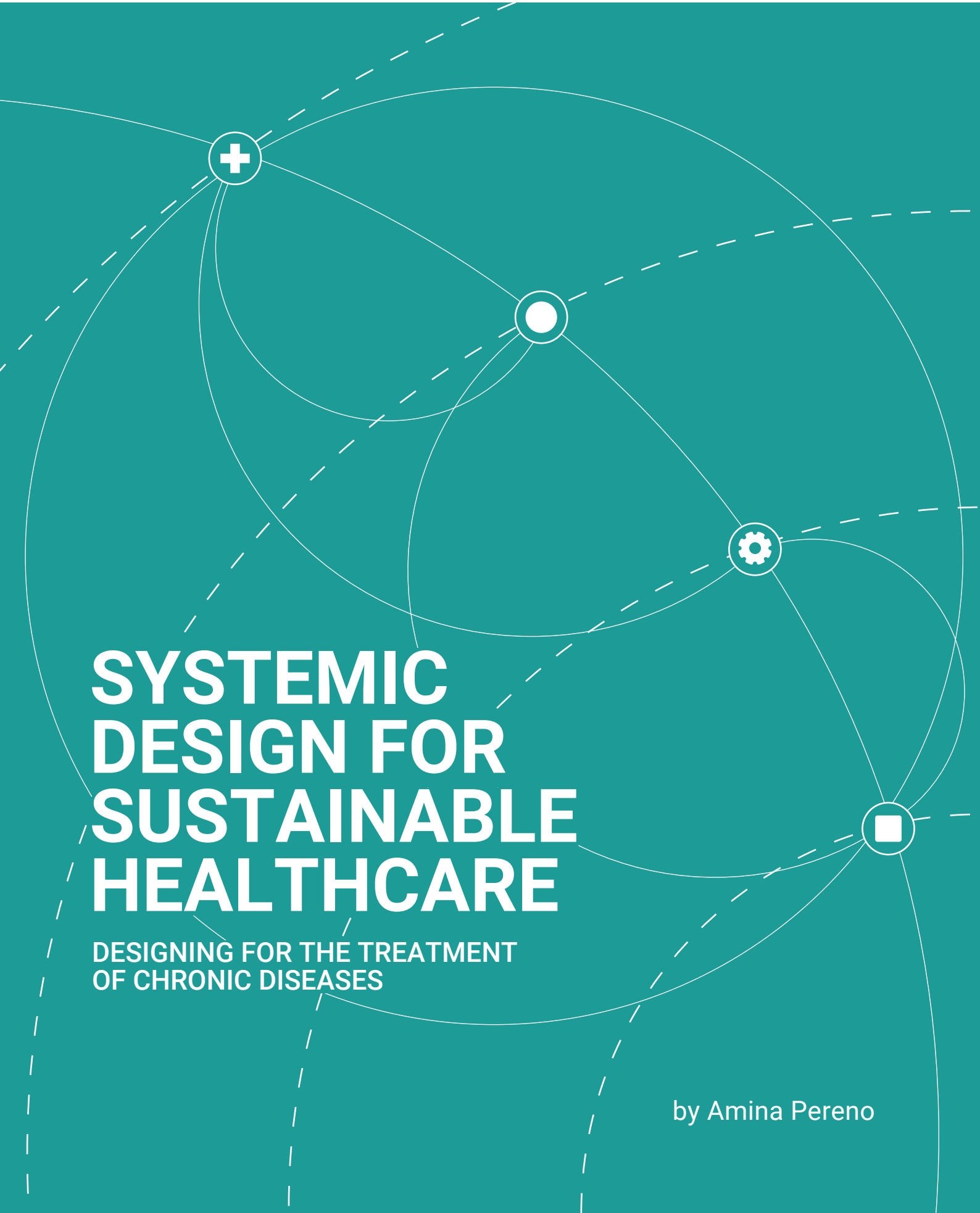
POLITECNICO
DI TORINO

Doctoral Dissertation
Doctoral Program in Management, Production and Design
29th Cycle



SYSTEMIC DESIGN FOR SUSTAINABLE HEALTHCARE

DESIGNING FOR THE TREATMENT OF CHRONIC DISEASES

by Amina Pereno

POLITECNICO
DI TORINO

ScuDo
Scuola di Dottorato ~ Doctoral School
WHAT YOU ARE, TAKES YOU FAR

Doctoral Dissertation
Doctoral Program in Management, Production and Design
(29th Cycle)

Systemic Design for Sustainable Healthcare

Designing for the treatment of chronic diseases

By
Amina Pereno

—

Supervisors
Prof. Paolo Tamborrini
Prof. Silvia Barbero

—

Doctoral Examination Committee
Prof. Peter H. Jones (OCAD University)
Prof. Patrizia Ranzo (Università degli Studi della Campania “Luigi Vanvitelli”)
Prof. Francesca Tosi (Università degli Studi di Firenze)
Prof. Carlo Vezzoli (Politecnico di Milano)
Prof. Pierpaolo Peruccio (Politecnico di Torino)

Politecnico di Torino
2017

For Miriam

Declaration

I hereby declare that, the contents and organization of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

Amina Pereno
2017

*This dissertation is presented in partial fulfillment of the requirements for **Ph.D. degree** in the Graduate School of Politecnico di Torino (ScuDo).

Aknowledgement

I would like to thanks the many people who so generously contributed to the work presented in this thesis.

First, I would like to express my gratitude to my supervisor Prof. Paolo Tamborrini for the support of my Ph.D. research, for his insightful comments and helpful advice.
Special thank goes to Prof. Silvia Barbero, who has been a truly dedicated supervisor, mentor, and friend. The enthusiasm she has for her research was motivational for me, even during tough times in these PhD study.

Profound gratitude goes to Daniel Eriksson, who provided me an opportunity to join the Nordic Center for Sustainable Healthcare as a guest researcher. I would also thank Marie Pettersson, Johannes Brundin and, especially, Anna Yelistratova for their precious support. I have very fond memories of my time in Sweden.
I would especially like to thank Mette Abilgaard, from SUS Malmö, and Paola Lendemar, from Frederiksberg Hospital, for their invaluable support and patience when I collected on-field data for my PhD thesis.

I am grateful to Prof. Peter Jones and Prof. Patrizia Ranzo who reviewed this thesis and gave me precious suggestions to improve it.

My sincere thanks also go to Prof. Giorgina Barbara Piccoli, Dr. Martina Ferraresi and Dr. Marta Nazha for believing in this research from the very start.
I thank Giorgio Garbuggio for sharing with me his experience on dialysis equipment, and Prof. Walter Franco who provided important support in the disassembly analysis.

Thanks to Imanol Urizar and Silvia Lo Noce for their precious help during the fieldwork.

I thank all my research teammates at Politecnico di Torino for the stimulating discussions, fruitful confrontation and for all the fun we had in the past three years. A special mention goes to Luca Giuliano, who shares with me this PhD journey.

A special thank to my family. I cannot express how grateful I am to my mother, my father, my brothers and my grandmother.

Finally, but by no means least, thanks to Fabrizio for your immense support and love, and thanks to Miriam, who actually shared nine challenging months of research, love and life: you are the most important people in my world.

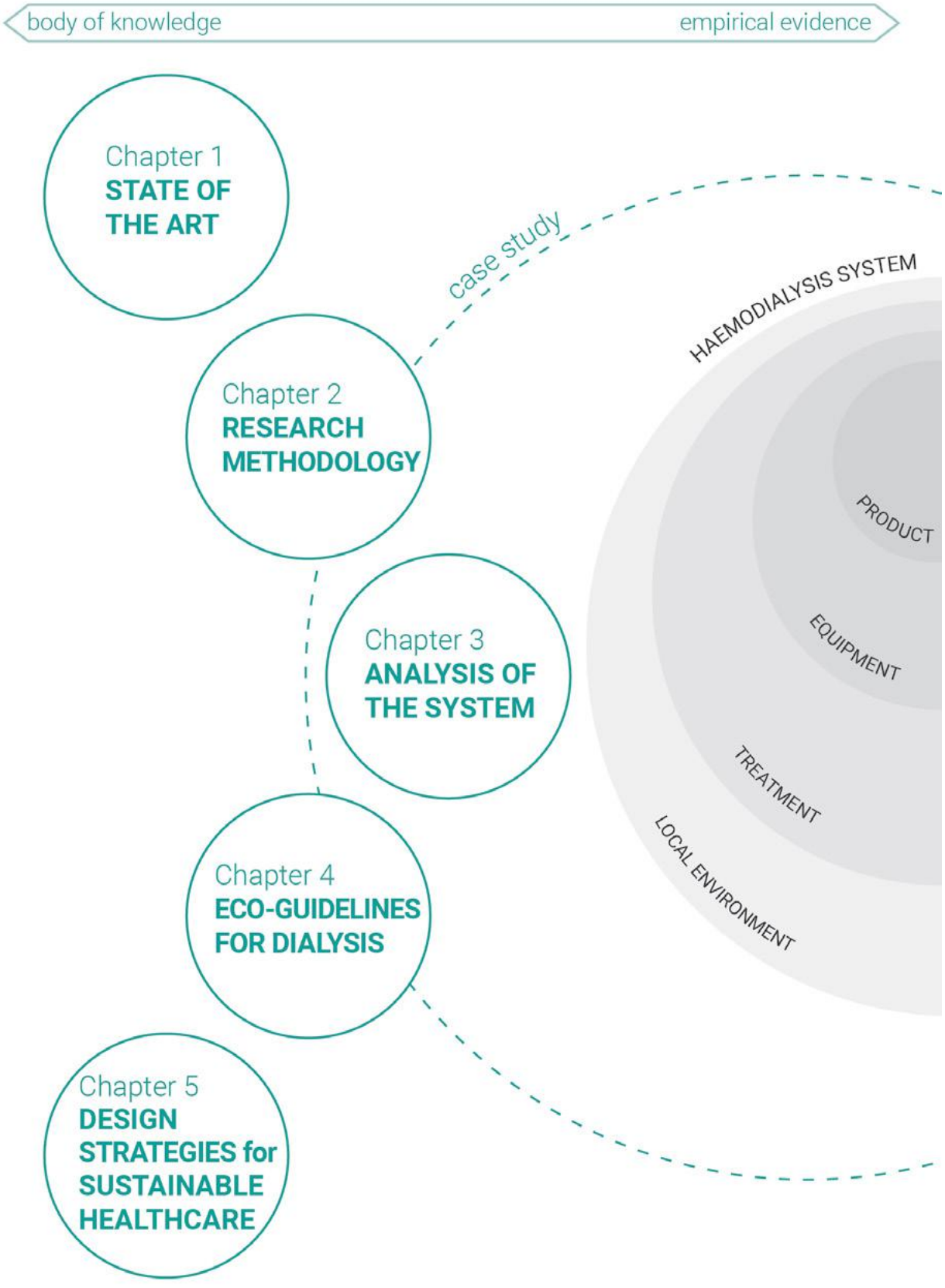
Abstract

Health systems are facing significant societal and organizational challenges that require enhancing their resilience and sustainability. Public expenditure on health care and long-term care is expected to increase: health systems are searching for new solutions to controlling spending, implementing the use of available technology and engaging patients in prevention and self-care. The transition toward more sustainable health systems is both delicate and complex, and it needs radical changes of perspective as regards the patients' role and the holistic and multi-disciplinary approach to health care.

Over the past years, interest in what is called "Sustainable Healthcare" has grown globally: there is no common definition, but all the approaches to this emerging domain focus on making health care environmentally, economically and socially viable. Although design could successfully address some crucial environmental issues of health care (from waste reduction to resource optimization), design research made almost no contribution to this field.

The present work aims at investigating the role of design towards Sustainable Healthcare, to propose, through case study experience, a systemic vision of the topic. Specifically, the research addressed the environmental issues of chronic haemodialysis, a life-saving treatment for people suffering from Chronic Kidney Disease. Medical treatments imply significant challenges because of their technical and operational complexity, that is further complicated by strict regulations and the presence of several users. Design should address environmental sustainability in such a complex system while maintaining the focus on user-centred care. Traditional design approaches cannot tackle the complexity of health care; therefore, a holistic approach is needed. Systemic Design integrates systems thinking and human-centred design methodologies to support designers working on complex design projects in multi-stakeholder and multi-environment systems.

The doctoral research is deeply rooted in the framework of Systemic Design, aiming at defining how design strategies can improve the environmental sustainability of medical products, services, and systems, considering its close relationship with the social (people empowerment) and economic (feasibility) aspects. The first part of the research focused on the definition of all the items which make up the system, and the users that directly or indirectly interact with them. Four system items have been identified: products (packaging, disposables, devices), equipment (dialysis machine), treatment (haemodialysis as a whole) and local environment (policy and management strategies). In the second part different approaches, borrowed from sustainable design and human-centred design, have been combined to analyse each item. In order to establish a general frame, three different dialysis units and hospitals based in different European countries (Italy, Sweden, Denmark) were compared. This comprehensive analysis allowed to set specific guidelines for dialysis products, equipment, and treatment. The comparison of three international case studies highlighted how design should work on product and equipment to improve environmental sustainability on a global scale while addressing local systems and their specific needs to improve sustainability on a local level. The outcome of the research is a set of design strategies for the healthcare sector that take into account the technical, operational, social and environmental requirements of chronic treatments. This final result aims at providing a practical tool for designers and health stakeholders to address the design of new solutions for Sustainable Healthcare, considering the needs of direct and indirect users.


body of knowledge
empirical evidence
Chapter 1
STATE OF THE ART
Chapter 2
RESEARCH METHODOLOGY
Chapter 3
ANALYSIS OF THE SYSTEM
Chapter 4
ECO-GUIDELINES FOR DIALYSIS
Chapter 5
DESIGN STRATEGIES for SUSTAINABLE HEALTHCARE
case study
HAEMODIALYSIS SYSTEM
PRODUCT
EQUIPMENT
TREATMENT
LOCAL ENVIRONMENT
design for Sustainable Healthcare
design for chronic diseases

Contents

Executive Summary **pag.14**

1 State of the Art **pag.24**

1.1 Design and Healthcare pag.25
1.2 A review on design for healthcare pag.26
1.3 A map of Design Research in health-related areas pag.27
1.3.1 Design for Healthcare Architecture pag.27
1.3.2 Design for Medical Technologies and devices pag.29
1.3.3 Design for eHealth pag.33
1.3.4 Design for Sustainable Healthcare pag.35
1.3.5 A cross-boundaries approach: Systemic Design pag.36

2 Research methodology **pag.38**

2.1 Theoretical Framework: Systemic Design pag.39
2.1.1 From Systems and Design Thinking to Systemic Design pag.39
2.1.2 Systemic Design and Sustainability pag.40
2.1.3 Systemic Design for Sustainable Healthcare pag.42
2.2 Methodological Path: From Theory To Practice pag.42
2.2.1 Research boundaries pag.43
2.2.2 Haemodialysis: principles and application pag.43
2.2.3 Designing for the local and the global pag.45
2.2.4 International case studies pag.46
2.2.5 Holistic diagnosis: the analysis of the system pag.48
2.2.6 Outcomes of the analysis pag.51

3 Analysis of the system: focus on chronic haemodialysis **pag.54**

3.1 Product: Packaging And Disposables pag.55
3.1.1 Product assessment through a qualitative-quantitative analysis pag.55
3.1.2 Qualitative comparison of product categories pag.58
3.1.3 Quantitative comparison of different methods pag.60
3.1.4 Quantitative comparison of different case studies pag.63
3.1.5 Product requirements pag.64
3.2 Equipment pag.65
3.2.1 Existing solutions of haemodialysis equipment pag.65

3.2.2 Equipment assessment through a disassembly analysis pag.72
3.2.3 Equipment requirements pag.78
3.3 Treatment pag.84
3.3.1 Treatment assessment through a routine analysis pag.84
3.3.2 Treatment requirements pag.89
3.4 Local environment pag.90
3.4.1 Regional organization for Sustainable Healthcare pag.90
3.4.2 Implementation of Sustainable Healthcare strategies pag.92
3.5 The current system pag.95

4 Ecoguidelines for haemodialysis **pag.98**

4.1 Definition of Design Ecoguidelines pag.99
4.2 Product and equipment guidelines pag.99
4.3 Treatment guidelines pag.109
4.4 Towards a new system pag.111

5 Design strategies for Sustainable Healthcare **pag.114**

5.1 From Practice to Theory: Designing for Sustainable Healthcare pag.115
5.2 Design Strategies pag.116
5.2.1 Reduction pag.117
5.2.2 Materials pag.120
5.2.3 Technology pag.122
5.2.4 Flexibility pag.125
5.2.5 Usability pag.128
5.2.6 Lifecycle pag.132
5.2.7 Information pag.136
5.3 Conclusions pag.139
5.4 Contribution to knowledge pag.140
5.5 Limitations and directions for future research pag. 141

References **pag.144**

Annex I. Analyses of the system items **pag.156**

Annex II. Publication list **pag.208**

List of figures

Figure I: Visualization of the methodology for the analysis of the system items pag.17

Figure II: Overall diagram of the Design strategies pag.21

Figure 1: Visualization of research areas supporting design for health care pag.28

Figure 2: Basic functioning of haemodialysis pag.44

Figure 3: Visualization of the haemodialysis system that includes users and items pag.45

Figure 4: Detail of the analysis of the system items pag.46

Figure 5: Map of the international case studies pag.47

Figure 6: Data comparison of the dialysis units pag.48

Figure 7: Visualization of the methodology for analysing the system pag.49

Figure 8: Example of the qualitative analysis applied to an acid concentrate bag for haemodialysis pag.55

Figure 9: Macro-components of Fresenius 5008 pag.71

Figure 10: Example of the disassembly analysis of a macro-component pag.72

Figure 11: Example of the accessibility analysis of a macro-component pag.75

Figure 12: Example of the analysis of the input-output flows pag.75

Figure 13: The overall essential scheme of FRESENIUS 5008 pag. 77

Figure 14: The dialysis unit at Frederiksberg Hospital during the set-up of the treatment pag.84

Figure 15: Example of the routine analysis applied to the Swedish case study pag.85

Figure 16: Example of the analysis of regional organization for Sustainable Healthcare pag.91

Figure 17: Example of the analysis of the implementation of Sustainable Healthcare strategies pag.93

Figure 18: Map of the current haemodialysis system pag. 96

Figure 19: Map of a sustainable haemodialysis system pag.112

Figure 20: Diagram of Design strategies for reduction pag.117

Figure 21: Diagram of Design strategies for reduction pag.119

Figure 22: Diagram of Design strategies for technology pag.123

Figure 23: Diagram of Design strategies for flexibility pag.125

Figure 24: Diagram of Design strategies for usability pag.128

Figure 25: Diagram of Design strategies for lifecycle pag.132

Figure 26: Diagram of Design strategies for information pag.136

List of tables

Table 1: Qualitative comparison of different products categories pag.59

Table 2: Quantitative comparison of different treatment methods according to the weight of the collected waste pag.61

Table 3: Quantitative comparison of different treatment methods according to the materials making up non-contaminated waste. pag.62

Table 4: Quantitative comparison of different treatment methods according to the cost of waste disposal pag.62

Table 5: Quantitative comparison of different case studies according to the weight of the collected waste pag.63

Table 6: Quantitative comparison of different case studies according to the materials making up non-contaminated waste pag.64

Table 7: Product requirements pag.66

Table 8: Benchmarking analysis of the existing haemodialysis machines pag.70

Table 9: Results of the benchmarking analysis pag.72

Table 10: Weight assessment of the equipment macro-components pag.75

Table 11: Weight assessment of the materials making up the equipment pag.76

Table 12: Equipment requirements pag.80

Table 13: Comparison of the treatment analyses pag.86

Table 14: Treatment requirements pag.88

Table 15: Cross-case comparison of the regional organization pag.92

Table 16: Cross-case comparison of the implementation of Sustainable Healthcare strategies pag.94

Table 17: Generic eco-guidelines for designing products and packaging pag.102

Table 18: Specific eco-guidelines for designing products and packaging pag.105

Table 19: Generic eco-guidelines for designing machines pag.106

Table 20: Specific eco-guidelines for designing medical equipment pag.107

Table 21: Specific eco-guidelines for designing for medical treatments pag.110

Executive Summary

BACKGROUND

Healthcare systems aim at meeting the health needs of populations and enabling people to live independently by providing social care services. There are several types of **healthcare systems worldwide**, but they **are all facing radical changes and common challenges**. First, the health care sector is moving toward **defragmentation**, pushed by increasing and emerging financial cuts to cope with massive budget deficits in public spending. New technologies play a vital role in this new trend, by optimizing treatments procedures and enhancing the digital connection between hospitals, physicians, and patients. Secondly, **population ageing** puts pressure on health systems, increasing the demand for care, services, and technologies to effectively prevent and treat **non-communicable diseases and chronic conditions**. Expenses and patient numbers will inevitably increase, and health care must pursue the goal of an *"effective, efficient, and equitable health care for all"* (DELOITTE, 2016). Health systems are controlling spending, engaging patients in prevention and self-care, optimizing processes, resources, and supplies, also driven by the increasing attention to their environmental burden.

