DESIGN TOOLS FOR A SUSTAINABLE HEALTHCARE: EMPOWERING MEDICAL PROFESSIONALS WITH MULTIFUNCTIONAL CONSUMABLES APP.

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ABSTRACT | Climate change, linked to greenhouse gas emissions, has been identified as the primary challenge to public health in the 21st century. The medical device supply chain contributes to over 70% of the healthcare sector's emissions, encompassing the production, transportation, and disposal of items such as drugs, hospital equipment, instruments, and medical devices. The doctoral research focuses on consumables management within the Department of Neonatology of Umberto I Polyclinic of Rome, aiming to support medical personnel and administrative staff in optimizing the procurement, utilization, and disposal of medical consumables. Through a collaborative design process involving key stakeholders, the objective is to create an innovative mobile application that improves the efficiency of managing disposable medical consumables associated with electromedical equipment and medical procedures. This app is anticipated to deliver several benefits, including enhanced operational efficiency, real-time tracking of consumables, and comprehensive data collection for investigating circular design strategies from both qualitative and quantitative perspectives. Relieving users' cognitive efforts, the application promotes sustainable practices throughout the lifecycle of disposable medical consumables, spanning procurement, usage, and disposal. This, in turn, contributes significantly to broader sustainability initiatives. In the long run, implementing strategies focusing on sustainable product use holds the potential to revolutionize how we approach medical consumables. By emphasizing redesign, reuse, recovery, and recycling, these strategies can improve resource availability, minimize waste, and foster systemic sustainability within the healthcare sector.

1. Introduction

Climate change, linked to greenhouse gas emissions, has been identified as the primary challenge to public health in the 21st century. The increasing aging population, rising rates of non-communicable diseases, and rapid advancements in medical technology combine to escalate the demand for healthcare. Without sufficient mitigation measures, this will increase the carbon footprint of healthcare systems (Smith, 2022). These converging factors pose significant challenges for healthcare systems (Karliner et al., 2019; Victoria Gov., 2021). The healthcare sector, in its ongoing dedication to improving societal well-being and health, provides curative care, generating significant economic and environmental impacts due to the extensive use of energy and resources, thereby becoming one of the most polluting sectors globally (Echkelman, 2020; Watts, 2019). To ensure a high level of care, these facilities require a wide range of medical supplies and equipment. Health Care Without Harm has highlighted that the medical supply chain contributes to over 70% of the healthcare sector's emissions, encompassing the production, transportation, and disposal of items such as drugs, hospital equipment, instruments, and medical devices (Karliner et al., 2019). Since the 1980s, SUDs have followed a linear product economy model, causing significant waste and emissions, leading to environmental and public health damage (Benedettini, 2022; Moultrie, 2015). This inherently unsustainable production and consumption model contributes to global ecological destruction, depletion of natural resources, excessive generation of solid waste, global greenhouse gases, and other harmful environmental emissions (Mac Neill, 2020; Rizan, 2023).
To reduce the high volume of waste produced daily by SUDs, the introduction of a circular supply chain can be implemented by adopting innovative human-computer technologies to improve efficiency and transparency in consumable management (SUDs and reusable medical devices), staff training (Walker, 2008; Wani, 2013), and the promotion of sustainable clinical practices (Mang, 2023; WHO, 2017). Similarly, to achieve an ecological transition in the healthcare sector, it is necessary to drive changes in healthcare practitioners' behaviors by engaging various stakeholders in sustainable systemic design phases related to SUDs throughout their entire lifecycle (Hinrichs et al., 2022). To understand and improve healthcare personnel behaviors in the use of consumables, this study focused on Neonatology and the Neonatal Intensive Care Unit at Umberto I Polyclinic of Rome. This department exhibits one of the highest uses of SUDs and significant impacts on costs and the environment (Newman, 2011; Nichols, 2014). The issue originates from a pilot study conducted by Verma et al. (2019), which highlighted that neonatal care, given its acute nature and the high frequency of admissions related to neonatal sepsis and infections, involves the disposal or sterilization of all unused items near neonates that test positive or are suspected of having an infection. Therefore, the doctoral research explored the lifecycle of medical consumables for Neonatology departments in hospital settings, where new sustainable solutions can be observed, designed, and tested for the entire product lifecycle, including proper separation and disposal within the hospital area. In particular, the research questions guiding the study were as follows:

