contributions of the article are in describing our research findings of the potential needs the technology in question addresses. This applies to different application domains and use cases, supporting a platform-approach in a technology-centric, multi-disciplinary research project. Within this study, six application areas were researched with designerly means. For brevity, this report focuses on two of those.

## 1.1 SCALING AS A DESIGN PROCESS

We consider scaling from the value creation perspective: how could more accessible MRI - device and service bring value to different application areas? An approach focusing on combining products with the corresponding services is often called Product-Service Systems (PSS) [3]. Adoption of service design approach in healthcare and participatory and co-design methods has been emerging for almost the last two decades now. E.g. Experience-Based Co-Design (EBCD) has been formalized as one answer to this objective [4].

Since service is a process in which value is co-created between the involved stakeholders, identifying and exploring them in different application areas was considered important. Service design is a challenging co-creation process, as the people involved are uniquely influenced by their initial conditions and setting [5]. This raises the importance of human-centered perspective, including e.g. identifying their needs and experiences. This study considers the potential operators of AMRI (e.g. paramedic, radiographer, nurse) as users.

It is a major challenge to identify the most suitable environment for scaling up a healthcare innovation [6]. The initial use cases for AMRI resulted from the technology researchers' state of the art expertise in the field. From the potential application areas, six were selected for design exploration, from which two (emergency and healthcare) are in focus of this report.

Product architecture design is concerned with mapping the functional elements of a product to the structural ones [7]. During the recent decades, platforms and modular product architecture approaches have become mainstream, enabling mass-customized production. For the enterprise, this allows addressing and managing external complexities (e.g., market and society complexities) as well as internal complexities (e.g., product portfolio and manufacturing complexities) [8]. The planned platform-approach with wide applicability poses a challenge for acquiring information sufficiently to guide the technology research. Designerly research methods may prove valuable understanding for furthering in this quest.

## 1.2 AMRI-SCANNER RESEARCH PLATFORM

MRI provides high soft-tissue contrast and is capable of generating anatomical images with high resolution and speed. The inherent limiting factor in exploiting these features is the signal-to-noise ratio, which is proportional to the magnet's strength. The continuous pursuit of high-resolution images within as short time as possible has led to strong superconductive magnets with field strengths of 1.5 and 3 tesla. Recently, 7 tesla scanners have been introduced.

Field strength determines costs (~$1M/T), safety measures, required facilities, and expertise in operating the system [2]. The high field magnet scanners are expensive and costs are not limited only to the price of the scanner. The requirements for the operating environment are also high and increase with the field strength. The operation of a high field

MRI unit assumes highly educated personnel. The strong magnet and high excitatory radio frequency power also causes safety risks for the people. These issues make the running costs of a high field MRI the most expensive radiology service. Due to the costs and the required infrastructure MRI scanners are mainly used in hospitals.

The AMRI project aims to identify new MRI concepts of high value in some applications where accessibility in terms of safety, costs, availability, and mobility is of significant importance. There are also several essential applications, which would benefit from openness and a possibility to bring life-supporting or monitoring pieces of equipment close to the magnet. The scanner's safe operation enables automation of the imaging process, and the image-based diagnosis may be delivered via teleradiology.

The AMRI scanner platform is composed of a VLF MRI scanner and a computer simulation platform. The scanner is based on a permanent magnet producing a VLF range, below 0.1 T, for whole-body imaging. Technology enables a more compact device design and transformability. The scanner will be used for collecting empirical data for the development of computer simulation tools. This research environment is used for modelling and optimization of VLF MRI systems for the chosen applications. The operation at a VLF range enables fulfilling the above-listed requirements for accessibility. The downside is that the signal to noise ratio will be significantly lower than at high field operation. When this is considered, one may find several health and wellness applications where VLF MRI provides high value due to good tissue contrast and accessibility.

The aforementioned improvements in accessibility (initial and running cost, safety, usability, user experiences, and mobility) of the AMRI scanner platform are the basis of the high value provided for healthcare and wellness of the population.

## 2 RESEARCH THROUGH DESIGN

AMRI's maturity-level allowed us to arrange design research parallelly with the development of the technology. Dorst [9] addresses the details and impacts of co-evolution of design problem-space and solution-space and the different levels on which this occurs in a project - especially in processes where design is used as a means for knowledge-building, as opposed to mere problem-solving. Re-framing of the problem takes place when the effort is made towards solutions, resulting in increased knowledge of the problem. Research through design is about building knowledge through design [10]. According to Koskinen et al. [11] constructive design research is an activity where the construction, typically of a prototype (product, system, scenario etc.) is a key element constructing the knowledge. In our study, design efforts towards developing a concept of emerging technology were placed into different application areas to build knowledge about its possibilities and limitations. As described above, knowledge-building via design requires field research and design-doing of representations. This also applies to service design; the significance and variety of benefits of design representations, including prototypes, are well documented [12].