Therefore, the interest in what is called **Sustainable Healthcare** has grown sharply in recent years: although in a fragmented manner, European countries are promoting new strategies in the field of Sustainable Healthcare, encouraged by international organizations which bring together hospitals, patient associations, companies and health stakeholders (Jamieson et al., 2015). There is no common definition of Sustainable Healthcare, but all the

approaches to this topic focus on **making health care environmentally, economically and socially viable**.

The transition toward more sustainable and resilient health systems is both delicate and complex, and it needs radical changes of perspective as regards the patients' role and the holistic and multi-disciplinary approach to health care. Technical and medical innovation is certainly crucial, but innovative healthcare solutions should meet the criteria of usability, utility, and acceptability to enhance self-management and improve care experience. **The creative and, at the same time, methodological approach of design to manage user-focused problems is attracting interest in healthcare stakeholders** (Ticehurst, Ward, & Clarkson, 2010). Design tools and methods are perceived as useful and effective to bring innovation in the healthcare sector. All design disciplines, despite any differences in the topics addressed and the tools used, aimed at understanding people's problems and creating solutions that fit the users' needs according to their social and cultural background. Furthermore, the knowledge of design for managing complexity is an attracting skill for complex sectors such as healthcare. Designers are called upon to bring order to the system, sharpening their focus not only on the artefact they are designing but on the system in which the artefact and the user are included.

The literature review has focused on how design thinking and design methods are applied in practice to healthcare research, aiming at understanding how, when and with what results design is bringing innovation to this sector. The review highlighted four main areas in which design research is facing different types of healthcare issues: **design for healthcare architecture, design for medical technologies and devices, design for eHealth, and design for Sustainable Healthcare**. Designers are dealing with innovative devices, user-centred hospitals and home spaces, as well as with ICTs, aiming at empowering people. Despite these outstanding contributions to health-related research, the literature highlights that design research has been unable to reach an all-comprehensive sustainability to date. In most studies, there is a lack of balance between economic, social and environmental sustainability, in particular concerning the environment. The complexity of health care is indeed particularly difficult to tackle through traditional design approaches. Therefore, a holistic approach to the sector is needed to go beyond conventional design categories.

Although its contribution to healthcare literature remains small, **Systemic Design** (SD) has a great potential for driving sustainable innovation in health care, and the few cases present in literature are of great interest to health-related research. SD is a **system-oriented design practice to tackle complex problems in complex systems**. As Jones (2014) states, *"Systemic design is concerned with higher order systems that encompass multiple subsystems. By integrating systems thinking and its methods, systemic design brings human-centered design to complex, multi-stakeholder service systems […]"*. SD approach confirms the central role of users, but it sets out the interwoven relationships within the system as the starting point of the design process, through a *"holistic diagnosis"* that highlights criticalities and potentialities of the system (Barbero, 2012). Social, economic, and environmental impacts are assessed to guide the design process towards innovative solutions that enhance the sustainability and resilience of the system, empowering the people within it.

RESEARCH GOALS

The methodology adopted directly relates to the theoretical framework of SD. As the literature review showed, there is a huge lack of research in the field of design for Sustainable Healthcare: health systems are slowly but surely moving toward Sustainable Healthcare and design could actively contribute to this paradigm shift. In the present research, Sustainable Healthcare has been investigated from a design perspective. For this purpose, a specific methodology has been implemented by taking into account the SD tools and methods, aiming at answering two main research questions:

1. **How might design strategies improve the environmental sustainability of medical products, services, and systems**, considering

its close relationship with **social** (people empowerment) and **economic** (feasibility) sustainability?
2. **How does the system affect the products and the people** (patient, clinicians, health staff, technicians, and other stakeholders involved in the system) **that interact with them**, considering environmental sustainability? How is the local system (ward/unit) influenced by the wider context (hospital, region, country)?

In order to answer the research questions, the study has focused on the analysis of a practical case study. The choice of the case study had to be significant in terms of relevance, diffusion, and environmental burden. **Chronic haemodialysis** constitutes a significant case study since it is a common treatment for Chronic Kidney Diseases (CKD) that involves millions of people worldwide. It is considered to be one of the most expensive medical treatments concerning care expenses, resource consumption, and waste production (Burnier & Martin, 2013). Despite the growing relevance of home care, it was decided to focus the research on **in-centre haemodialysis** because it engages a wider range of users (patients, clinicians, nurses, and technicians) and it is directly affected by national and international policies and strategies towards Sustainable Healthcare.

METHODOLOGY

Haemodialysis is a complex system consisting of different items (product, equipment, treatment, and local environment) that, in turn, may differ depending on the treatment method and the place where the therapy is performed. The case study analysis has been carried out in **three hospitals and regions in different European countries**, so as to investigate the impacts of the context on the local system, and to ensure the validity of the design assessment:

1. San Luigi Gonzaga University Hospital, Orbassano - Piedmont Region (**Italy**)
2. Skåne University Hospital, Malmö - Skåne Region (**Sweden**)
3. Frederiksberg Hospital, Frederiksberg - Hovedstaden Region (**Denmark**)

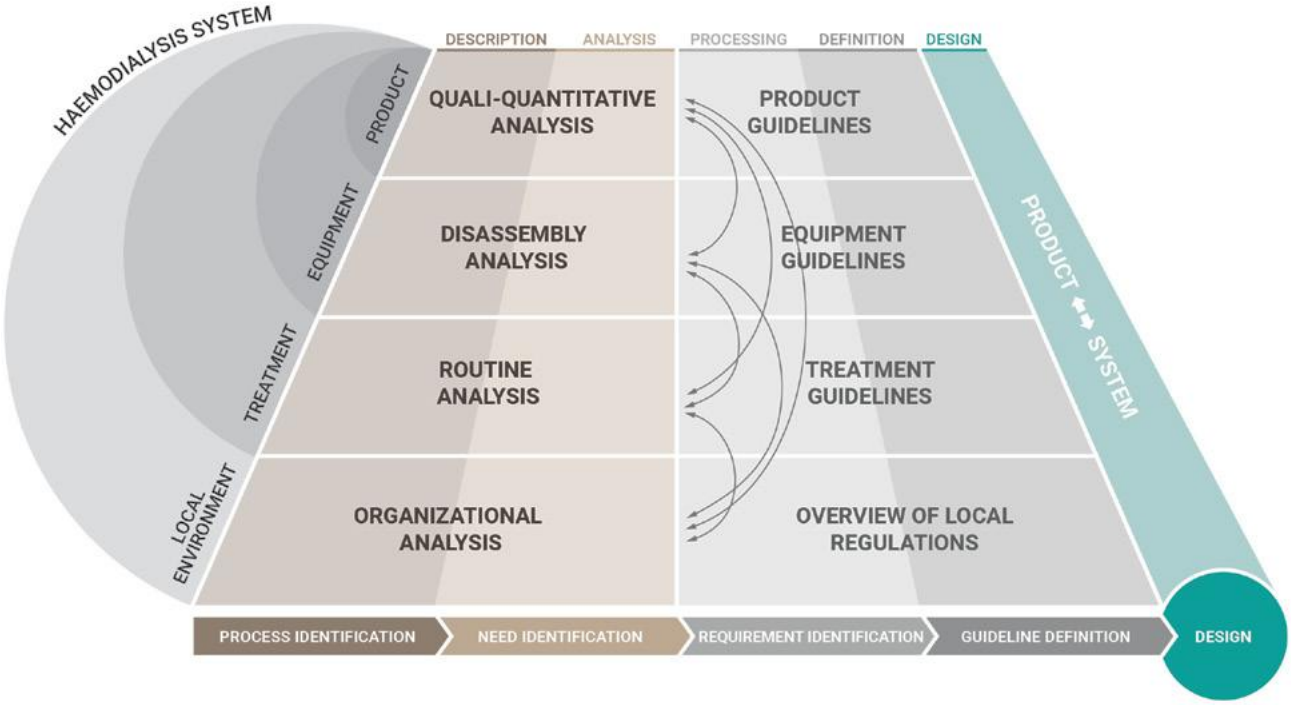
The choice of the case studies has been endorsed by the **Nordic Center for Sustainable Healthcare**, led by TEM Foundation at Lund University, which has supported the case study analysis.
The methodology has focused on the **analysis of the four items** that represent the four levels of the system (Figure I): **product** (packaging, disposables, devices), **equipment** (haemodialysis machine), **treatment** (haemodialysis routines) and **local environment** (national and local policies and strategies). The levels have been defined focusing on the relationship between product, process and system to keep the focus on environmental sustainability. Direct and indirect users are involved in all the levels; special attention is paid to the treatment level which especially involves patients, nurses, clinicians, and technicians.
The analysis of the items has followed a **common methodological path**, that focuses on the holistic analysis of the current scenario (Barbero, 2016), by adopting and implementing existing design processes (Germak, 2008):

- **Process identification:** the goal of this first step is to understand in depth how the system items behave and how they relate to direct users and the other items, identifying the processes behind them. The item features have been observed and described according to different methods.
- **Need identification**: this phase aims at identifying the main problems of the item and defining the primary needs design should face from a functional, social, and environmental perspective.
- **Requirement identification**: this step starts from the identified needs to define the main technical, operational, social and environmental requirements.
- **Guideline definition**: The final step of the analysis is the definition of the design guidelines for improving environmental sustainability. This phase gathers and processes the results of the previous steps to establish a specific set of guidelines for each system item.

Fig. I - Visualization of the methodology for the analysis of the system items

Since the items have highly varied features, the study adopted different design methods to carry out the first two steps of analysis (Process and Needs identification):

- **Product – Quali-quantitative analysis**: a qualitative-quantitative methodology has been used for analysing packaging and product. It is a proven and field-tested method developed by the Politecnico di Torino, within the Observatory of Eco-Pack (OEP) (Barbero, Pereno, & Tamborrini, 2011). It combines a quantitative assessment of weights and materials with a qualitative evaluation of the immaterial features that characterize design issues (concerning function, sustainability, and communication)
- **Equipment – Disassembly analysis**: the analysis of the equipment builds upon the well-known approaches of Design for Disassembly (Bogue, 2007) and Design by Components (Bistagnino, Marino, & Virano, 2008). The implemented method consists of three steps: the disassembly analysis focuses on the ease of disassembly aimed at optimizing the reuse, remanufacturing or recycling of materials, components and sub-assemblies; the accessibility analysis evaluates the issues and requirements of accessibility for the users that directly interact with the equipment (patients, nurses, technicians); the input-output analysis assesses the material flows and the relations between the components.
- **Treatment – Routine analysis**: The analysis aims at identifying the main organizational issues that affect affect patients, nurses, and clinicians behaviours and product management towards sustainability. Therefore, a specific routine analysis has been set out to assess different tasks, staff interaction, and patient empowerment, starting from well-known visualization tools (such as patient's journey techniques).
- **Local environment - Organizational analysis**: The organizational analysis provided an overview of different approaches to Sustainable Healthcare (SH), analysing environmental strategies both at the macro (Region) and the micro level (hospital and dialysis units). Different stakeholders and their responsibilities and tasks have been considered.



This comprehensive analysis allowed to set specific eco-guidelines for each item, taking into account technical, operational, social and environmental requirements.
After the analysis has been completed, all the item guidelines have been combined to define a common set of design strategies for the healthcare sector. The strategies address different levels of the system (product, equipment, treatment), driving the design process towards a systemic view.

FINDINGS OF THE ANALYSIS OF THE SYSTEM

PRODUCT

Chronic haemodialysis includes different methods of treatment according to the patient's disease, which uses various types of disposable products and packaging. The product analysis considered the **qualitative and quantitative aspects of products**, allowing to compare different product categories, treatment methods, and case studies.
The qualitative-quantitative analysis highlighted some specific problems:

- **Functional issues**. The comparison shows a widespread oversizing of packaging, that affects their ability to protect products against impacts, as well as their environmental burden, because of the overuse of materials. At the same time, usability issues negatively impact on staff and patients' tasks: the difficulty in handling and the lack of visual codes make the daily supply more difficult; disposables and devices require high cognitive efforts to set up the therapy, this problem particularly affect the patient empowerment towards self-care.
- **Weight issue**s. The total amount of waste produced in each dialysis session may be from 2 up to 8 kilogrammes: this result not only confirms the general esteems carried out in previous works (Agar, 2012), but it highlights even larger numbers whether waste sorting is not done properly.
- **Material issues**. On average, the 95% of non-contaminated waste is made of plastics. Composite polymers are widely used and are more difficult to recycle. Many packs are made of recyclable materials that, however, are often difficult to separate because of the use of permanent joints.
- **Disassembly issues**. The disposal phase presents major operational problems concerning the management of contaminated waste and the sorting of non-contaminated waste. In particular, many packs, such as bicarbonate cartridges and solution bags, are difficult to sort since they cannot be open to being emptied. The total weight is strongly affected by the emptying of waste: the weight of non-emptied waste can increase by 43% to 315%, according to the type of treatment.
- **Communication issues**. The lack of communication on packs does not facilitate the identification of products during the supply operations. Information about materials and disposal are almost absent: this makes waste sorting more difficult and requires a greater cognitive effort to the health staff.

EQUIPMENT

Because of its cost and complexity, the dialysis equipment is designed for a global market and can perform different types of treatment, adapting to different contexts and infrastructures. The research has focused on the **disassembly analysis of a specific equipment**, Fresenius 5008 (by Fresenius Medical Care) that the benchmarking analysis has proven to be a valuable example of haemodialysis machine.
The study was performed in collaboration with the team of the San Luigi Gonzaga Hospital (Department of Clinical and Biological Sciences, University of Torino) and the team of the Department of Mechanical and Aerospace Engineering (Politecnico di Torino). Technicians from ACTEM S.r.l. (partner of Fresenius Medical Care) provided technical advice on the operation of the equipment.
The complex nature of a biomedical equipment exceeds many other products, from a technical, regulatory and ethical point of view. The analysis of this kind of machine has to face many challenges, from the need to gain specialist knowledge to the time required for developing, testing and patenting the components, to the systemic complexity of the ancillary products. In order to address this complexity, the equipment should be divided into nine macro-components, which have been individually assessed. The equipment analysis

has concentrated on components and materials (disassembly analysis), the type and ease of access to the device by technicians, nurses and patients (accessibility and interaction analysis), and the definition of inputs and outputs (flows analysis). The analysis highlighted specific design issues:

- **Accessibility issues**. The accessibility problems mainly affect maintenance. Many internal components are not easily accessible because of the complexity of layout and the position of screws. The use of protective foams does not provide effective protection to electrical components and makes them more difficult to access.
- **Material issues**. There are few mono-material components (31% in weight, mainly made in PUR, ABS, Iron, and Aluminium) that are mostly shell parts and cover elements. The major part of components is made of composite materials or different materials joined together (25%) and WEEE (44%), that have to be managed apart.
- **Disassembly issues.** The presence of several types of fasteners make the disassembly more difficult: interlocking is often combined with screw fastening, clamps and other interlocking elements are very hard to remove. The use of different screws requires several tools, and this is due to the lack of standards for suppliers. Moreover, components are grouped into units that take time to be disassembled, because of the high number of screws and fasteners. Lastly, the little information about materials does not support technicians in recycling faulty or deteriorated components.
- **Operational issues**. The analysis did not show significant issues in operation. Minor problems concern: the disinfection components that could be accessed by non-expert people, causing possible errors; the bloodline positioning in the peristaltic pumps that may be potentially fatiguing. Previous works highlighted patient injury due to inadequate equipment disinfection and dialyzer errors (Garrick, Kliger, & Stefanchik, 2012).

TREATMENT

Haemodialysis differs from other chronic noncommunicable diseases, such as diabetes or heart disease, because CKD patients are highly dependent on the medical equipment and they need daily or weekly treatments throughout their lives or until they receive a kidney transplant. Despite dialysis has always been considered a passive treatment regime, today there are several possibilities for home and in-centre patients to get involved in the treatment and play a more active role in their own care. Therefore, the treatment analysis has taken into account both clinicians and patients' roles, with a special focus on patient empowerment towards limited-assistance and self-care.

On-field observation allowed to collect **data about dialysis routines**, monitoring the actions of nurses, patients, and physicians. The data have been visualized through a specific map, based on patient's journey technique, that combines different levels of analysis: routine activities, users' role, strengths and weaknesses.

The comparison of the three case studies revealed many issues that design can contribute to improving:

- **Work condition**. Nurses' activities involve physical and mental efforts, due to the daily supply, the equipment set-up, and the need of handwriting information about the therapy. Time pressure may cause errors both in treatment set-up and in waste sorting: design has to take into account this work condition.
- **The role of nurses.** Nurses play a leading role, but their autonomy is directly affected by the presence of the physicians, who may limit their freedom and decision-making abilities. No professional and environmental training is foreseen for all nurses.
- **The role of patients**. If the role of nurses may vary depending on the hospital, the role of patients is always passive: their contribution to the treatment is very limited as well as their awareness and decision power. Entertainment is a key issue in chronic treatments which require 3-4 hours per session: in most cases, there is little attention to this aspect and patients shall provide for self-entertainment or they might opt for the limited and not customizable offer delivered by the hospital.
- **Sustainable behaviours**. Environmental awareness is considered as an essential aspect to promote, but often sustainable initiatives are poorly supported by the hospital. Even in the

hospitals more committed to environmental aspects, sustainable behaviours, such as proper waste sorting, are deeply connected to personal commitment.