- What behaviors do stakeholders exhibit during the lifecycle of single-use medical devices in Neonatology and the Neonatal Intensive Care Unit at [hidden for peer review]?
- How can interdisciplinary collaboration involving healthcare service users, stakeholders, and hospital staff enhance the delivery and use of healthcare services, particularly in the sustainable management of single-use medical devices?
- What sustainable solutions can be designed and tested to optimize the entire lifecycle of medical consumables, including acquisition, management, use, separation, and disposal?

The research aim is to improve and make transparent the acquisition and management practices of medical consumables for healthcare professionals through the implementation of a mobile application for real-time access to critical information, such as consumables inventory, usage, disposal methods, and their linkage to electromedical equipment and daily clinical treatments in the hospital. After implementing the mobile application in the departments, the results will be analyzed, and staff satisfaction will be assessed. These data will guide future research, providing insights into the procurement, use, and consumption of consumable products within the department. The goal is to identify consumables suitable for circular design strategies without compromising the efficiency and quality of the supply chain.

2. Literature review

2.1 Single-Use Medical Devices and Environmental Impact

Medical devices constitute a significant portion of emissions from healthcare supply chains (Eckelman, 2020; Sousa, 2021). Numerous studies compared the use of SUD with reusable alternatives, highlighting that SUDs typically involve significantly higher petrochemical consumption and global greenhouse gas emissions over their lifecycle (McGain et al., 2010; Sanchez et al., 2020; Sherman et al., 2018). Research, such as that conducted by KPMG (2023), has examined the end-of-life of single-use medical devices and their contribution to environmental pollution. Indeed, the study emphasizes that:

> "Currently, many single-use medical devices and equipment are disposed of through incineration, which generates a dangerous emission of greenhouse gases and has poor ecological credentials. However, every other potentially 'greener' disposal option should be carefully considered, as its benefits are not always easily attainable, with complications such as collection, sorting, and transportation that could add to harmful emissions as much as incineration, especially if size and volume are not managed correctly." (KPMG, 2023)

2.2 Single-Use Medical Devices and Environmental Impact

Effective management of medical consumables has become an area of growing importance in the healthcare sector, identified as a key lever for cost containment in industrialized countries (Volland et al., 2017). An urgent issue pertains to costs and waste associated with the management of medical consumables, which represent about 30% of hospital operating budgets (Zepeda, 2016). There is a growing emphasis on optimization techniques to address the rising healthcare expenditure (Volland, 2017), suggesting the implementation of new management methods to improve operational performance (Aptel et Pourjalali, 2001). For example, an audit in an Australian intensive care unit revealed that 60% of total waste was potentially recyclable with proper processes (McGain et al., 2009). Effective consumable management is closely linked to the optimization of the supply chain, and leveraging inventory management and control can enhance hospital supply chain performance (Dasaklis, 2012). Integrating information systems through technologies like RFID could improve logistics and supply chain management in healthcare (Çakıc et al., 2011; Chong et al., 2015; Reyes et al., 2012). Research suggests that the integration of digital technology into healthcare systems serves as an innovative solution to address the complexities of supply chain management for quality healthcare management (Kim et al., 2016).

3. Methodology

To address challenges and gaps in hospital consumable management, this study adopted a research-based design methodology (Leinonen, 2008) aimed at building on shared evidence to generate design solutions [Figure 1]. This methodology includes the following phases: 1. contextual inquiry, 2. participatory design, 3. product design, 4. prototyping as hypothesis.