Design exploration of the possible application areas considered Finnish municipal healthcare system providing 95% of all specialized medical care [13] during a Master’s course in Aalto University, School of Arts, Design and Architecture in Autumn 2020. The participating 18 graduate design students were divided into six groups of three persons each, with a heterogeneous distribution of backgrounds with regards to gender, country of origin, and design discipline. Each group was assigned to work with one of the six possible application areas for six weeks. Medical imaging was a new domain for most of the participants. Progress was endorsed with supporting lectures and reading material on e.g. design emergence, user-centered design, design research methods, design for medical context and MRI technology. The Authors advised the groups from technical and design perspectives during the whole process. Groups had the freedom to re-frame the given initial problem-space based on revealed insights.

In the following, the design exploration related to point-of-care, and mobility domains is summarized, respectively.

## 2.1 POINT-OF-CARE DIAGNOSTICS

Insights of point-of-care diagnostics were gathered from a total of eight expert interviews (2 Radiologists, 2 doctors, Radiographer, ICU medic, ICU nurse, and medical engineer), and from one person with prior experience on MRI scanning as a patient. ICU personnel were interviewed in situ, and other interviews were conducted via videoconferencing. The acquired data was transcribed and structured with affinity diagrams [14]. Key findings for the conceptualizing the use of AMRI in general diagnostics were:

1. Accessible MRI would enable the imaging in the first appointment with a nurse or doctor, and many times only the 'yes' or 'no' answer from the images would be enough for precluding conditions. However, currently only radiologists can consider the clinical significance of the findings, hindering the MRI use among other medical experts. Artificial Intelligence (AI) could aid in scanning decisions.
2. Technology provides significant time and effort saving potential in ICU. MRI scanner could be brought next to the patient bed, instead of taking the patient to the scanner. The 'yes' or 'no' answer from the images would be often enough in ICU for precluding conditions.
3. MRI would be used more if it would be more accessible. AMRI could and should provide a safer, more inclusive and pleasant experience for the users. However, excessive imaging could congest healthcare.
4. MRI process design should be comprehensive and include the individual needs of patients, and improve the pleasantness of the scanning environment. Operators are key actors in reducing the negative experiences. Devices should be tailored according to different target groups and application domains.
5. MRI service is a profitable business for private healthcare, whereas in public healthcare scanning requires careful consideration due to costs.

Based on the background research findings, further design efforts focused is developing concepts for MRI utilization in more efficient primary health care examination. Another team re-framed their design research towards a new bed-side MRI experience in ICU context from these conclusions. The research through design was illustrated with stakeholder mapping [12], key stakeholder personas [12], a storyboard [12], and a product design concept [11], and a user experience (UX) journey map [15].

## 2.2 MOBILE APPLICATION AREAS

Two conceptual mobile AMRI approaches were researched, those of ambulance use, and mobile non-emergency diagnostics. Multiple user-research and co-design methods were used. Total of 9 expert interviews were conducted (3 Medical engineers, 2 Paramedic lecturers, Emergency Medical Technician officer, Sales director, Electrical design manager, and Area sales manager). Two of the interviews were conducted at the premises of an emergency vehicle manufacturer, and at a rescue center, respectively. A co-design workshop took place in paramedic teaching facilities.

The background study identified emergency cerebrovascular diagnosis (stroke) as a potential mobile use case for MRI. The main purpose of the conceptualized stroke unit is to differentiate strokes and brain hemorrhage of a patient. This time-sensitive diagnosis aims to select the right treatment from the mutually exclusive ones. In cerebrovascular issues, all means that expedite care have a crucial positive impact on patients' life, recovery, and quality of life post-event. The other key findings were:

1. The standard for ambulance design [16] makes it challenging to install AMRI into the already weight-burdened current ambulance platforms.
2. Paramedics perform multiple parallel tasks and are simultaneously co-operating with multiple units, hospitals, and call centers. The knowledge is distributed to the environment (system) and the people involved.
3. There is no standard ambulance: paramedics have considerable influence in designs of ambulances, and the manufacturer provides the role of technical implementation specialist.

The findings necessitated focusing on diagnostic units not to be used primarily for patient transportation. As a next knowledge-building effort, a co-design workshop [17] with paramedic students was set up. It was organized in a training ambulance, after having built a mock-up of AMRI device, and having generated a protocol addressing a cerebrovascular emergency event with the contact points paramedics are involved with. During the workshop, the paramedics acted out the protocol of moving the patient in and out from the scanner with the stretchers and maintaining contact with the patient in different scanning phases.