LOCAL ENVIRONMENT

The complexity and interdisciplinarity of healthcare systems require a multilevel analysis that takes into account different aspects affecting the implementation of environmental sustainability strategies. The various **stakeholders and their related responsibilities** and tasks have been considered to define a methodology that can be applied to different contexts and countries. The analysis has been carried out considering **two levels of the organization**, each of which shows specific criteria of analysis: the Regional organization for Sustainable Healthcare and the implementation of Sustainable Healthcare strategies.

The combination of both levels allowed comparing different regional strategies for Sustainable Healthcare and, at the same time, verifying their implementation at the ward level:

- **Regional organization for Sustainable Healthcare**. The cross-case comparison shows different levels of complexity and the inconsistent presence of environmental coordinators within the organisational hierarchy. The presence of environmental coordinators for each level of organization is crucial to translate environmental strategies into practice. The hospital environmental coordinator constantly relates to the regional department, and his/her role is important to implement long-term strategies. At the same time, the organizational complexity may lead to top-down initiatives, making it difficult to propose and discuss bottom-up ideas, and encourage shared responsibility and cooperative efforts among staff and patients. Conversely, a less complex organization can increase horizontal communication and promote self-initiatives.
- **Implementation of Sustainable Healthcare strategies.** In all cases, regions are responsible for defining the environmental programme and the related goals to achieve. The hospital feedback is limited to occasional projects. At unit level, the staff has to implement the environmental routines, translating into practice the guidelines and projects that regions are promoting. So, despite the global attention to sustainability, units are only aimed at implement strategies, but they can only take minor decisions. As regards Sustainable Product Procurement, the decision-making power of units (that involve nurses, which directly use the products) is extremely limited: there are no official procedures to allow the staff to ask for more sustainable products. Furthermore, the slow pace of change in public procurement and the rigidity of supply categories make the introduction of innovative products more difficult. Current practices of public procurement may be an obstacle to design new systemic solutions that integrate different system items.

RESEARCH OUTCOMES

The analysis of the system has led to define **a broad set of requirements**, starting from the issues and potentials that the analyses of the items have highlighted. Requirements address the environmental sustainability and the functionality of haemodialysis from a design perspective. A further step was done to summarize the results of the analysis and provide a **comprehensive overview of design issues in haemodialysis**. The **design eco-guidelines** provide clear and practice-based guidance for designing innovative products, services, and systems toward environmental sustainability and user-centricity in dialysis treatments.

In order to facilitate reading and comprehension, the guidelines have been divided into seven categories, which directly refers to Design for Sustainability (Vezzoli & Manzini, 2007):

1. **Reduction**: rethink the product and its function, aiming at reaching a new solution that minimizes materials, volumes, and thickness toward dematerialization (Braungart, McDonough, & Bollinger, 2008).
2. **Materials**: the design choice made in relation to the product makes that material sustainable (Muenchinger, 2011)
3. **Technology**: choose the proper technology according to the actual needs of application

(Thackara, 2005)

4. **Flexibility**: design products, services, and systems that are able to meet the needs of different users, adapting to the change of these needs over time (Van Nes & Cramer, 2005)
5. **Usability**: give an answer to the actual social, cultural, and operational needs of users (Maeda, 2006)
6. **Lifecycle**: extend the life of the product and its components, enabling maintenance and upgrading and planning secondary uses (Shedroff, 2009)
7. **Information**: communicate to creating awareness in the user, throughout the whole life cycle (Scudieri & Gill, 2008).

The guidelines provided important highlights on haemodialysis issues, by providing practical suggestions for designers to address this type of treatment. However, the aim of the PhD work was to address health care and health treatments more broadly, by **transforming the research findings in a practical tool** that can be made available to **designers and health stakeholders** addressing Sustainable Healthcare. The Design strategies are a set of 15 strategies directed to designers and professionals, that aims at describing the main issues to face in chronic treatments, the role of design in the resolution of these problems, and the relationships among patients, staff and technicians and the system items. The Design strategies are divided into the seven categories of Design for Sustainability; this allows to include the strategies in an overall framework that designers are familiar with, so as to make them able to seek references for deepening and updating their knowledge.
Strategies provide **detailed information on the key issues and how design can address them** in relation to the system items (product, equipment, treatment) and the direct users (patient, health staff, technician) involved in a chronic treatment (Figure II).

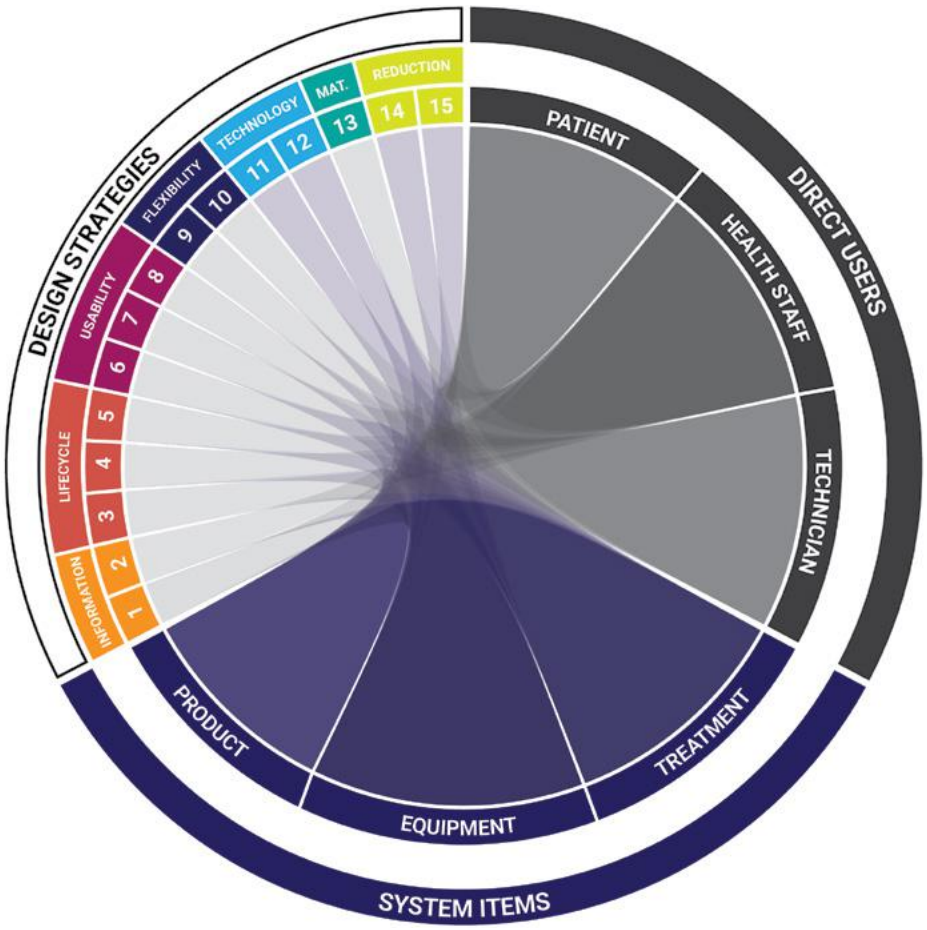


Fig. II – Overall diagram of the Design strategies

Overall, the PhD research has demonstrated how the application of a systemic approach to health care enables to address environmental sustainability in multi-stakeholder and multi-environment systems while maintaining the focus on patient empowerment and user-centred care. SD allows including environmental sustainability into the design process, considering the environment as a cross-item of the system which dialogues with the other stakeholders.

The application of SD to a complex medical treatment, such as haemodialysis, highlights important strategies to move toward a more sustainable and resilient system:

1. **Relationships among users improve the system.** The final goal of the design process is to improve care experience through improving the relationships among different users and between the user category and the system items. The starting point is the identification of the actual needs according to the tasks of patients, health staff and technicians and their roles within the health treatment. Answering those needs means to enhance the autonomy, awareness, and self-confidence of all different type of users. Patient empowerment is considered as a key challenge for health systems, but all direct and indirect users should be enabled to take an active part in the system.
2. **Considering material flows from a circular perspective.** SD analyses material flows to enhance the waste of health processes, transforming them into resources for other systems. Despite the focus on outputs, the design process involves all the stages of a product lifecycle, acting both upstream of the production and downstream of the health treatment. Material reduction and resource optimization are important strategies to prevent waste production and rethink products and services in a different way, finding new solutions to manage waste and turn them into new resources.
3. **Integrated vision of products and services.** The traditional view of product and service design cannot tackle the complexity of healthcare. Design should consider products as small parts of a wider system. The relation between products and medical equipment is essential: they can not be considered as different goals of the design process, but they should be designed as a single integrated system. This approach leads to rethinking the product itself, moving towards dematerialization.
4. **Sustainability as a cross-item feature of the system.** Environmental sustainability always embeds economic and social aspects, representing a pervasive and flexible feature of the system. Therefore, policies can not address environmental sustainability through a top-down sectoral approach: Design should support policymakers to broaden their perspective on sustainability, moving from the product to the system and promoting people awareness, that represents the first goal to achieve towards Sustainable Healthcare.

REFERENCES

Agar, J.W. (2012). Personal viewpoint: hemodialysis - water, power, and waste disposal: rethinking our environmental responsibilities. *Hemodialysis International,* 16(1), 6-10.

Barbero, S. (2012). *Systemic Energy Networks: the theory of Systemic Design applied to energy sector (Vol. 1)*. Raleigh, NC: Lulu Enterprises, Inc.

Barbero, S. (2016). Opportunities and challenges in teaching Systemic Design. Paper presented at *6th International Forum of Design as a Process Systems & Design: Beyond Processes and Thinking*, Valencia, Spain.

Barbero, S., Pereno, A., & Tamborrini, P. (2011). Qualitative/quantitative cross analysis to design eco-pack. Paper presented at *3rd International Symposium on Sustainable Design* (pp. 105-115). Recife: UFPE.

Bistagnino, L., Marino, G.P., & Virano, A. (2008). *The outside shell seen from the inside*. Milan, Italy: CEA.

Bogue, R. (2007). Design for disassembly: A critical twenty-first century discipline. *Assembly Automation*, 27(4), 285-289.

Braungart, M., McDonough, W., & Bollinger, A. (2008). Cradle-to-cradle design: creating healthy emissions – a strategy for eco-effective product and system design, *Journal of Cleaner Production*, 15(13), 1337-1348.

Burnier, M., & Martin P.Y. (2013). Nephrology between economy and ecology. *Revue Medicale Suisse*, 9(375), 443-444.

DELOITTE (2016). *Global health care outlook. Battling costs while improving care.* Retrieved from https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Life-Sciences-Health-Care/gx-lshc-2016-health-care-outlook.pdf

Garrick, R., Kliger, A., & Stefanchik, B. (2012). Patient and Facility Safety in Hemodialysis: Opportunities and Strategies to Develop a Culture of Safety. Clinical Journal of the American Society of Nephrology, 7(4), 680–688.

Germak, C. (Ed.) (2008). *Man at the Centre of the Project: Design for a New Humanism.* Torino, Italy: Allemandi.

Jamieson, M. et al (2015). Becoming environmentally sustainable in healthcare: An overview. *Australian Health Review*, 39(4), 417-424.

Jones, P.H. (2014). Systemic Design Principles for Complex Social Systems. In G. Metcalf (Ed.), *Social Systems and Design* (pp. 91-128). New York, NY: Springer.

Maeda, J. (2006). *The Laws of Simplicity.* Cambridge, USA: The MIT Press

Muenchinger, K. (2011). The green product design network: Focusing on the role of materials in product design. *Design Principles and Practices*, 5 (5), 215-221.

Scudieri, P., & Gill, C. (2008). Giving the product a voice: Users and information in sustainable systems. Paper presented at DS 46: Proceedings of E and PDE 2008, the *10th International Conference on Engineering and Product Design Education* (pp. 6P).

Shedroff, N. (2009). *Design Is the Problem: The Future of Design Must be Sustainable*. Brooklyn, USA: Rosenfeld Media.

Thackara, J. (2005). *In the Bubble: Designing in a Complex World.* Cambridge, USA: MIT Press.

Ticehurst, A., Ward, J., & Clarkson, J. (2010). Barriers to Design in Healthcare, *AMJ*, 3(9), 570-579.

Van Nes, N., Cramer, J. (2005). Influencing product lifetime through product design. B*usiness Strategy and the Environment*, 14(5), 286-299

Vezzoli, C., & Manzini, E. (2007). *Design per la sostenibilità ambientale*. Bologna, Italy: Zanichelli.

Chapter 1

State of the Art

"The overall system of healthcare — from services to payment to policy — has grown so complicated that a redesign of its components would not change the system substantially. New design thinking is called for, yet where do we start? Designers have no access to the system levers, and most of our work today is aimed at making the components run better and safer."

(Jones, 2013)

1.1 Design and Healthcare

Healthcare systems aim at meeting the health needs of populations by providing services to satisfy the people's right to health. They help to preserve and restore good health, and enable people to live independently by providing social care services. There are several types of **healthcare systems** worldwide, but they **are all facing radical changes and common challenges**.

Firstly, the health care sector is moving toward **defragmentation**, pushed by increasing and emerging financial cuts to cope with massive budget deficits in public spending. This is leading to merging individual hospitals with each other to increase cost-efficiency and exploit economies of scale while offering broader service. New technologies play a key role in this new trend, by optimizing treatments procedures and enhancing the digital connection between hospitals and physicians. The need of keeping health costs down is also leading to an increased transparency into care quality, results, and expenditure, due to mandatory or voluntary monitoring. Secondly, healthcare has to face **new health needs** and find new and efficient ways to meet them. The population is ageing quickly and by 2030 the number of persons over 60 years is expected to grow by 56%, from 901 million to more than 1.4 billion (United Nations, 2015). Population ageing puts pressure on health systems, increasing the demand for care, services, and technologies to prevent and treat noncommunicable diseases and chronic conditions associated with old age. Overall, there is a **shift toward chronic care**: chronic noncommunicable diseases are responsible for 68% of world's deaths, more than 40% of cases are premature deaths under age 70 years (WHO, 2012). Chronic diseases also represent a huge economic burden: they account for around 71% of healthcare spending in USA (Gerteis et al., 2014), and between 70 to 80% across the EU (Busse et al, 2010). Overall, the healthcare sector plays a very important economic role: in the European Union, it accounts for 10% of GDP and 8% of the total workforce. **Public expenditure on healthcare** and long-term care is expected to increase, so policy makers will focus on this key sector in the near future, as highlighted in the Joint Report on Health Care and Long-Term Care Systems & Fiscal Sustainability by the European Commission (2016):

"The sector contributes to economic prosperity through improving labour market participation and productivity and will be crucial to ensure longer working lives in the context of an ageing society. All EU Member States face strong and growing fiscal pressures on their health and long-term care systems, driven by already high levels of public expenditure and debt in most countries, demographic pressures and technological advances. Further policy action will therefore be needed to safeguard and sustain the contribution of health care and long-term care systems to improve population health. The need to make health systems sustainable by making them more effective, accessible and resilient has been duly recognised by policy makers at the EU and national level. " (p. 1).

This attention to regulations, policies and management practices of healthcare does not concern only Europe. Healthcare systems worldwide need to respond to these challenges, and healthcare stakeholders (health professionals, companies, policymakers, and patients) need to cooperate to face these new societal needs and move towards more sustainable systems. Expenses and patient numbers will inevitably increase, and healthcare must pursue the goal of an *"effective, efficient, and equitable health care for all"* (DELOITTE, 2016), controlling spending, improving and implementing the use of available technology and engaging patients in prevention and self-care.

The **transition toward more sustainable and resilient health systems** is both delicate and complex, and it needs radical changes of perspective as regards the patients' role and the holistic and multi-disciplinary approach to healthcare. The increasing of chronic disease and long-term care requires people to play an active role in their own care, changing their behaviours for preventing the disease or its effects, and becoming active caregivers from a self-care perspective. This trend is reinforced by the widespread use of Internet to search for information on health and health services. The impact of web deeply affects health decision-making and, leaving aside the information issues, it is contributing to motivate patients toward being involved in their health

(Powell, Darvell, & Gray, 2003 ; Oh & Lee, 2012; Tan & Goonawardene, 2017), also creating new ways of communication with physicians (Van der Eijk et al., 2013). This change towards patient-centred care demands a holistic approach to designing **new healthcare products and services**. Different disciplines must cooperate to address innovation in healthcare, managing the complexity of this sector, and focusing on people without losing sight of the system perspective. Technical and medical innovation is certainly crucial, but innovative healthcare solutions must meet the criteria of usability, utility, and acceptability to enhance self-management and improve care experience. If we want to make the current system into a new patient-centred system, healthcare stakeholders must empower patients, creating services and products that actually start from people's needs to make them able to desire, understand and use these innovations.

The creative and, at the same time, methodological approach of design to manage user-focused problems is attracting interest in healthcare stakeholders (Ticehurst, Ward, & Clarkson, J, 2010). **Design tools and methods are perceived as useful and effective to bring innovation in the healthcare sector.** All design disciplines, despite any differences in the topics addressed and the tools used, aim at understanding people's problems and creating solutions that fit the users' needs according to their social and cultural background. Furthermore, the knowledge of design for managing complexity is an attracting skill for complex sectors such as healthcare:

"Studying the way designers work and adopting some designerly practices could be interesting to these organisations because designers have been dealing with open, complex problems for many years, and the designing disciplines have developed elaborate professional practices to do this. The challenge of dealing with these open, complex problems leads to a particular interest in the ways designers create 'frames', and the way design organisations deal with frames in their field of practice." (Dorst, 2011, p. 522).

Design has often been involved in the creation of biomedical products and services for the healthcare sector, focusing on specific care issues (products for the disabled, surgical instruments, biomedical tools, stretchers and other patient handling equipment, computer interfaces, etc.). However, the current interest in design disciplines is specifically directed towards what is commonly known as 'design thinking': *"a method of meeting people's needs and desires in a technologically feasible and strategically viable way"* (Brown, 2008). It is a systematic innovation process that aims at deeply understand user's desires and needs to design inclusive and effective solutions that answer the real problems of the user (Roberts, Fisher, Trowbridge, & Bent, 2016).
The role of design includes the creation of artefacts, which remains the crucial part of designers' tasks, but design thinking allows to address the design activities from a systemic point of view. Designers are called upon to bring order to the system, sharpening their focus not only on the artefact they are designing, but on the system in which the artefact and its user are included. As Jones (2013) states:

"Designing for care brings a holistic and systemic design perspective to the complex problems of healthcare. We are already improving services by designing better artifacts, communications, and environments. What remains missing is the mindset of professional care in designing for people, practitioners, and societies. Like clinicians, designers in the health field can take responsibility for helping people and societies become healthier in all aspects of living." (p. 8).