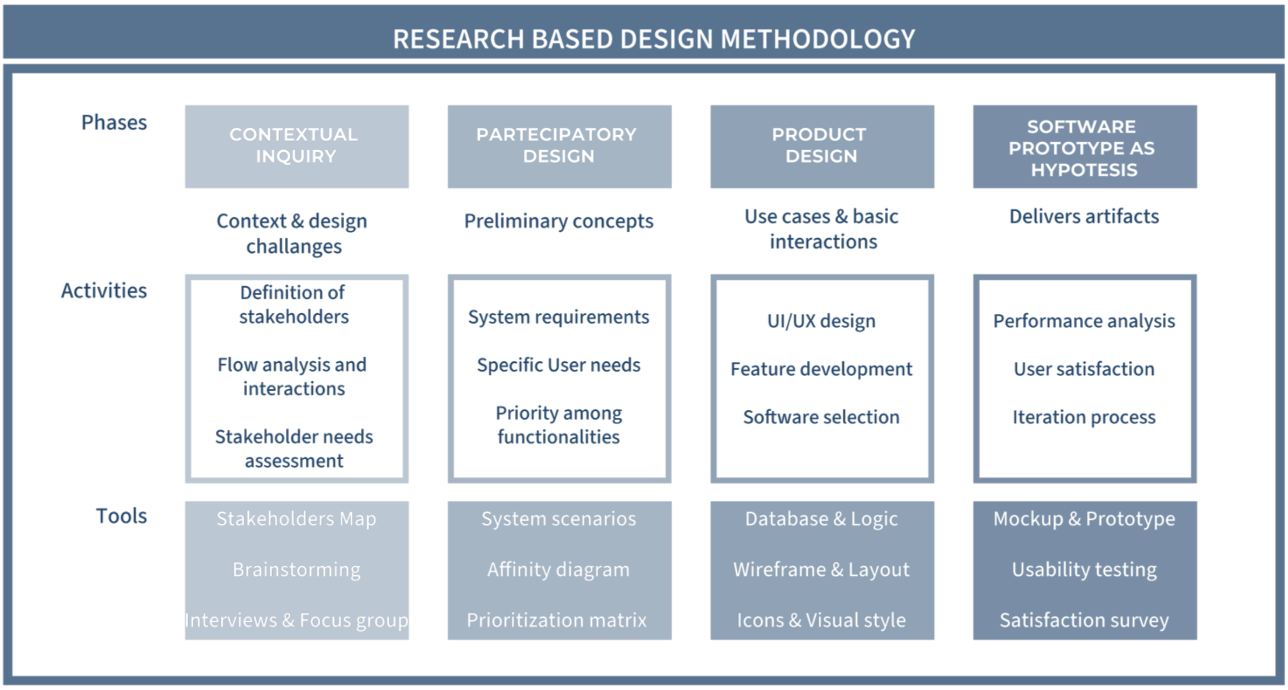

Figure 1. Research-based Design Methodology – adopted from Leinonen, 2008.

1. Contextual Inquiry:
   - Identification of stakeholders involved in consumable management.
   - Analysis of flows and interactions of single-use medical devices (SUDs).
   - Needs assessment through interviews and qualitative research.

2. Participatory Design:
   - Involvement of hospital staff in the development of the mobile app.
   - Collection of key app requirements, including features and technical specifications.
   - Identification of specific needs of hospital staff and stakeholders.

3. Product Design:
   - Selection of tracking management software.
   - User interface design through prototypes and mockups.
   - Development of identified crucial features, considering graphic preferences and design standards.

4. Prototyping as Software Hypothesis:
   - Creation of functional prototypes to evaluate proposed solutions.
   - Evaluation of app performance through usability tests.
   - Collection of feedback on performance, usability, and user satisfaction.

4. Results

The phases of action research have led to several significant outcomes in different stages of the process:

1. Contextual Inquiry:
   - During the stakeholder identification process through comprehensive mapping, it emerged that medical and nursing staff play crucial roles in hospital consumable management. This highlighted the need to create a consumable management support tool capable of guiding nursing staff in adoption decisions.
   - In the analysis of flows and interactions, stakeholders emphasized the importance of compatibility between consumables and department equipment, indicating that some previous consumables were not suitable for the new equipment and vice versa [Table 1]. This was identified as a critical point where consumables were not effectively used. Consequently, solutions were proposed for user training and management in the selection of consumables related to equipment and specific medical procedures and treatments.

Table 1. Stakeholder's needs, challenges, and proposed solutions.