During the workshop, the participants fine-tuned the protocol, found detailed improvement needs, and strengthened our intuitions. Situated Post-it notes were used to indicate the issues in the device mock-up or elsewhere in the physical context, enabling effective documentation. The participants were motivated as they could see their insights having an effect on the actual protocol development. The mock-up and the environment served as essential framing elements for staging and piloting the process and the system mock-up, in alignment with [12]. For example, it became apparent that both paramedics operating the system need to have visibility to the system status, initially not possible in the mock-up.

# 3 DISCUSSION

Design research in the project aimed to find out needs and analyze and describe certain related tasks, as well as the physical, social, and process-related environments of use. Results provided vital guidance in goals, requirements, constraints, and opportunities for the technology and the PSS development. The technology will potentially replace elements in the current healthcare service provision models, introduce new processes, and change the roles and even power dynamics, requiring systemic understanding and thoughtful planning.

## 3.1 INVOLVEMENT OF DIFFERENT STAKEHOLDERS

Clinicians, as decision-makers and operators of the MRI, are vital as users and informants in the domain. They were the primary group of informants at this stage of our research. On the other hand, patients are equivalently important informants. E.g., uncomfortable patient experience in current MRI systems is a well-known issue, as the experience is considered claustrophobic, noisy and long-lasting by many. For a good reason, patients have been included lately more and more into the design process of healthcare services [4]. Patients will be involved more in the design process when our design process develops. In PSS development, insightful co-design workshops are encouraged [18] and these will take place in later phases, involving clinicians and patients. Two of the interviews were contextual inquiries: the medical doctors and nurses at the Töölö Hospital's ICU unit and Helsinki Rescue Department (both located in Finland) were interviewed in their natural work setting. The context enables the interviewees to point-out examples from their surroundings for additional information [19]. We found the clinicians very willing to discuss their work and the role of technology, including different imaging modalities in healthcare. In the discussions, they were also able to project towards the future. However, they were very much aware of the various constraints towards applying new technology.

The process of knowledge building through design exploration resulted in a corpus of analyzed research material. This included: context scenarios (8), personas (7), user journeys (5), and with product, service, and User Interface design concepts (10). Next, some issues for scaling the AMRI as a Product Service System are discussed.

### 3.2 IMAGING PROCESS

Accessible MRI could enable other practitioners to complement radiologists in solving simple clinical questions [2]. In the early phases of medical care, AMRI could streamline the current processes. Safe operability in a normal hospital room and lower investment cost would enable the acquisition of the scanner to department level. Compact size and mobility could allow shared use of scanners between departments. We found that ICU doctors were expected to have basic image reading skills. There, early interpretation could support radiology and improve efficacy, with proper technology and process.

As an example of further service system level potential, the broader use of scanning enables longitudinal monitoring of patients' recovery. Extensive use of scanning provides cumulative data and extends the human health archives. Accurate early diagnostics could decrease specialist care need.

Recently, the integration of complex machine learning algorithms and artificially intelligent systems within medical safety and image review has increased [20]. AI holds a promise to support clinical decisions for appropriate justifications of examinations and in improving throughput. AI assistants could complement humans and depend on us for tasks in which we have a comparative advantage. As Stanford University radiologist Curtis Langlotz put it: "AI won't replace radiologists, but radiologists who use AI will replace radiologists who don't." [21]. Siemens recently introduced an AI-based MRI scanner that enables automated routine scans [22]. This releases radiologists and radiographers from the routine work and broadens the pool of operators.

## 4 CONCLUSIONS

Technologies based on very low field MRI are under increasing interest in medical imaging [2], promising a significant downscaling of cost, risk, volume, training, and other accessibility-related metrics compared to conventional MRI. We reported a concerted effort and results involving design research in the need-finding phase of a research project. We evaluated application areas of point-of-care for the emerging technology called Accessible Magnetic Resonance Imaging (AMRI). Designerly knowledge building methods provided insights on goals, requirements, constraints, and opportunities for further development of the core technology and the Product-Service System (PSS). Accessible MRI technology would enable broader use of medical imaging in healthcare services. We discovered a potential in Intensive Care Units: the imaging process efficacy would improve if moving the patient for scanning is eliminated. Emergency cerebrovascular diagnosis proved a potential use case for VLF MRI on a mobile platform.

Further research is needed as the more accessible medical imaging suitable for healthcare services causes systemic changes to the processes, humans, technologies and operating environments. These impacts and opportunities pose an inspiring co-design challenge, when furthering our research on selected application areas.

**Acknowledgments.** We wish to thank the Technology Industries of Finland Centennial Foundation, and Jane and Aatos Erkko Foundation for their support of this research.

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