1.2 A review on design for healthcare

Design thinking is a common approach among all design disciplines. In all healthcare domains, issues have to be faced from a broad perspective to achieve breakthrough innovations which focus on people's rights, needs, and well-being. However, in most cases, the design team is composed of experts coming from different disciplines (medicine and health-related professions, design, engineering, management, computer sciences), where each has his/her own methodological approach. Moreover,

the health topics addressed, because of their peculiarity and different level of complexity, may profoundly affect the design tools and methods to be used. Given the multi-disciplinarity and the segmentation of health care, it is important to establish how and in which areas design research is contributing to face healthcare challenges. Although healthcare stakeholders are increasingly acknowledging the role of design thinking, designers have various backgrounds and are often coming from engineering sciences. If we consider design research as *"the study of and research into the process of designing in all its many fields"* (Design Research Society), a literature review on design for healthcare should focus on the design process, despite the professions involved.
Consequently, the literature review has focused on **how design thinking and design methods are applied to healthcare research**, aiming at understanding how, when and with what results design is bringing innovation to this sector. So the review has first taken into account relevant scientific publications concerning the design process in all the health domains. Then, special attention has been paid to the works made by researchers with an industrial design background, to understand how design research is contributing to this sector.
In particular, the literature review aimed at answering two main questions:

- **In which domains of healthcare does design research currently focus?** This is crucial to understand in which areas design is playing an important role and in which ones it makes only a marginal contribution.
- **What contribution does design give to health care?** The aim is to identify the primary outcomes of design research in the health sector, by assessing results design researchers have obtained.

In the following paragraphs, these questions are examined to create a detailed overview of this binomial research field.

1.3 A map of Design Research in health-related areas

Currently, the literature shows four main areas in which design research is facing different types of healthcare issues (Figure 1): design for healthcare architecture, design for medical technologies and devices, design for e-Health and design for Sustainable Healthcare. Peculiar scientific fields distinguish each area; they can be strongly connected or relatively independent.
The relative weighting of the research areas is considerably different. The contribution of design research to medical devices and e-Health applications is significant, and it is bringing innovative results concerning health management, usability, user's safety, and patient's empowerment. Healthcare architecture is a significant domain, but the contribution of design research is limited to interior design and user experience. All these three domains show interconnected projects, in particular, e-health application for devices and environments are widely addressed. Design for Sustainable Healthcare is a minor emerging field: the contribution of design research is still limited, but the potential of design for sustainability in health care is enormous.
In the following sections, the contribution of design to the four domains is detailed, so as to provide a comprehensive overview of the State of the Art of Design research for Health care.

1.3.1 Design for Healthcare Architecture

Healthcare architecture is an established and growing sector of research and practice. It concerns build environments and how they can improve patient healing and well-being, and support clinician workflows while meeting higher standards of safety, energy efficiency, and environmental sustainability. We can highlight two main fields of research, deeply interconnected: Evidence-Based Design and Sustainable Healthcare Architecture.

EVIDENCE-BASED DESIGN

Evidence-Based Design (EBD) is one of the main fields of research in architecture for healthcare. The EBD approach starts from the in-depth investigation of state of the art to hypothesize innovative outcomes that, at the end of the process, have to be measured (through a post-occupancy evaluation) and shared. According to Cama (2009), Evidence-Based Design can be defined as:

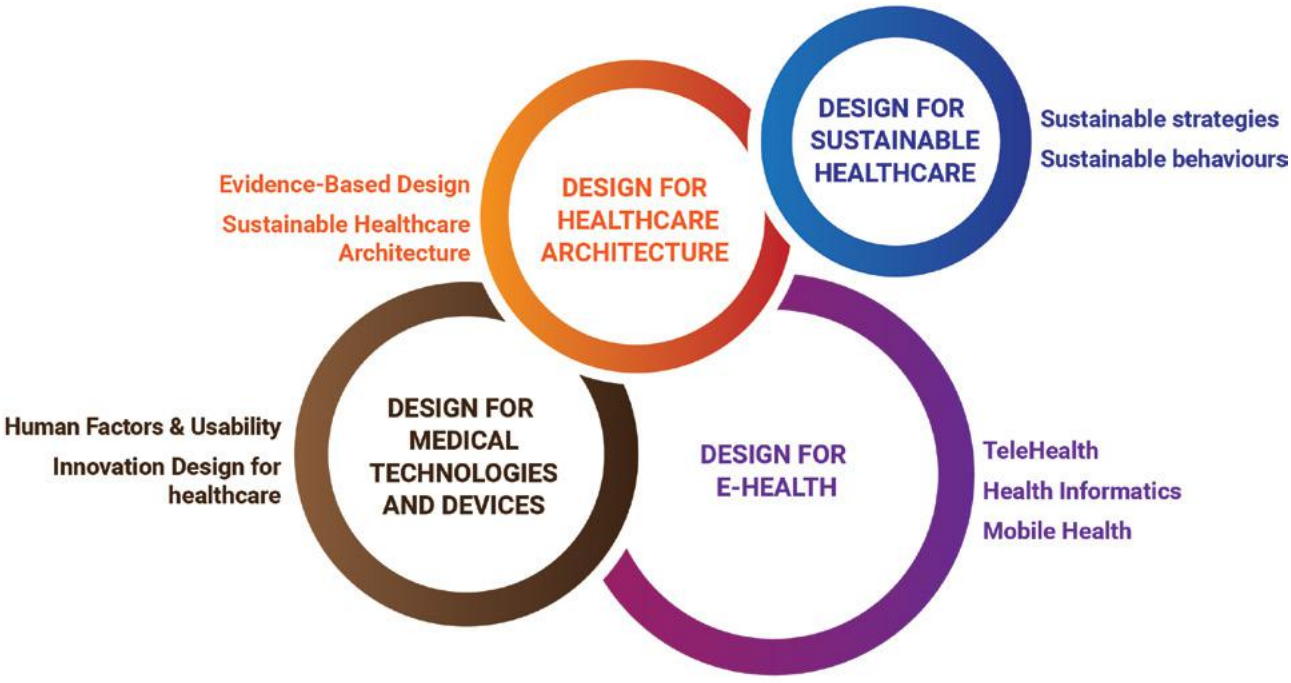
"an iterative decision-making process that begins with the analysis of current best evidence from an organisation as well as from the field. It finds, at the intersection of this knowledge, behavioral, organizational, or economic clues that when aligned with a stated design objective can be hypothesized as a beneficial outcome. It does not provide prescriptive solutions, but rather a platform from which to add to an existing base of knowledge or to launch innovation. It espouses an ethical obligation to measure outcomes and share knowledge gained for particular design successes and failures, ideally in a peer-reviewed fashion, as is common in academia." (p.7)

EBD differs from Healthcare Design Research which, instead, concerns the theories and methodologies of healthcare design and the evaluation of their effects on patients or staff outcomes (Stichler, 2017).

EBD aims at being a practice methodology, that focus on how the spatial layout and the environmental design can affect health and behaviour outcomes (MacAllister, Zimring, & Ryherd, 2017 ; Alvaro et al., 2016).

Multi-disciplinarity is a key-feature: EBD foresees the cooperation of different disciplines (architecture, interior design, construction engineering, and others) and people with different roles and responsibilities (designers, hospital administrators, facility managers, clinicians, and patients). These stakeholders are involved in processes of co-design and other participation tools (Braun & Barnhardt, 2014 ; Payne et al., 2015).

In EBD research, the role of design mainly deals with designing the inner spaces. Over the last decades, interior design has addressed the effects of healthcare environments on healing (Ulrich, 1991) and how to start from the needs of final users (patients, families, and health staff) to design the interiors of healthcare facilities. The literature shows two primary lines of research in interior design for healthcare: first, many authors have focused on how interiors can improve staff performance and, consequently, patient safety. On the other hand, design researchers have put into practice the theories about the effects of physical environmental stimuli on patients' health to interior design.



Patient safety
The first strand of research has explored the role of interior design to influence users' behaviours. Interior environments can reduce staff stress and support clinicians' work thus increasing operational efficiency and reducing error risks (Reiling, 2006 ; Pati, Harvey & Pati, 2014). This allows designing interior environments that are supportive both of the health staff and the patient, improving safety and outcomes (Stroupe, 2014).

Biophilia
Another field of research starts from the concept of biophilia, the innate tendency to focus on life and life-like processes (Wilson, 1984). The presence of natural stimuli in hospital interiors has been shown to reduce physiological and psychological stress-related health measures, positively influencing patient outcomes (Beil & Hanes, 2013; Pati et al., 2016). This significant link between nature and wellness has influenced the interior design, which has worked to include and emphasize biophilic features (Kellert, 2008; McGee & Marshall-Baker, 2015).

Salutogenesis
Salutogenic Architecture is based on the concept of salutogenesis that has been coined by Antonovsky (1979) to describe a model for socioenvironmental influences on health. It implies a change of paradigm in designing for health: the attention moves on those factors that affect and improve health and well-being. The application of salutogenesis principles to healthcare architecture led to a new architectural discipline, the Salutogenic Architecture (Golembiewski, 2016). This design approach aims at *"promoting health and well-being by creating build environments that focus on health promotion,"* (Dilani & Armstong, 2008) focusing on stimulating patient healing rather than designing around the treatment of disease.

SUSTAINABLE HEALTHCARE ARCHITECTURE

The attention to environmental sustainability in Healthcare Architecture results in three main research fields, that apply sustainable design methods to healthcare facilities. As EBD, Sustainable Healthcare Architecture (SHA) promotes a human-centred approach to building design, combining people's needs and the requirements of the environment.

Life cycle thinking
The first research approach to SHA focuses on life cycle thinking, that is usually applied to new buildings or major renovations of existing buildings. The building is considered as *"a system unto itself, a part of other nested systems at multiple scales. In a sense, sustainable buildings affirm their intrinsic interconnectedness."* (Guenther & Vittori, 2015, p. XVII). Life cycle thinking starts from a "cradle-to-cradle" approach (McDonough & Braungart, 2002), going beyond the three R's – reduce, reuse and recycle –, to design buildings that are fully interconnected to the territory and considers all the processes that take place inside them. Special tools are used to assess and certificate the building life-cycle impacts (Asdrubali et al., 2015) and its indoor environmental quality (such as thermal and acoustic comfort, air quality). This approach is taken up by research projects about 'Zero Carbon' buildings (Ng et al., 2016) and the major strand of green building. Both aim at minimizing the impacts on the environment, enhancing the health conditions of people, returning on investment to developers and local community, and considering the life cycle during all the process (Robichaud & Anantatmula, 2010; Zuo & Zao, 2014).

The role of natural spaces
Finally, as in EBD, the natural spaces in healthcare facilities are taken into account, as well as their role in improving patient outcomes and well-being. This approach includes studies about the design of internal and external green areas (Cui & Miao, 2012), and the usage of natural materials in healthcare buildings.

Although SHA is the object of keen interest and study, designers and design researchers play a little role in this sector. While in EBD the interior design has a significant weight, in SHA life cycle design, as well as resource consumption and natural space design, are exclusively addressed by architectural research.

Fig. 1 - Visualization of research areas supporting design for health care

1.3.2 Design for Medical Technologies and devices

The design of medical devices starts with the description of a precise user-based problem. Then, designers must identify who will use the device and how to meet his/her needs. This is the starting point of a complex process dealing with strict regulations and management standards since the early phase (Fearis & Petrie, 2017), as well as with different stakeholders and users. Privitera, Evans, & Southee (2017) effectively summarizes the different stages of the design of a medical device:
"In order for a new device to be used within the clinical environment, certain development procedures must be undertaken, such as a regulatory plan and design optimization through verification/validation. Furthermore, the integration of human factors in the medical device design process is required to reduce risk and improve patient safety. Additionally, Design Control is a fundamental requirement to meet regulatory approval for international standards" (p. 251)

The design process is always deeply affected by restrictive regulations and by the attention to users' needs. However, the literature shows that researchers have focused their attention on different aspects of medical device design.
A first research sector is dealing with human factors and human factors design methods to incorporate them into the medical device design and development process. A key topic is the identification of users, their actual needs, and their role and value in the design process (Money et al., 2011). This point is essential to define new methods to integrate human factors into an interdisciplinary design process.
The second sector is focusing on innovation design and how to identify and assess new scenarios which would profoundly improve users' life, affecting their approach to health. This includes radically innovative medical devices but especially the design of new medical technologies which can change the way people make or receive treatments. From this perspective, design moves from the product to the system, integrating devices within more complex systems.

HUMAN FACTORS AND USABILITY

Human Factors (HF) represent an interdisciplinary field that can be applied to different disciplines, ranging from engineering to psychology, architecture, and design. One of the best-known definitions of HF is given by Stramler (1993):

"Human Factors is that field which is involved in conducting research regarding human psychological, social, physical, and biological characteristics, maintaining the information obtained from that research, and working to apply that information with respect to the design, operation, or use of products or systems for optimizing human performance, health, safety, and/or habitability. "
Design well fits this definition, which meets the interest of designers in users' behaviours and needs, and their holistic approach towards products and systems. Design has provided its contribution to HF in different sectors, but health care is a prominent field in which designers can help to improve usability and safety. However, the studies by Vincent, Li, and Blandford (2014 ; 2017) show how there are still several challenges that designers must face regarding the communication between different teams, and the value given by health professionals to usability. Despite the legal recognition of the importance of HF in medical device design, recent research highlights how *"purchasing is driven by engineering standards, and [...] the emphasis is on functional requirements rather than those relating to social or organisational needs."* (Vincent & Blandford, 2017, p.120). Nonetheless, the design research is rapidly advancing in this field and is mostly focusing on three most important aspects. First, how design can reduce, through HF, human errors and facilitate clinical processes, thus increasing patient safety. Secondly, which methods designers can use to define the actual needs of users, understanding the psychosocial aspects of medical devices. Thirdly, how to help patients to cope with complexity, supporting them towards their self-empowerment.

Patient and staff safety
Medical errors are considered a significant problem by 78% of EU citizens, and research suggests that errors in health care happen in 10% of cases (Commission of the European Communities, 2008), causing major financial and human costs. The

design of equipment and devices can contribute to solving the problem: health staff often have to deal with confusing interfaces and equipment that make their tasks more difficult, increasing the risk of errors (Fairbanks & Caplan, 2004; West et al. 2014).
It is commonly agreed that the first step in the medical device development process is to identify the problem to address. This means to understand the needs of the users that will manage the device but also to investigate use-related problems that have occurred with similar devices. Much research has focused on how to define, measure, and integrate the requirements of clinicians and health staff during medical device development, to improve both device effectiveness and patient safety (Lin, Vicente & Doyle, 2001; Martin et al., 2006). Other researchers have considered how to identify the potential used-related problems of devices. This concerns both the use of publically available device incident databases (Gupta & Pidgeon, 2016) and the development of methodologies for the ergonomic assessment of medical devices (Furniss et al., 2014). A branch of HF research is also dealing with self-care devices and inclusive design. People with lower levels of ability that have to handle and use medical devices may be exposed to higher risk than clinicians and mainstream users. Thus design has to consider their specific issues to improve usability and avoid frustration (Santos, Olumese, & Vaughn-Cooke, 2014 , Goodman-Dean et al., 2014 ; Fung et al., 2015).
Finally, other researchers have focused on staff safety, aiming at improving the ergonomics of devices and equipment to reduce physical efforts in daily routines, contributing to prevent work-related illnesses (Cai et al., 2015; Zhou and Wiggermann, 2017).

Psychosocial aspects of using medical devices
HF research on medical devices is investigating how designers can identify the psychosocial needs of users. The focus is on the tools and aspects to consider to define who are the final users and which are their actual requirements, assessing those subjective and psychological factors that come into play within the use of medical devices.
The first branch of research has evaluated design tools and methods to define final users' needs. In particular, qualitative tools are the subject of many studies that assess their effectiveness for the healthcare sectors. Among them, the use of *personas* has been commonly identified as a significant tool to design patient-centred medical equipment and services (Wärnestal, Svedberg & Nygren, 2014 ; Vincent & Blandford, 2014).
In other cases, the research goal was the category of users, understanding the main psychosocial issues to address when designing for a specific user group. The work of Lang et al. (2014 , 2014), for example, focuses on how to involve adolescents in the medical device design, so as to create devices that can be appropriate, efficient and pleasant to use. Many studies have been carried out on devices for elderly people (Liang et al., 2013), but most of them apply HF to eHealth, focusing on web-based solutions for monitoring and supporting seniors in home care or residential care.
Finally, a minor strand of HF research is dealing with medical design for low- and middle-income countries. The medical devices to be used in low-resource settings have to fulfil environmental and economic requirements that are highly challenging (McGuire & Weigl, 2014), at the same time they have to be culturally and contextually appropriate (Watkins et al., 2017).

Device usability in a home environment
The increasing diffusion of self- and home care is making the role of design more challenging: designers are asked to support patients by providing them tools and devices easy and safe to use, even at home. HF studies investigate how design techniques can improve the understanding of the interactions between different users (patients, families, caregivers, nurses, and physicians) in a home environment (Kaufman-Rivi, Collins-Mitchell, & Jetley, 2010; Rajkomar, Mayer & Blandford, 2015). Other studies concern how HF can help patients to cope with the complexity of medical treatments, by creating patient-friendly medical devices that improve the accessibility to safe and effective home care (Lemke & Mendonca, 2013; Rajkomar et al., 2014).

INNOVATION DESIGN FOR HEALTHCARE

Medical devices are part of a complex system of activities, information, social structures, and

physical layouts, in which is difficult to overview problems and provide comprehensive solutions.
Many studies highlight the connection between design and system thinking (Pourdehnad, Wexler, & Wilson, 2011; Jones, 2014). Indeed, the holistic approach of design is particularly suitable to generate a better understanding of issues and interactions within highly complex contexts, such as healthcare, and to provide innovative and effective solutions (Thies, 2015). Research in this field is focusing on two different kinds of users and their relative environments: on the one hand, design can facilitate the work of clinicians by creating new devices able to supplement or replace the existing treatments. On the other hand, Innovation Design (ID) aims at creating radically new solutions for healthcare provision: this is mainly affecting the growing sector of home and self-care.

Innovation in medical devices

Medical device innovation is usually considered an area of expertise of biomedical engineering. In recent years, industrial designers and design researchers have been attracting interest from health innovators and biomedical companies: design "offers a critical bridge amongst and between diverse disciplines in the problem finding and problem solving processes, and then helping to transform emerging technologies from the laboratory into real products that benefit users, and decreasing time from concept development to market introduction."(McDonagh & Thomas, 2013, p.29).
Although still limited, design research in medical device innovation proposes an approach of need-based innovation, in which the design process focuses on need finding and characterization (Schwartz et al., 2016). When dealing with innovation design in medical devices, there is a large number of stakeholders to consider. Patients, physicians, insurance companies, public administration, and companies: "each stakeholder has diverse and unique needs relating to the medical device, the needs of one may highly affect the needs of another, and the relationships between stakeholders may be tenuous." (De Ana et al., 2013, p.1811). In addition to the technical, economic and operational requirements, the cultural influences and unexpressed needs of all stakeholders have to be assessed. Although an innovation may offer substantial improvement over conventional treatment, it may be perceived as involving significant risks; at the same time, the rigid adherence to established practices (especially by physicians) may represent an additional obstacle to device innovation (Cheung, 2012). Design research is dealing with all these issues, to enhance needs identification and improve collaboration between different disciplines and stakeholders.