Stakeholder	Needs and Challenges	Proposed Solutions.
Manufacturers	Timely delivery and product quality, regulatory compliance	Supply chain monitoring, quality audits
Medical Device Suppliers	Efficient delivery processes, technical support, long-term supply relationships	Delivery automation, technical support, long-term supply contracts
Hospital Pharmacy	Efficient inventory management, timely procurement	Inventory management systems, real-time inventory monitoring
Administrative Staff	Consumables shortage prevention, optimal costs, supplier management	Improving procurement processes, negotiating contracts with suppliers, reviewing policies.
Medical Staff	Compatibility between consumables and equipment, stock availability, patient safety	Compatibility assessment, entry and exit tracking systems
Nursing Staff	Efficient reordering, quick access to consumables, error reduction	Stock-based reordering, bar codes to identify consumables, staff training
Social and Health Care Workers	Easy consumable acquisition and transport, proper waste separation	Transportation procedures knowledge, waste management training
Waste Collection and Disposal Companies	Safe collection and disposal of medical waste. Reduced environmental impact waste	Waste treatment training, collection and disposal operations monitoring, environmental regulations compliance
Local and National Health Authorities	Regulatory compliance, transparency in hospital practices, quality of care	Policy review, promotion of audits, compliance support.

   - Through interviews with departmental staff, various challenges related to the supply and management of consumables emerged. During these interviews and multidisciplinary brainstorming sessions with doctors and nurses, qualitative observations were made, highlighting the need to create an IT system capable of monitoring consumable depletion rates and issuing alerts for inventory management.

2. Participatory Design:
   - To address the needs, a quantitative analysis was conducted, categorizing clinical procedures, equipment, and department consumables. This led to the creation of Excel databases to store this information. The goal was to automate reordering based on stock levels, implement a consumable tracking system, develop an app for staff training, and integrate everything with the hospital's supply system. Currently, the research focuses on finalizing the app structure and guidelines for consumable disposal in collaboration with a Computer Science Department student at Sapienza University of Rome.

3. Product Design:

The product design phase for the identified solutions was divided into two stages: user interface design, feature development, and software selection.

- User Interface Design: completing these activities allowed the design of the app's user interface in the considered context together with healthcare professionals [Figure 2]. The goal was to make navigation seamless for users, with elements arranged logically and easily accessible. Regarding colors, a palette inspiring trust and seriousness was chosen, using dark blue tones for the main sections and light blue for buttons highlighting positive actions. This color scheme aimed to create a professional and minimalist atmosphere. Additionally, the contrast between text and background was considered to ensure good readability. As for fonts, a clear and easily readable font type was selected, with a size suitable for both mobile devices and desktop or tablet stations.