Design for innovative technologies

New technologies are introducing radical innovation in the healthcare sector, bringing new possibilities to individualized care. Among them, 3D printing is a promising technology for designing artificial organs and prostheses that will be fully customizable and compatible with the human body. Besides the medical and bioengineering issues to face, there is often a problem of personal and cultural acceptability to deal with. Design focuses on visual culture and personal acceptance of prostheses and other medical devices (Hoyos & Scharoun, 2013). Research is finding new ways to exploit the potential of new technologies to customize the aesthetics and the use of devices to improve users' well-being (Dombrowski, Smith, & Buyssens, 2017).

Innovation in home care

Home care is a growing sector, because of global demographic changes and progresses in the health system. It combines economic and social sustainability, representing an effective cost-management strategy that brings social benefits by providing care in a positive family environment. Patients are enabled to monitor, prevent and treat their disease without needing to physically go to clinics and hospitals.
If HF research helps them to cope with the complexity of traditional medical devices, ID finds new self-care solutions by creating new domestic scenarios.
Bitterman (2011) notes that design for home medical devices have to deal with several challenges: the heterogeneity of users (people with different ages, knowledge, and background), the environmental variables (sterility, illumination, electromagnetic disturbances, thermal variables),

and the features of a home environment (spaces, interior layout, aesthetics). Design does not simply create the medical item but it plans for the whole home setting, promoting a human-centred approach to social innovation in home care (Tosi, Rinaldi, & Ricci, 2015).
Recent studies have assessed the potential of smart home technology to integrate healthcare devices and services through a combination of networked physical and digital artefacts (Ing & Summers, 2015 ; Pang et al., 2015). Other studies start from the assumption that "it is important to look beyond purely technology-driven solutions and to develop technologies and services that are flexible and reflect a sensitive understanding of the diverse users of such systems." (Burrows, Gooberman-Hill, & Coyle, 2015, p. 1233). Therefore, design research investigates the home healthcare systems, understanding the user abilities and task demands and how they interact with the home environment (Fausset & Harley, 2014).

1.3.3 Design for eHealth

WHO (2005) defines eHealth as *"the cost-effective and secure use of information communication technologies (ICT) in support of health and health-related fields, including health-care services, health surveillance, health literature, and health education, knowledge and research."* In this domain, Design research provides a contribution to three main areas: Telehealth concerns remote care services, such as behavioural therapies, remote monitoring of patients, remote consultation of physicians, and chronic disease management.
Interaction design is the main discipline which contributes to developing user-centred services to enhance health staff works and patient empowerment. Health Informatics mainly deals with Electronic Medical Records (storage and tracking of patient health information) and Clinical Decision Support (digital tools to improve routine care and reduce human errors). Interaction Design and Information Design has provided their contribution to software usability and data management. Finally, mHealth is aimed at different goals: on the one hand, mobile health can improve users' awareness and knowledge to enhance their control over health experience; on the other hand, it promotes care-seeking behaviours and provides training for healthcare workers. Even in this case, interaction and information designers are dealing with usability and acceptability of mHealth applications.

TELEHEALTH

Telehealth is using digital information and communication technologies to allow people to manage their health without visiting hospitals or other health facilities. ICTs can remotely connect clinicians and patients, providing innovative tools to support their daily tasks.

Emergency Medical Services

One of the first branches in which telehealth has been applied concerns Emergency Medical Services. ICTs enable to supervise paramedics and nurses and coordinate urgent patient transfers or other emergency actions (Amadi-Obi et al., 2014). Technologies support the flow of information between teams to improve medical diagnosis in prehospital settings and to ensure continuity in the workflow (Madhu et al., 2009). This allows to increase the efficiency of Emergency Medical Services and to better evaluate and manage emergencies according to the actual needs of patients (Langabeer et al., 2016).

Remote care for chronic patients

Remote care services for chronic patients are the main focus of current research in telehealth (Wherton et al, 2015). ICTs monitor and help patients to managing their diseases in a home environment (Ekelanda, Bowes, & Flottorp, 2010). In many cases, telehealth provides continuative support to patients affected by chronic diseases (such as chronic heart failure or psychiatric diseases), allowing to provide immediate intervention in the event of urgent needs (Dellifraine & Dansky, 2008). Innovative smart home technologies (cf. par. 1.1.2) can be integrated with telehealth services to monitor patients in assisted living facilities (Gale & Sultan, 2013). Web-based programmes provide remote training to patients, helping them to carry out self-care therapies or follow a behavioural therapy (such as special diets or physiotherapy exercises),

according to their health conditions (Van Den Berg, Schoones, & Vlieland, 2007).

HEALTH INFORMATICS

Health Informatics (HI) investigate the methods and resources for managing health information, aiming at reducing the costs and improving the quality of medical care (Agha, 2014). Different research domains of Health Informatics consider distinctive types of information to achieve specific health goals. The sub-disciplines range from supporting clinical research and clinical trials through informatics methods (Clinical research informatics), to managing prescribing and medication (Computerized Physician Order Entry). However, design research has mainly provided its contribution to two huge field of HI: Electronic Health Records (EHR) and Clinical Decision Support Systems (CDSS).

Electronic Health Records

Electronic Health Records (EHR) focus on the storage of patient information, ranging from test results and medications to the patient's appointment history, to the physicians' notes. A personal EHR is an official health record that tracks the patient's health over time, and it is shared among different facilities and agencies. Research in this sector is still facing some issues especially concerning the quality of data and the standardisation of EHR to improve the global access to patient's records (Weiskopf & Weng, 2013). Designers can play a key role in implementing EHR. As Bresò et al. (2016) argues, "in the eHealth domain, user rejection of computer-based systems is a major barrier to exploiting the maximum benefit from those applications developed to support the treatment of diseases, and in the worst cases a poor design in these systems may cause deterioration in the clinical condition of the patient." Human factors and interaction design should improve EHR usability to ensure the efficient use of EHR, reduce medical errors, and guarantee patient privacy (Middleton et al., 2012).

Clinical Decision Support Systems

Research on CDSS focuses on the analysis of data to support physicians in making clinical decisions (Islam et al., 2015; Yang, Kang, & Lee, 2016). CDSS can examine the medical history of patients and compare it with relevant clinical research: the provided information can thus help physicians to prepare or review a diagnosis, helping them to avoid possible adverse effects. CDSS also improves daily care by providing timely reminders to nurses and health staff (Green, Nease, & Klinkman, 2015), so as to reduce human error risks (Garg et al., 2005). Even in this case, Interaction Design is crucial to define which information the users would find useful to making correct diagnoses and how to visualize and interact with the CDSS (Bussone, Stumpf, & O'Sullivan, 2015). The complexity of the information to manage and the heterogeneous contexts of use makes the creation of a usable CDSS a challenging task (Kashfi, 2010): design should take into account both the information perception and the organisational process to minimise medical errors (Kanstrup, Christiansen, & Nøhr, 2010).

MOBILE HEALTH

Mobile Health (mHealth) can be broadly defined as a medical and public health practice supported by mobile phones and wireless communication devices (van Heerden, Tomlinson, & Swartz, 2012).

Chronic disease management

The main research area in the mHealth field is the use of mobile technologies to support chronic disease management and disease monitoring (Fiordelli, Diviani, & Schulz 2013 ; Li et al., 2013). The presence of mobile devices in our daily life is pervasive but, at the same time, users perceived it as non-invasive: the use of mHealth applications can enable care and enhance user's control over health experience. At the same time, apps can gather real-world information to increase clinicians' understanding of actual patients' exercises/treatment and to monitor their health parameters, before re-hospitalization becomes necessary (Dobkin & Dorsch, 2011 ; Steinhubl, Muse, & Topol, 2015).

Preventive health care

The second area of research is the use of mobile applications to promote public health, by encouraging care-seeking behaviours and educating people about preventive health care. Hundreds of mobile applications are available

to provide personalized health information (suggestions, challenges, reminders), aiming at improving people's psycho-physical well-being, from fitness to weight loss. Many studies have investigated the effectiveness of these mobile tools, highlighting how mHealth can improve healthy behaviours, but in many cases, apps are not based on evidence-informed content, and much research is needed to promote an informed use of mHealth (Breton, Fuemmeler, & Abroms, 2011). The use of wearable devices is a further tool for mHealth, which allows people to self-track their biometric data and to monitor and check them through mobile applications, aiming at increasing their well-being (Kumar et al., 2013).

Access to health care

mHealth is considered to have high potential to improve access to health care and health outcomes in low- and middle-income countries. Many researchers are addressing mHealth application in this areas, aiming at solving the global problem of structural barriers to access health care (Tomlinson et al., 2012). Especially in those countries, mHealth can support healthcare givers, by allowing them to access clinical updates and learning materials, and offer them online training and reminders on everyday tasks (Källander et al., 2013).

In mHealth, Design research is especially dealing with the usability and acceptability of mobile apps: it is essential to define which are the most relevant data to visualize and how to let people manage them. Interaction designers and Information and Visual designers are working on making personal data easy to read and manage, in order to promote a behavioural change (McCurdie et al., 2012; Banos et al., 2015).

1.3.4 Design for Sustainable Healthcare

In a context of global economic crisis, healthcare is one of the earliest areas that meet budgetary cuts, but the need of reducing hospital expenditure carries the risk of cutting across the board in public spending. This could affect the quality of healthcare services (Clemens et al., 2014), reducing the hospital bed ratio, the pharmaceutical supplies or the number of medical treatments. Conversely, a qualitative vision of the subject is already endeavouring to approach savings from the point of view of selective reduction and optimisation of resources, processes, and supplies (Evans, Hills, & Orme, 2012). Furthermore, many healthcare stakeholders are calling into question the Hippocratic principle *"primum non nocere"* (first do no harm), that leads to searching for new ways to prevent environmental diseases (HCWH, n.d.). Therefore, *"increasing numbers of hospitals have committed to minimizing the adverse environmental effects of their operations on patients, staff, and the community, serving as role models for the health sector and society at large."* (Kaplan et al., 2012, p.1).

Sustainable healthcare is taking concrete form in the local and international policies that wish to foster a greater sustainability of the medical treatments (Walker & Brammer, 2009 ; Richardson et al., 2014), as well as in the several organizations that are promoting a sustainable approach to the sector.

Even if healthcare organizations are asking for more sustainable products, services, and systems, the literature showed that the contribution of design research is still limited. Management and education are primarily pursuing Sustainable Healthcare, addressing policies and education programmes for nurses, caregivers, and patients. Although the proposed strategies could positively affect the long-term sustainability of healthcare facilities, both research fields mainly focus on the downstream end of the process. Conversely, design research could act upstream to improve the environmental sustainability of products and systems to reduce impacts during their entire life cycle.

SUSTAINABLE STRATEGIES

Research on Sustainable Healthcare is concentrating on formulating appropriate strategies, policies, and actions to tackle the main economic, social and environmental issues of the healthcare sector. These preventative strategies aim at improving sustainable management practices, addressing three main topics: carbon emission reduction and climate change commitments (Evans, Hills, & Grimshaw, 2010 ; Connor, Lillywhite, &

Cooke, 2011), waste management (Grose et al., 2012 , Nichols & Mukonoweshuro, 2016), and resource optimization (Agar, 2012 ; Balbus et al.,2016). Furthermore, public commissioning is a powerful tool to encourage companies to improve their sustainability, which has already been used successfully in other sectors. Although its implementation at national and international levels is still limited, many studies are investigating how to encourage new approaches to Green Public Procurement (GPP) in healthcare (Wilson & Garcia, 2011 ; Chiarini & Vagnoni, 2016). The achievement of new GPP standards will open up new opportunities for companies intending to market more sustainable products and services. Design research could effectively help the industrial sector to make environmental sustainability a major driver in the improvement of their offer. However, today the contribution of design in this research field is very limited.

SUSTAINABLE BEHAVIOURS

Alongside the management issues, several studies are focusing on the development of educational initiatives to encourage staff and patients to adopt more sustainable behaviours. In some cases, research is dealing with initiatives and tools to address specific issues, such as waste sorting and recycling (Vogt & Nunes, 2014). In most cases, research investigates and proposes environmental education programmes to be implemented in academic curriculum and refresher training courses for physicians and nurses (Goodman & East, 2014; Richardson et al., 2014). A special attention is paid to nurses' education, since they daily face decisions and actions that affect environmental sustainability, from waste sorting to eco-friendly cleaning substances (Ryan-Fogarty, O'Regan, & Moles, 2016). Many studies argue that a "green healthcare team" (composed by physicians, nurses, clinical staff, and environmental specialists) would be needed to boost environmental sustainability in health care (Chenven & Copeland 2013 ; Weiss et al., 2016). No study has been made about the role of patients in sustainable healthcare: environmental sustainability is sometimes integrated into comprehensive health education programmes for specific patient/user categories, such as children (Davis, Spaniol, & Somerset, 2014) or teens (Guarneri & Andreoni, 2014). In this case, as well, Design research is almost completely absent from this field, although it has the potential to make a major contribution to the realisation of communication and training tools for environmental education.

1.3.5 A cross-boundaries approach: Systemic Design

The literature shows that design research, in all different domains of healthcare, has primarily focused on usability and need identification towards innovative scenarios of care and self-care (patient safety and healing, patient empowerment, self-awareness). Designers have been dealing with innovative devices, the redefinition of hospitals and home spaces, as well as with ICTs to connect and support people. Despite these outstanding contributions to health-related research, the literature highlights that design research has been unable to reach an all-comprehensive sustainability to date. In most studies, there is a lack of balance between economic, social and environmental sustainability, in particular concerning environment. It cannot be doubted that the complexity of health care is particularly difficult to tackle through traditional design approaches: first, because of its technical requirements (high performances, multi-faceted management, and strict regulations), secondly, because of the complexity of the healthcare systems (multi-stakeholder and multi-environment). Therefore, a holistic approach to healthcare is needed to go beyond conventional design categories.

Although its contribution to healthcare literature remains small, Systemic Design (SD) has a great potential for sustainable innovation in this sector, and the few cases present in literature are of great interest to health-related research. Rather than a design discipline, SD is a cross-boundaries approach able to harmonise different design approaches:

"Systemic design intends to develop methodologies and approaches that help to integrate systems thinking with design towards sustainability at environmental, social and economic level. It is a pluralistic initiative where many different approaches are encouraged to

thrive and where dialogue and organic development of new practices is central." ("Systemic Design", n.d.)

In health care, SD approach integrates tools and methods from information design, as well as from product design, interior design, and sustainable design. SD addresses design issues from a system thinking perspective, proposing comprehensive solutions that take into account all the elements in the system, avoiding side-effects and prompting environmental, economic and social sustainability. SD theories and its practical application will be dealt with in chapter 2.

Chapter 2

Research methodology

“We design experiments, but we also act as designers in how we act in these experiments. We design the experiences and objects we find through experiment by finding commonalities (simplification): and we design how we assemble them into patterns (explanatory principles, theories). Looking at these patterns, we make further patterns from them — the theories of our theories. Thus, in doing science, we learn.”

(Glanville, 1999)

2.1 Theoretical Framework: Systemic Design

2.1.1 From Systems and Design Thinking to Systemic Design

Systems theories mainly developed during the second half of the 20th century, within research domains such as ecology, biology, psychology, and cybernetics (Capra, 1997). In the following decades, systems thinking has been applied to numerous scientific fields, ranging from education, environmental sciences, public health, operational research, management, urban planning, and other physical sciences. Systems theories study the structure of systems and how they function and communicate with other systems or with their own components (Heylighen, 2000). Instead of reducing an entity to the properties of its parts or elements, systems thinking focuses on the relationships between the parts that connect them into a whole. Despite its acknowledged validity, there have been several claims about systems thinking because of its conflicting methodological pluralism (Cabrera, Colosi, & Lobdell, 2008) and its little effect on the global society (Ackoff, 2004). Recent studies aimed at integrating the approach of systems thinking to complex problems with the intuitive and practical attitude of design thinking. Li (2002), referring to the thought of Bela Banathy, claims that design can be considered *"as one of several disciplined inquiry domains of social systems in which systems thinking is manifested."* The work of Pourdehnad, Wexler, and Wilson (2011) points out that, from a systems thinking perspective, design *"became the preferred approach to problem solving and planning for a variety of reasons: the belief in the synthetic mode of thought; the belief that the future is subject to creation (design being the creative process); the belief that you need to dissolve problems (and not solve) through redesign of the system."*

As already observed by Horst W.J. Rittel in the 70s, this blend of system theories and design is based on the fact that *"science is concerned with factual knowledge (what-is); [while] design is concerned with instrumental knowledge (how what-is relates to what-ought-to-be), how actions can meet goals."* (Rith & Dubberly, 2007, p.2). This is an essential attitude to tackle what are called *"wicked problems"* (Rittel & Webber, 1973): open and complex problems that cannot be defined in a unique, objective, and unambiguous way. Most relevant social and environmental issues can be defined as wicked problems since they are indeterminate problems that cannot be analysed through standard methods of problem-solving. Wicked problems require an interdisciplinary and multi-stakeholders approach to solve them, even if they have neither single nor definitive solutions. According to Buchanan (1992), the nature of design as an integrative discipline, makes it able to address this kind of complex and not linear issues: *"the problem for designers is to conceive and plan what does not yet exist, and this occurs in the context of the indeterminacy of wicked problems, before the final result is known."* (p.18).
The "instrumental knowledge" and the indeterminate attitude of design has been advocated to address wicked problems in complex sociotechnical systems, giving rise to what is called **Systemic Design** (SD). Rather than a new discipline, SD is an innovative system-oriented design practice to tackle complex problems in complex systems. To quote from Jones (2014),

"Systemic design is distinguished from service or experience design in terms of scale, social complexity and integration. Systemic design is concerned with higher order systems that encompass multiple subsystems. By integrating systems thinking and its methods, systemic design brings human-centered design to complex, multi-stakeholder service systems as those found in industrial networks, transportation, medicine and healthcare. It adapts from known design competencies - form and process reasoning, social and generative research methods, and sketching and visualization practices - to describe, map, propose and reconfigure complex services and systems."

Notwithstanding the paucity of literature on SD theories, it is currently acknowledged to be a valuable approach to integrate systems thinking and design methods. SD is particularly well fitted to address the complex and multi-dimensional problem of sustainability in the healthcare sector.

2.1.2 Systemic Design and Sustainability

Although SD is a relatively recent design practice, there are currently different schools which propose distinct approaches to SD methodology, following their own *"logic for combining methods in a coherent sequence to move between deepening understanding of the challenge and generating actions to improve the situation."* (Ryan, 2013, p.1). SD commonly considers environmental sustainability as an intrinsic part of the design process: when focusing on the set of relationships within the system, the environment becomes a key item which dialogues with the other stakeholders. However, each school offers a resolutely different approach to sustainability, by approaching it more or less directly and at different levels (sustainable products, sustainable services, and sustainable local systems).

In the following paragraphs, different academic approaches are analysed in detail, with particular attention to environmental sustainability in SD. The author has taken into account the academic groups that are currently part of the **Systemic Design Research Network**, and are actively facing SD theories and applications both in their teaching and research activities.

SYSTEMS ORIENTED DESIGN AT AHO

The **Oslo School of Architecture and Design** (AHO) has developed its own approach to systems thinking in design practice, that has defined **Systems Oriented Design** (**SOD**) (Sevaldson, 2009). The AHO's design process focuses on the data analysis and the visualization of the complex set of relations between the entities, aiming at gaining and sharing the understanding of the system. The focus shifts from the hierarchy between the entities of the system to their relationships: the comprehension of this complex system of relations is the key to innovative solutions for the design issues (Sevaldson, 2010). SOD aims at introducing systems thinking as a practical design skill, providing designers new tools and techniques, such as GIGA-mapping (Sevaldson, 2011), to cope with complexity in product and service development.
AHO researchers are applying SOD to different industrial sectors, combining standard and proprietary design methods to provide practical solutions to *"wicked problems"* within complex business systems.
The approach of SOD to sustainability is mainly based on Industrial Ecology: environmental sustainability is considered as intrinsic in the design process, and it embeds economic and social aspects (Sevaldson, Hensel, & Frostell, 2011). SOD combines traditional environmental decision-making tools (such as LCA, LCC, and CBA) with systems thinking, to address sustainability at macro and micro level, assessing environmental impacts from a wider perspective (Laurenti et al., 2014). Particular attention has been paid to sustainable built environments, proposing a systemic approach to architectural design which involves local ecosystems, environment and the spatial–material organization of architecture (Hensel, 2012).

SYSTEMIC DESIGN AT OCAD UNIVERSITY

In Toronto, the Strategic Innovation Lab at **OCAD University** is leading research in the field of **Systemic Design**. SD is defined by Jones (2014a) as a research-based practice which refers directly to systems theories and pertains to sociotechnical systems in complex policy, organizational or product-service environments. Jones (2014b) summarized the methodological approach of OCAD in ten systemic design principles, that are shared between design and systems disciplines:

1. **Idealization**: idealized future scenarios should be identified to drive design actions toward an ideal outcome.
2. **Appreciating complexity**: the complexity of wicked problems is related to the human perception of it, therefore design resolutions only apparently simplify complexity.
3. **Purpose finding**: all systems have a purpose that can be determined by agreement and designed.
4. **Boundary framing**: problem framing helps to define the most suitable design solution, with regard to its target environment.
5. **Requisite variety**: in a complex system, the control system must be able to adapt to the environment according to the effects of the system in operation.

6. **Feedback coordination**: feedback management is included in the design process and addresses three orders of feedback.
7. **System ordering**: designers order all elements of the system in a useful and meaningful way, to enable the visibility and comprehension of complex situations.
8. **Generative emergence**: design must investigate the effects of perturbations of relationships on the environment to anticipate and define compositional and created emergence.
9. **Continuous adaptation**: design should incorporate cyclic feedback into the social system to enhance its resilience to unforeseeable changes.
10. **Self-organizing**: design actions must increase awareness and incentivise organizing behaviours.

SD principles and methodologies are applied to multi-stakeholders and multi-environment systems, mainly from the healthcare, policy and business sectors. OCAD researchers have focused on information and educational services to enhance social engagement and strategic innovation. Great attention is paid to the healthcare sector and the information systems related to care: SD focuses on the care experience, investigating how to move toward stakeholders' enhancement by managing complexity through new information technologies. The approach of OCAD to sustainability is implicit in the design activity: SD is thought to be a valuable design practice to address wicked problems, and most environmental issues are considered as indeterminate complex problems (see the Continuous Critical Problems by Özbekhan, 1970).

SYSTEMS THINKING IN DESIGN AT NID INDIA

The contribution of the **National Institute of Design (NID) India** to SD origins from the research of Ranjan (Lomas, 2015), which includes **Systems Thinking** into the fourth and last level of design, that he calls Strategic Design (Ranjan, 2013a). According to Ranjan (2013b), Design must look beyond the mere artefact, to investigate its effects on a complex set of user-related parameters and the environment, throughout its life cycle. Therefore, design plays an active role in shaping the future, and new design methodologies are needed to cope with complexity and improve system resilience.

NID approach to Systems Thinking in Design focuses on understanding the interrelationships that make up the system, in order to address complex issues at social, cultural, economic, and environmental levels (Nahar, 2013). Even in NID approach, the role of visualization methods is essential to the comprehension of the system and the resulting issues and potentials.

The attention of NID toward sustainability arises from a design focus on the enhancement of natural resources and local artisan skills (see the NID Centre for Bamboo Initiatives - Ranjan & Singh, 2004). Together with the use of appropriate technology, systems thinking in design aims at facing social and public design challenges to encourage inclusive innovation.

SYSTEMIC DESIGN AT POLITECNICO DI TORINO

Finally, the methodological approach to **Systemic Design** developed at **Politecnico di Torino** (PoliTo) especially focuses on the environmental sustainability of the system, addressing social and economic issues from a holistic perspective. Particular emphasis is placed on the flows analysis, assessing the inputs and outputs of the system and the complex links they generate. As Barbero (2012) has indicated, the methodology of SD *"looks at making better use of material and energy flows in order to model our production and energy systems after nature. Material and energy loops are open in order to decrease environmental impacts and resource depletion."* (p.45). This approach to SD confirms the central role of users, but it sets out the interwoven relationships within the system as the starting point of the design process, through a "holistic diagnosis" that highlights criticalities and potentialities of the system. Social, economic, and environmental impacts are assessed to guide the design process towards innovative solutions that enhance the sustainability and resilience of the system, empowering the role of people within it.

The approach of PoliTo to SD has been summarized into five key principles by Bistagnino (2011):

1. **Outputs become inputs**: just as in nature, in the sociotechnical systems, the waste (output)

of a system becomes a resource (input) for the development of another one, giving rise to a circular economy.

2. **The relationships create the system**: all the system items are deeply interrelated and the material and immaterial flows that connect them generate the system itself. The design process focuses on this relations, investigating them to define new sustainable patterns of production and consumption.
3. **Towards autopoiesis**: in nature, living systems are able to reproduce and maintain themselves, by continuously managing their own organization and the production of their own components. In sociotechnical systems, autopoiesis means the ability to efficiently and equally distribute material and immaterial flows.
4. **Act locally**: living systems are closely connected to their environments; in the same way, a sociotechnical system should be rooted in its environment, by exploiting and integrating human, environmental and cultural local resources, so as to boost local development.
5. **The man is the centre of the project**: sociotechnical systems must meet the explicit and implicit needs of the users that are part of them, by fostering their active participation toward community empowerment. The design process considers the social, cultural, ethical and biological values that all users share.

2.1.3 Systemic Design for Sustainable Healthcare

The methodology adopted for the purposes of this research directly relates to the theoretical framework of Systemic Design (SD). Indeed, SD is the only design orientation that maintains its **focus on users while addressing the indeterminate complexity in which they are immersed**. SD approach is especially suitable to face healthcare challenges, since any type of health and medical issue has a multi-stakeholder and multi-environment system behind.

As seen in the previous chapter, there is a huge lack of research in the field of design for Sustainable Healthcare: health systems are slowly but surely moving toward Sustainable Healthcare and design could actively contribute to this paradigm shift. However, traditional Sustainable Design methods cannot deal with the complexity of healthcare products and services. **The environmental sustainability of health systems is a wicked problem**: it is characterized by indeterminateness and there is no unique and objective solution to address it.

In the present research, Sustainable Healthcare has been investigated from an SD perspective. For this purpose, a specific methodology has been implemented by taking into account the common features of the analysed SD approaches. They can be summarized in six points:

1. The interrelationships between and within system items are the core of the system.
2. People empowerment is the primary goal.
3. It is necessary to visualize complexity to gain understanding.
4. Design should increase awareness toward self-organizing.
5. It is necessary to provide practical tools and methods to apply SD to real socio-technical systems.
6. Environmental sustainability always embeds economic and social aspects.

2.2 Methodological Path: From Theory To Practice

The review showed a lack of literature that addresses the role of design in the growing field of Sustainable Healthcare (cf. Chapter 1). The present research aims at providing its contribution to start bridging the gap between design and Sustainable Healthcare.

There are two main research questions this study aims at answering:

1. **How might design strategies improve the environmental sustainability of medical products, services and systems, considering its close relationship with social (people empowerment) and economic (feasibility)**

sustainability? This implies to investigate which are the problems design should address in health care and which are the system items involved in the design process.

2. **How does the system affect the products and the people (patient, clinicians, health staff, technicians, and other stakeholders involved in the system) that interact with them, considering environmental sustainability? How is the local system (ward/unit) influenced by the wider context (hospital, region, country)?** This means understanding how treatment routines are settled in different environments, and how different users behave within a specific context. Since the same treatment may differ depending on the patient, it is important to explore how the type of therapy affects environmental sustainability. Furthermore, the national and international strategies and policies may have a huge influence on the local system.

Within the reference framework of SD, a specific methodological path has been defined to answer the research questions. The study has focused on a practical case study to prove the validity of the methodology when dealing with real products, stakeholders, and environments. After illustrating the research boundaries, the methodology is explained in detail in the following paragraphs.

2.2.1 Research boundaries

The research has dealt with the **analysis of a practical case study**. The choice of the case study had to be significant in terms of **relevance** (it represents a broader category of treatments), **diffusion** (it is widely used), and **environmental impacts** (it has a high environmental burden).

Chronic haemodialysis constitutes a significant case study since it is a common treatment for Chronic Kidney Disease (CKD) that involves millions of people worldwide. Chronic noncommunicable diseases represent a growing issue for the health systems (cf. par. 1.1) and haemodialysis is a prominent example of the human, economic, and environmental problems that this kind of diseases implies. It is indeed one of the most expensive medical treatments concerning care expenses, resource consumption, and waste production (Connor, Mortimer & Tomson, 2010; Burnier & Martin, 2013).

Haemodialysis can be carried out in two different environments: **in-centre haemodialysis** (CHD) is the most common option, and it is performed within hospitals and satellite dialysis units, while **home haemodialysis** (HHD) is administered by the patient and the family caregivers, and it is a steadily growing phenomenon of self-care. Despite the growing relevance of HHD, it was decided to focus the research on CHD for several reasons. First, hospitals are the primary health care institutions, and they entail huge environmental and economic costs, for that reason many organizations are focusing on hospitals to promote Sustainable Healthcare (such as Global Green and Healthy Hospitals or Health Care Without Harm). Secondly, CHD daily involves several direct and indirect users: patients, families, nurses, health staff, physicians, hospital managers; this allows a wider analysis of the relations that occur between the stakeholders. Thirdly, products, equipment, and services are usually the same as those used in HHD; therefore, design can positively affect both the therapy options. Lastly, national and international policies towards Sustainable Healthcare are primarily implemented in hospital strategies: this is important to understand how the wider context affects local sustainability.

In order to investigate the impacts of the local context on the system, and to ensure the validity of the design assessment, the case study analysis has been carried out in **three hospitals** in different countries (**Italy, Sweden, and Denmark)**. The choice of the case studies has been endorsed by the **Nordic Center for Sustainable Healthcare**, led by TEM Foundation at Lund University, which has supported the research in the case study analysis.

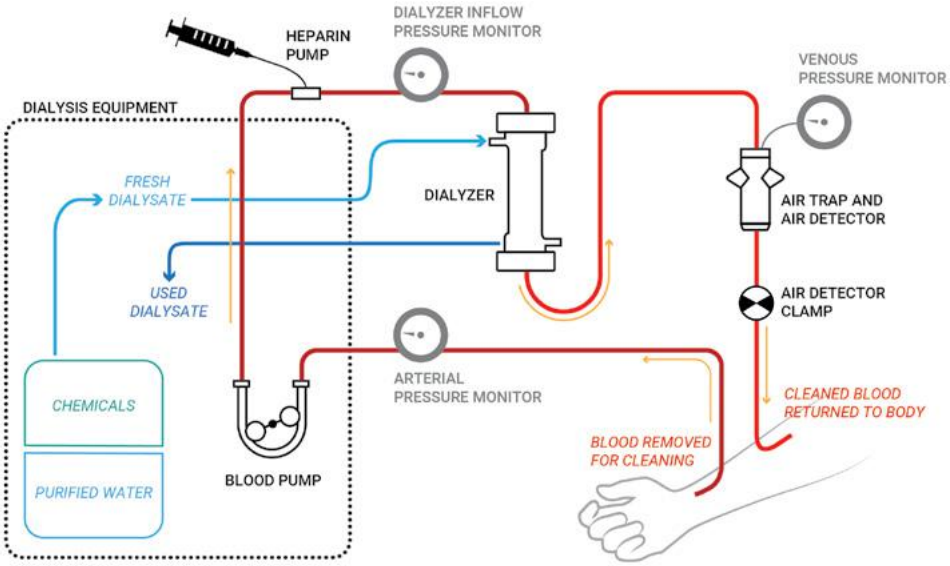


Fig. 2 - Basic functioning of haemodialysis

2.2.2 Haemodialysis: principles and application

Chronic Haemodialysis is a life-saving treatment, presently sustaining the life of over 2.5 million people worldwide (European Renal Care Providers Association, 2013). It allows the prolongation of decades of life in **patients who lost the function of kidneys**. It is also one of the most expensive medical treatments, not only regarding medical devices, and medical care but also regarding water and energy consumption and waste production.

Together with peritoneal dialysis, a likewise complex treatment, employing a different strategy of blood purification, haemodialysis accounts of 2% of the overall health care expenditure in European Countries. Haemodialysis is more widely employed, and over 80% of the dialysis patients worldwide are treated by haemodialysis.

The basic idea of haemodialysis is the washing machine: when kidneys fail the blood is no more purified by a vast array of toxins, so an "artificial kidney" takes care of "washing blood" on the average three times per week. **A dialysis system is made up of a dialysis equipment, a dialyzer, a disposable blood tubing set, purified water, and chemical solutions** (usually bicarbonate and acid concentrate) that will be mixed during the treatment to formulate the dialysate solution (see figure 2). The dialyzer acts as the kidney, separating wastes from the blood, thanks to a highly porous membrane. The blood, moved by a peristaltic pump, passes through the tubing set and enters into the blood compartment of the dialyzer. Contemporarily, the dialysate is transported to the dialysate compartment of the dialyzer. The pores of the membrane are designed to make the toxins passes by osmosis from the blood to the dialysate solution, while vital components pass from the dialysate and enter into the blood. The used dialysate solution is pumped out of the dialyzer, and the cleaned blood is passed back into the patient's body.

A haemodialysis session consists of three phases:

1. **Set-up of dialysis**. Before the scheduled session, the health staff prepares the dialysis equipment by connecting the dialyzer, the bicarbonate solution, and the acid concentrate solution, and by setting up the arterial-venous bloodlines which are worked out to make blood pass through the filter. The equipment starts the priming phase, which removes air from the tubing set and the dialyzer by making sterile saline solution flow through them.
2. **Start of dialysis**. Once the equipment is primed, the patient can be connected to it. First, the patient is weighed and blood pressure and temperature are taken. Then, he/she is connected to the bloodline tubes by

Fig. 3 - Visualization of the haemodialysis system that includes users and items.

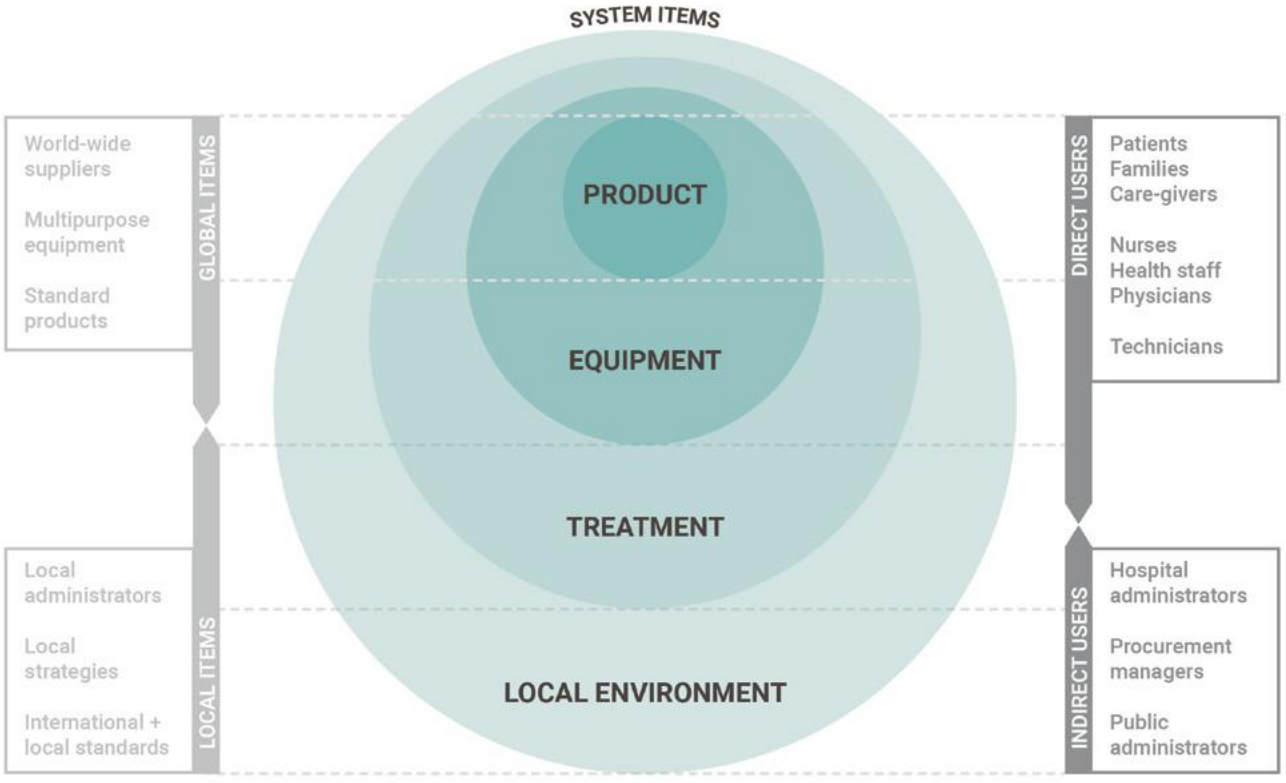
the fistula needles, which are inserted in the arterial-venous fistula or through a catheter in the chest. An anti-coagulant (e.g. heparin) is injected to prevent blood clotting and allow for efficient haemodialysis. The nurse can start the equipment, which moves the peristaltic pumps that make the blood flows through the tubing set and the filter. The equipment automatically controls the blood and the dialysate flows to remove toxins and excess fluids. The session usually takes from 3.5 to 5 hours.

3. **End of dialysis**. At the end of the session, the equipment stops and the patient is disconnected from the tubing set and medicated. Temperature, blood pressure, and weight are taken again. All disposable products and packaging are disposed of as common or infectious waste. Finally, the equipment is automatically cleaned and disinfected by a thermal or chemical process.

The haemodialysis includes different treatment methods according to the patient's disease, some of the most common ones are bicarbonate haemodialysis, hemofiltration, and hemodiafiltration. Each method requires different types of disposable products and packaging, while the in-center equipment is usually designed to perform different treatment methods.

2.2.3 Designing for the local and the global

Haemodialysis is a complex system (figure 3) consisting of different items (product, equipment, treatment, and local environment) that, in turn, may differ depending on the treatment method and the place where the therapy is performed. The analysis of the system had to consider all the variables that could indeed have an adverse impact on environmental sustainability. At the same time, some items can be regarded as "**global items**" (product - features -, and equipment) since they are designed for the world market, and, despite some minor differences, they would be the same regardless of the context. Other items are defined as "**local items**" (product - waste management -, treatment, and local environment) because they are related to and affected by the context where haemodialysis takes place.