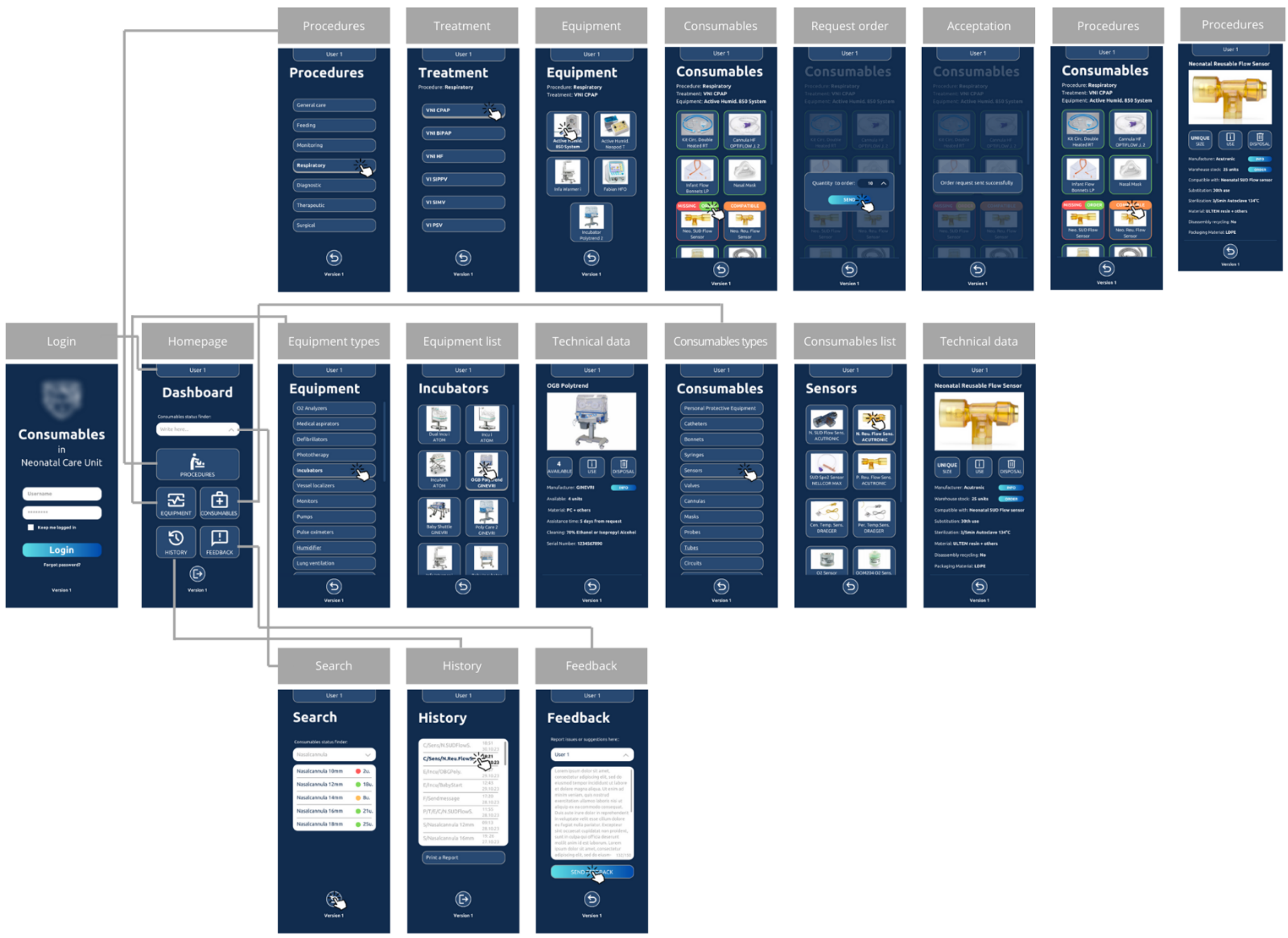

Figure 2. User flow App prototype.

- Feature Development: during the feature development phase, the app was enhanced with a welcoming home page, user access and profile management, a functional dashboard, and a smart consumable search feature. Relationships between procedures, equipment, and consumables were established, and comprehensive management systems for equipment and consumables were implemented. A feedback system was integrated for continuous improvement, and a history and reports function was added for monitoring and compliance purposes.

4. Software Prototype as a Hypothesis:
   - Evaluation of the app through performance analysis: a clearly defined protocol involving healthcare professionals was employed to assess the app's performance. The evaluation included various activities such as app access, consumable search, report generation, barcode scanning, and real-time inventory viewing. The results provide valuable insights into app performance and inform targeted improvements to enhance the user experience in healthcare material management. Key parameters evaluated include:
     - Completion Time: The average time users took to complete assigned tasks, measuring speed and efficiency.
     - Success Rate: The percentage of users who completed tasks without issues, reflecting app usability and user competence.
     - Issues Encountered: Documentation of problems or challenges encountered by users during app usage, such as interface errors, technical difficulties, or navigation confusion.

5. Conclusions and Future Developments

The integration of a mobile app for hospital consumable management is a significant step toward optimizing healthcare operations and achieving sustainable environmental goals. Achieved through a co-design process with key stakeholders, this approach addresses specific needs and challenges in Neonatology and Neonatal Intensive Care. Analysis of fluctuations and interactions highlights the importance of medical device compatibility and inefficiencies in consumable management. The app addresses these issues, offering efficient inventory management, detailed reporting, waste reduction, and improved healthcare operations. Ongoing user involvement and feedback ensure adaptability. The current phase focuses on the tracking system and the user interface, with plans for further system refinements. This project underscores the value of interdisciplinary collaboration and user involvement, promoting behavioral change at various levels. Investing in innovative technologies enhances healthcare efficiency and quality, paving the way for future research in hospital consumable management.

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