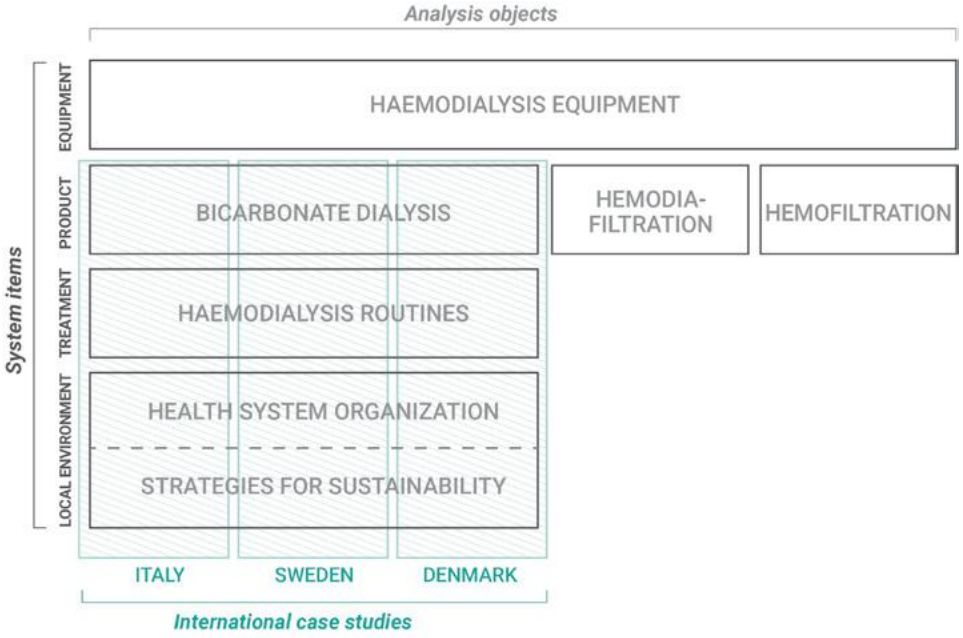


Fig. 4 - Detail of the analysis of the system items.

Furthermore, different stakeholders act within the system and relate to the items. They can be divided into two categories: "**direct users**" are directly and daily affected by the treatment. They may undergo the therapy (patients), support the patient (families and caregivers), administrate the therapy at different levels (nurses, health staff, and physicians), or respond to technical and maintenance problems (technicians). Conversely, the "**indirect users**" do not directly manage the treatment but are responsible for it at the political (public administrators), operational or managerial levels (hospital administrators and procurement managers).

In order to address the complexity of haemodialysis, the system has been divided and analysed according to the four items that make it up: **product, equipment, treatment, and local environment**. As argued above, some items are deeply affected by the local scenario while the other ones basically remain unchanged worldwide. As shown in Figure 4, global items have been analysed regardless of the context. The analysis of the equipment has focused on a specific in-centre machine: a preliminary analysis of the haemodialysis machines available on the market has allowed identifying the most representative one, that has been analysed in detail. The product analysis concerns packaging and disposables for the dialysis; in this case, the products are designed for the global market but their disposal is affected by the local waste management strategies. Thus, the analysis has started from the three most common methods of haemodialysis (bicarbonate dialysis, hemodiafiltration, and hemofiltration) to compare them and assess the impacts of different methods. Then, bicarbonate dialysis, which is the most popular method, has been evaluated within three dialysis units based in three European Countries (Italy, Sweden, Denmark) to investigate how routines and behaviours affect the waste sorting. Also, the other local items have been analysed in all the three dialysis units: the treatment analysis has concerned the routines of in-centre haemodialysis while the analysis of the local environments has taken into account the organization of the local health systems and the strategies for sustainability implemented at regional and hospital level.

2.2.4 International case studies

The choice of the case studies resulted from national and international partnerships that enabled to face the research topic from an interdisciplinary and international perspective.

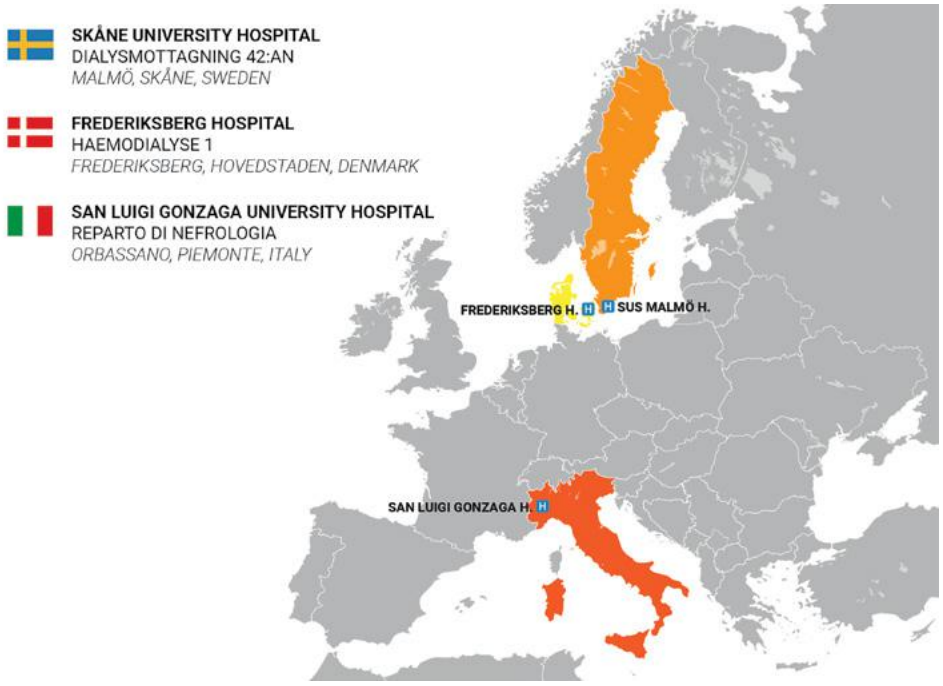


Fig. 5 - Map of the international case studies

The collaboration with the nephrology team of the **Department of Clinical and Biological Sciences** (University of Torino, Turin, Italy) has brought together interdisciplinary skills to jointly address the research problem. The first case study was the Dialysis Unit of the **SS Nephrology at San Luigi Gonzaga University Hospital** (Orbassano, Italy), in which all the three dialysis methods have been analysed and compared.

The collaboration with the **Nordic Center for Sustainable Healthcare** (NCSH), based in Malmö (Sweden), was essential to involve Nordic regions and hospitals in the present research. The NCSH is an independent and interdisciplinary platform that brings together several stakeholders from Northern Europe in the field of Sustainable Healthcare. It was founded and is managed by TEM at Lund University, aiming at helping the healthcare stakeholders to reduce their environmental impacts.

Therefore, the presented methodology has been applied to **three European regions and one specific hospital for each region** (figure 5).

Even if the three regions are slightly different regarding their area and population, the selected hospitals are similar in size, and they all have small-medium dialysis units that can be compared in regard to strategy implementation and complexity of organization (Figure 6):

SAN LUIGI GONZAGA UNIVERSITY HOSPITAL, ORBASSANO, PIEDMONT REGION (ITALY).

The hospital is located close to Turin, in North-western Italy. It provides medical care to a wide population in the province of Turin, and it hosts the Department of Clinical and Biological Sciences of the University of Torino. The Dialysis Unit is part of the SS Nephrology of San Luigi Gonzaga University Hospital, and it delivers haemodilaysis treatments to 36 patients. 4 doctors (one of which is a junior doctor) manage the unit in cooperation with 7 nurses. There are no permanent technicians in the unit, but an external company provides maintenance and extraordinary technical support.

SKÅNE UNIVERSITY HOSPITAL, MALMÖ, SKÅNE REGION (SWEDEN).

Malmö is home to the main facilities of the Skånes Universitetssjukhus (SUS), the University Hospital of Skåne region, in the south Sweden. The analysis has been carried out in Dialysmottagning 42:AN, one of the dialysis units of SUS Malmö, which provides care to 40 patients (out of 96). Every day, there are two sessions of fully assisted haemodialysis that are managed by 42 nurses, supervised by two doctors and supported by eight health workers who attend to cleaning. Two full-time technicians are working within the unit to

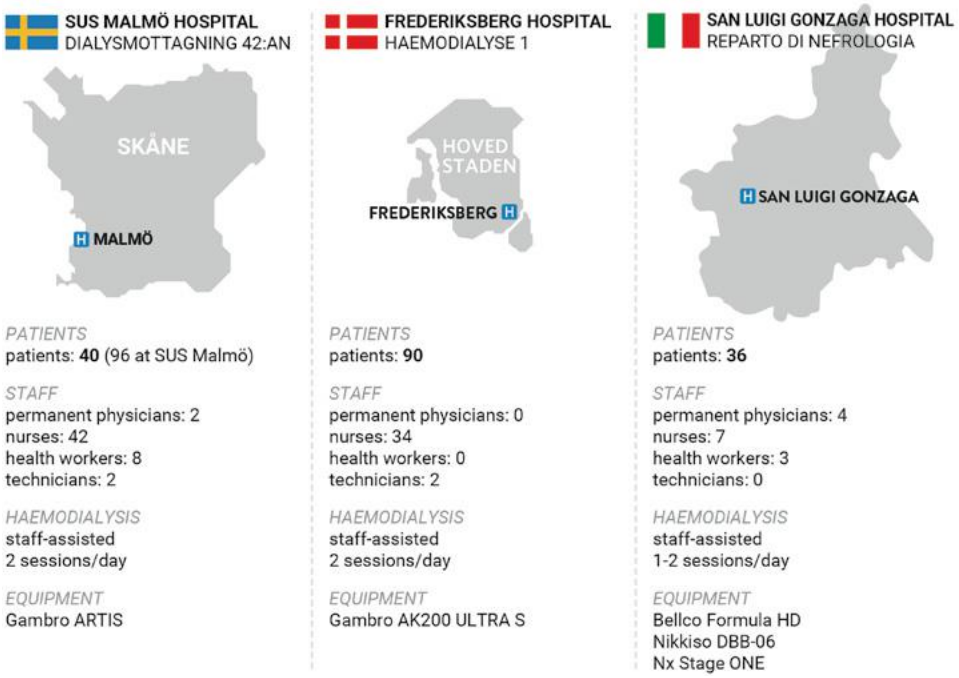


Fig. 6 - Data comparison of the dialysis units

manage both the preventive and the extraordinary maintenance of dialysis equipment.

FREDERIKSBERG HOSPITAL, FREDERIKSBERG, HOVEDSTADEN REGION (DENMARK).
Frederiksberg is geographically located in the area of Copenhagen, the capital of Denmark. It provides care services to Copenhagen inhabitants that represent the main part of the population of the Capital Region (Hovedstaden), in eastern Denmark. Haemodialyse 1 is one of the four dialysis units at Frederiksberg Hospital, and it offers full-assisted treatments, two sessions per day. The Unit serves about 90 patients, who are assisted by 34 nurses. There are no doctors (nephrologists can be reached by phone at all times) and no health workers. Two technicians provide assistance for technical issues and maintenance.

2.2.5 Holistic diagnosis: the analysis of the system

The complexity of healthcare systems requires a multi-level approach to carrying out a comprehensive analysis of the different items that make them up.
Following the developed methodology, the analysis has concerned the four items that represent the four levels of the system (Figure 7): products (packaging, disposables, devices), equipment (dialysis machine), treatment (haemodialysis routines) and local environment (national and local policy and management strategies).
The levels have been defined focusing on the relationship between product, process and system to keep the focus on environmental sustainability. Direct and indirect users are involved in all the levels; special attention is paid to the treatment level which especially involves patients, nurses, clinicians, and technicians. The analysis of the items has followed a common methodological path, that focuses on the holistic analysis of the current scenario (Barbero, 2016), by adopting and implementing existing design processes (Germak, 2008):

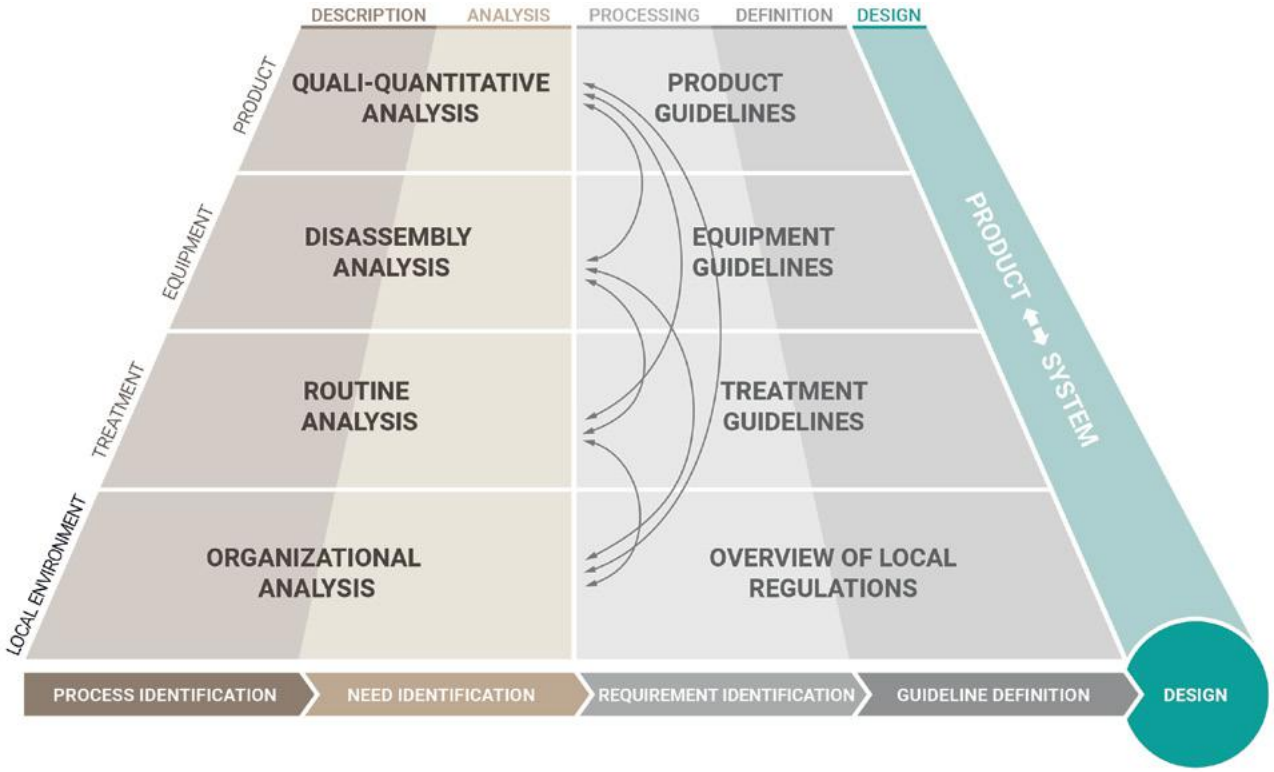
1. **Process identification**. The processes that govern the dynamics of items are first observed and described. The method of description differs according to the type of item, and it may use qualitative or quantitative tools (such

Fig. 7 - Visualization of the methodology for analysing the system

as product disassembly, on-field observation, qualitative interviews). The goal of this first step is to understand in depth how the system items behave and how they relate to the users and the other items, identifying the processes behind them.

2. **Need identification**. Each item reveals particular issues that have to be addressed and improved. Specific methods of analysis, varying according to the nature of the items, enable to identify the main problems of the system. The following paragraphs provide a detailed description of the methods applied to each item. This phase aims at defining the primary needs that design must face from functional, social, and environmental perspectives.
3. **Requirement identification**. The design process focuses on the definition of system requirements, starting from the needs defined in the previous step. Needs are analysed in detail from a design perspective to identify the main technical, operational, social and environmental requirements. For each requirement, the interaction with the other items is indicated, to establish the common requirements of the system. Moreover, the analysis shows the existing solutions that could be applied to meet each requirement, as well as the possible alternative solutions to address it. This step is crucial to set out the guidelines.
4. **Guideline definition.** The final step of the analysis is the definition of the design guidelines. This phase gathers and processes the results of the previous steps to establish a specific set of guidelines for each system item. The guidelines provide a quick reference tool to guide the designers toward defining innovative design strategies to improve functionality and sustainability of the item addressed. Because of the novelty of the sector, the tool includes both general guidelines, that can be applied to a wide range of projects and sectors, and specific guidelines which start from the peculiar requirements of the medical treatment.

The four system items highly differ in complexity, breadth, technical nature, and ways to interact with users. The identification of the needs and requirements related to a product is very different from the analysis of equipment, treatment or



hospital organization. Indeed, the study has adopted different design methods to carry out the first two steps of analysis (Process and Needs identification). The choice has focused on well-established methods in the fields of Human-Centred Design and Design for Sustainability, to implement them in order to fit the purposes of the research.
Overall, four design methods were defined to analyse the four system items.

PRODUCT – QUALI-QUANTITATIVE ANALYSIS

This method is based on the qualitative-quantitative methodology that has been developed at the Politecnico di Torino, within the Observatory of Eco-Pack (OEP) (Barbero, Pereno, & Tamborrini, 2011). It is a proven and field-tested method that has previously been applied to several industrial sectors. It is particularly suitable for products and packaging analysis because it combines a quantitative assessment of weights and materials with a qualitative evaluation which takes into account the immaterial features that characterize design issues (as regards function, sustainability, and communication). The methodology has been implemented for the packaging and disposable products for haemodialysis; especially, the quantitative assessment has focused on the waste analysis, comparing different ways of sorting and different categories of packaging/products. This was essential to include the behavioural variables in the analysis of weights and materials.

EQUIPMENT – DISASSEMBLY ANALYSIS

The analysis of the equipment builds upon the well-known approaches of Design for Disassembly (Bogue, 2007) and Design by Components (Bistagnino, Marino, & Virano, 2008). The implemented method consists of three steps: the disassembly analysis, which focuses on the ease of disassembly aimed at optimize the reuse, remanufacturing or recycling of materials, components and sub-assemblies; the accessibility analysis which evaluates the issues and requirements of accessibility for the users that interact with the equipment; the input-output analysis, that assesses the material flows and the relations between the components.
The systemic complexity of medical equipment requires improved implementations of the existing methodologies: first of all, it is necessary to divide the equipment into several macro-components, according to their function, to cope with its technical complexity. Second, the first part of the analysis should focus on acquiring a basic understanding of the equipment, while in items of daily use the designer has usually a previous knowledge of the product. Thirdly, the visualization of the input-output flows should shape the existing layout to provide a reference map for the design team. Finally, the analysis of the local environment cannot be included in the product analysis, but it has to be investigated separately because of the complex set of relationships involved. The overall goal of the implemented disassembly analysis is to evaluate the usability, accessibility and component layout in relation to the use and final shape of the equipment.

TREATMENT – ROUTINE ANALYSIS

In the case of treatment analysis, different design methods have been evaluated to assess dialysis routines; however, the focus on environmental sustainability requires a special implementation of the existing tools to make them perfectly suited for the purpose of the research. The goal of this phase is not to evaluate the effectiveness of logistics and management of the therapy, but to identify the main organizational issues that affect users' behaviours and product management toward environmental sustainability. Therefore, we started from known visualization tools to create a specific method of analysis of the treatment dynamics. In particular, the Customer Journey Map techniques are well-established graphic tools used by Service Designers to represent the journey of a user through the touchpoints that mark his interaction with a service (Alves & Jardim Nunes, 2013). This tool has increasingly been used to design business-oriented services, both physical and online (Rosenbaum, Otalora, & Ramírez, 2017 ; Samson, Granath, & Alger, 2017). Then, Customer Journey Mapping has found application in the healthcare field to improve the quality of the "patient's journey", aiming at improving patient outcomes and well-being through more efficient services (Curry, McGregor, & Tracy, 2006 , Marzilli Ericson, 2009; Boyd et al., 2012, McCarthy et al., 2016). In our case, the primary goal was to visualise and compare the "journey" of

three different user categories (patient, physician, nurse) that interact with products and equipment within the treatment. The visual map aimed at highlighting their behaviours toward products and equipment, considering from an environmental sustainability perspective. The map is based on field analysis that allowed to collect the data through contextual interviews with different users and two full-time days, for each case study, of on-field observations. The resulting map combines three levels of analysis: routines activities, roles of users, strengths and weaknesses.

LOCAL ENVIRONMENT – ORGANIZATIONAL ANALYSIS.
The analysis has been carried out in parallel with the product and equipment analyses, focusing on the contexts in which the haemodialysis system is located. The organizational analysis aims at providing an overview of different approaches to Sustainable Healthcare (SH), analysing environmental strategies both at the macro (Region) and the micro level (hospital and dialysis wards). The complexity and interdisciplinarity of healthcare systems require a multi-level analysis that takes into account different aspects affecting the implementation of environmental sustainability strategies. Different stakeholders and their related responsibilities and tasks have to be considered to define a methodology that can be applied to different contexts and countries. The analysis has been carried out considering two levels of organization: the regional organization for SH and the implementation of SH strategies.

The results of the analyses of the system items have focused on the requirement identification and the guideline definition. Each method allowed to identify the main issues that design should address to improve the overall sustainability of the system. Starting from the issues and requirements, a broad set of guidelines has been defined to provide a practical guidance to design eco-innovative solutions.

2.2.6 Outcomes of the analysis

The analysis of the system items has led to define a broad set of eco-guidelines to guide the design of new products, services, and systems toward environmental sustainability and user-centricity. Then, a further step was needed to give a greater significance to the research results. So a detailed set of design strategies for the healthcare sector has been defined, taking into account the technical, operational, social, and environmental requirements of medical treatments. This final result aims at providing a practical tool to designers and healthcare stakeholders to address the design of new solutions for Sustainable Healthcare.

DESIGN ECO-GUIDELINES
The analysis of products, equipment, and treatment highlights specific issues affecting the environmental sustainability of haemodialysis and the relationships with the users. Design guidelines start from the quantitative and qualitative results of the analysis to provide practical guidance for designing more sustainable solutions for dialysis treatments.
Each guideline addresses a specific aspect of the design. The guidelines refer to common strategies of Sustainable Design (Vezzoli & Manzini, 2007):

5. Reduction: designing to reduce and optimize volumes and materials.
6. Materials: sustainable materials in relation to the design application.
7. Technology: adopting new technologies to improve usability and sustainability.
8. Flexibility: facilitating customization to different users and applications.
9. Usability: ensuring user-friendliness, avoiding unnecessary physical and cognitive efforts.
10. Life cycle: designing for extending the life cycle, through reuse, update or long lasting product life.
11. Information: promoting users' awareness throughout the whole life cycle.

In most cases environmental sustainability can only be achieved through the coordinated design of different elements; therefore, the system items involved (product, equipment, treatment) should be indicated.

DESIGN STRATEGIES

The design guidelines represent a valuable instrument to cope with the design complexity of haemodialysis system while keeping the common focus on users and environment. Despite the general nature of guidelines, their application to other medical treatments may be not immediately easy. Therefore, a further step was needed to give a significant contribution to the novel research domain of design for Sustainable Healthcare.

From the guidelines developed within the case study, a set of design strategies has been laid down, aiming at providing a practical tool to designers and healthcare stakeholders.

The Design strategies are divided into the seven categories of Design for Sustainability; this allows to include the strategies in an overall framework that designers are familiar with, so as to make them able to seek references for deepening and updating their knowledge.

Each strategy provides detailed information on the key issues and how design can address them in relation to the system items (product, equipment, treatment) and the direct users (patient, health staff, technician) involved in a chronic treatment.

Chapter 3

Analysis of the system

Focus on chronic haemodialysis

"While medical health professionals are trained to detect, treat, and comfort, they are not trained to consider the environmental impact of the services they provide. […] Dialysis services must begin to explore eco-dialysis potentials. The continued plundering of resources without considering reuse or recycling, exploration of renewable energy options, or the reduction of the carbon footprint of the dialysis process…is unsustainable. Sustainable dialysis practices should be a global goal in the coming decade."

(Agar, 2012)

3.1 Product: Packaging And Disposables

Chronic haemodialysis needs a huge quantity of disposable biomedical products for extracorporeal circulation and blood filtering, that assures the sterility of the parts in contact with the patient while avoiding any contamination. The high number of disposables results in a considerable amount of waste: according to the works of Agar (2012), each dialysis session produces between 4 and 6 kg of waste, of which 2 kg is infectious waste. The nature and quantity of disposables may vary, but the following products are used in all types of haemodialysis:

1. Arterial and venous bloodlines (including the tubing set)
2. Bicarbonate
3. Acid concentrate
4. Dialyzer
5. Saline solution
6. Arterial fistula needle
7. Venous fistula needle
8. Connection kit (crosspiece, gauzes, swabs, patches, gauze balls)
9. Disconnection kit (crosspiece, gauzes, swabs, patches, gauze balls)
10. Anti-coagulant injection

There are further products that may be needed according to the dialysis method (such as infusion set and additional filters) or the type of equipment or facility (e.g. a washing solution is used where there is no automatic on-line system for priming). Moreover, each product has its packaging and, optionally, over-packaging that contribute significantly to increase the total volume of waste. Previous works (Burnier & Martin, 2013; Agar, 2012; Connor, Milne, & Owen, 2010) have described in general terms the impacts of waste production, aiming at highlighting the significant environmental burden of haemodialysis. The goal of the present analysis is to evaluate both the waste production and the qualitative features of products and packaging to highlight the design issues and potentials of dialysis disposables. Therefore, a qualitative-quantitative method has been implemented and applied to carry out the product assessment of chronic haemodialysis (see par. 3.1.1).
Dialysis products are designed for the global market, but their disposal is affected by the local waste management strategy; thus the analysis has been carried out by comparing different treatment methods (see par. 3.1.2) and international case studies (see par. 3.1.3). The overall analysis resulted in the definition of the main requirements of the system item (see par. 3.1.4).

3.1.1 Product assessment through a qualitative-quantitative analysis

Chronic haemodialysis includes different methods of treatment according to the patient's disease, which uses various types of disposable products and packaging. The type of products can also vary, to a lesser extent, according to the supplier, the equipment, and the local routines.
Therefore, there are many variables which could influence the products used in the treatment. The analysis methodology aimed at considering all the **qualitative and quantitative aspects of product and packaging**, allowing to compare different product categories (par 3.1.2), treatment methods (par. 3.1.3), and case studies (par. 3.1.4). All products used in the treatment were analysed, and the waste produced during the whole session was checked and weighed.

PRODUCT CATEGORIES

All the disposable products and their packaging were reported and divided into five categories, according to their operational function. The categorization is fundamental to assess the main issues related to the type of product, but it is also important to establish a common language between different disciplines, bringing greater clarity to the terminology used.
First, we should differentiate the products that are commonly defined as "packaging":

1. **Packaging for transport** is a secondary packaging allowing to transport and store primary packaging and products. It is thrown away as urban waste (e.g. cardboard boxes).
2. **Packaging for distribution** is a primary

packaging allowing to transport and handle the medical device until it is used. It is discharged just after being open and can usually be disposed of as urban waste (e.g. plastic films).

Some of the products that are generally considered devices can be called "packaging" from a design point of view because they contain and protect the product itself:

3. **Packaging for treatment** is a primary packaging that enables to transport, handle and use the product. It is directly connected to the haemodialysis equipment to allow using the product it contains. It must cope with high biocompatibility standards, but it can be disposed of as urban waste (e.g. saline solution bags).

The last two categories include all the medical devices, that differ in the level of complexity:

4. **Disposables** are one-use products for medication (e.g. gauzes) and therapeutic procedures (e.g. fistula needles). Disposables must meet biocompatibility requirements and functional effectiveness. They are usually considered contaminated waste.
5. **Biomedical devices** are key products of the dialysis treatment. They need to comply with a high level of biocompatibility and technical requirements. They are usually disposable and discharged as contaminated waste (e.g. dialyzer).

Packaging for transport has not been considered in the comparative analysis because secondary packaging (mainly cardboard boxes) cannot be referred to only one dialysis session, but it includes the primary packs for several sessions.

QUALITATIVE-QUANTITATIVE METHODOLOGY

The method used to assess the haemodialysis products is based on the qualitative-quantitative methodology that has been developed at the Politecnico di Torino, within the Observatory of Eco-Pack (Barbero, Pereno, & Tamborrini, 2011). It is a proven and field-tested method that has previously been applied to several industrial sectors, aiming at identifying the main design problems and potentials to improve the environmental sustainability of industrial packaging.
It is particularly suitable for the purpose of the present analysis because it combines a quantitative assessment of weights and materials with a qualitative evaluation which takes into account the immaterial features that characterize design issues (concerning function, sustainability, and communication). Qualitative and quantitative analyses have advanced in parallel to achieve a comprehensive definition of the main requirements that product design should aim at, even considering the relations with the other system items (equipment and treatment).

The **quantitative analysis** has mainly concerned weights and materials since they are huge issues both for environmental and economic impacts (Agar, 2013). Indeed, the **type and weight of waste** deeply affect the potential for recycling, resource consumption (within production and transportation phases) and the cost of waste disposal. All waste produced during the whole treatment was collected and weighed using an electronic weighing scale. In many cases packaging for treatment contained residual non-contaminated fluids (e.g. saline solution). Even though many packaging could not be emptied, the emptying was forced employing cutting tools to verify the potential weight reduction.
Another aspect that must be taken into account is the **contamination of waste** after the treatment, as it impacts the cost and the potential for recycling and reuse. The contaminated products (infectious waste) and the non-contaminated ones (urban waste) were identified to understand which ones should be designed to facilitate recycling and which ones should immediately be discarded.
Then, all **materials** were reported to verify which are the most used and which might affect waste recycling. In particular, some composite materials and polymers (e.g. PVC) need special recycling

Fig. 8 - Example of the qualitative analysis applied to an acid concentrate bag for haemodialysis

processes (Carvalho, 2012) and they often have a lower level of recyclability (Sadat-Shojai and Bakhshandeh, 2011). This allowed providing indications about the choice of materials.
The assessment of waste production considered two different practices of waste sorting that could deeply affect the cost of disposal:

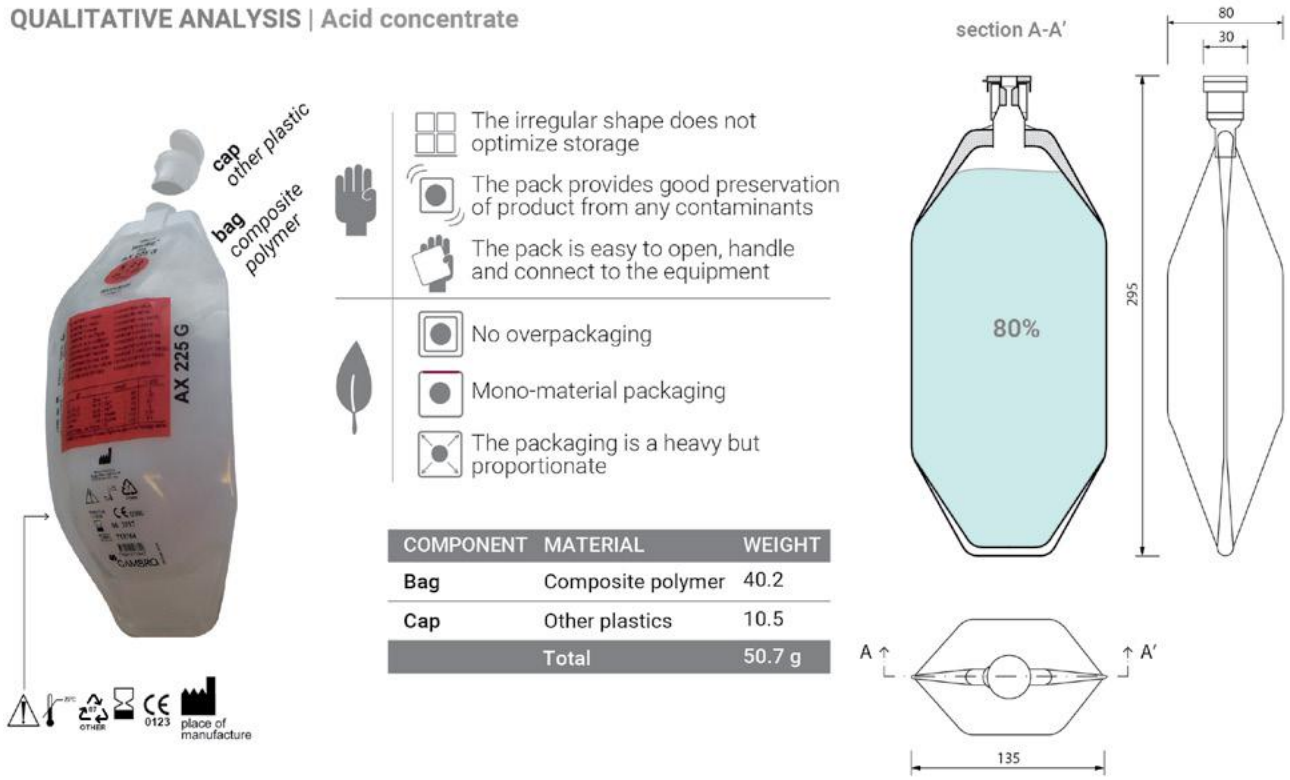
1. **Careless practice**: no waste is emptied, and residuals are thrown away within the product.
2. **Careful practice**: all products are emptied and the materials properly sorted.

The cost of waste disposal is a significant economic issue that is prompting healthcare organizations to ask for more sustainable solutions.
A **economic assessment** has been performed, but it involved only the comparison of different treatment methods (considering the disposal costs in Piedmont Region, Italy) because it aims at providing a general idea of the economic impact of haemodialysis; an international comparison would not offer any further suggestions about the problems to address.
Quantitative data are significant but not sufficient to determine the design problems of products and packaging.

The **qualitative analysis** was performed to compare the quantitative features of packaging and disposables (weight, materials, volume) and the qualitative ones. The analysis is based on the disassembly of the product, that is represented by an exploded view; volumes and technical features are shown through orthographic projections while a table summarizes the weight and materials of all the components. A qualitative table reports the observations about the design issues concerning functionality, sustainability, and communication (Figure 8).

In particular, the qualitative table summarizes the whole analysis according to special criteria that relate to:

1. **Functionality**. The functional criteria address three critical aspects of product design:
- *Storage optimization* takes into account the product volume and layout, that can deeply affect storage capacity and transportation;
- *Preservation and protection* concern the specific requirements of the content;
- *Usability* pays special attention to handling operations and the opening/closing system



which may act either as a facilitator or as an obstacle for the set-up and disposal of the treatment.

2. **Environmental sustainability**. The sustainable criteria concern three primary areas of environmental issues:
- *Over-use of materials*, because the unjustified use of over-packaging and additional materials can increase resource consumption and hinder waste recycling;
- *Easiness of disassembly* takes into account the use of reversible/irreversible joints and the material composition of the product. Both aspects can make recycling more difficult.
- *Volume optimization* considers the volume ratio of packaging to packed product, evaluating possible oversizing of packs.

3. **Communication**. In the healthcare products, communication criteria mainly deal with information:
- *Operating information* regards the presence of appropriate operating instructions to facilitate the set-up of the therapy;
- *Waste sorting information* concerns the information about the end of life, providing useful suggestion for waste sorting and recycling;
- *Use of standard labels* is essential to provide universally comprehensible information about products and materials, promoting environmental awareness.

The qualitative analysis has been applied to **all the type of products** used in different dialysis methods and all the three case studies. Most of the qualitative criteria consider **the packaging and the packed product** in close relationship (e.g. storage optimization, usability, volume optimization, waste sorting information). Consequently, disposables and biomedical devices have been analysed together with their packaging (packaging for distribution) while packaging for treatment has been considered alone since they already include the product (usually liquids or powders).
Because the analysis led to qualitative observations, it is not possible to compare methods and case studies according to the qualitative outcomes. Conversely, it is useful to **compare different product categories**, to highlight the main qualitative issues according to the type of product.

Therefore, the assessment of different dialysis methods and different case studies has based on the quantitative analysis, by comparing materials and waste weight. In this case, the product categories have been considered individually, because the choice of materials and the type of disposal (municipal or infectious waste) is deeply related to the product function.
The qualitative and quantitative results of the different comparisons enabled to achieving a comprehensive assessment to define the product requirements.

3.1.2 Qualitative comparison of product categories

The qualitative analysis, presented in par. 3.1.1, has been applied to the haemodialysis products in order to define the **qualitative design issues that affect the functionality, sustainability, and communication** of different product categories.
The qualitative analysis addressed the **disposables and devices along with their packaging for distribution**, so as to understand the problems related to the filling ratio, the product-pack shapes, and the overall ease of use (which includes daily supply and opening/closing).
Furthermore, it has been taken into account the **type of packaging/product**, so only the products which differ from the kind of material or shape have been analysed. For example, only two dialyzers (out of 6) have been analysed because the dialyzer is basically the same and all the packs are standing under two types of packaging (mono-material bag and two-layers pack).

The individual analyses of all the dialysis products are reported in Annex I.

Table 1 shows the overall results of the qualitative

Table 1 - Qualitative comparison of different products categories

PRODUCT AND PACKAGING	FUNCTIONALITY			SUSTAINABILITY			COMMUNICATION		CODE
	FILLING RATIO	PROTECTION	EASE OF USE	OVERPACKAGING	EASE OF DISASSEMBLY	PACK WEIGHT	STANDARD LABELS	INFORMATION	
BLOODLINES *Bi-component wrapper*	65% - 70% *slight oversized*	medium *good preservation of sterility*	medium *easy to identify and open*	high *no overpackaging*	high *dissassembly to open*	10.8 gr / n.a. *lightweight*	STERILE EO	low *no info about materials and disposal*	medium
DIALYZER *Mono-component wrapper*	30% *oversized*	low *good preservation of sterility, low protection against impacts*	medium *easy to identify*	high *no overpackaging*	very high *mono-material*	10.6 gr / n.a. *lightweight*	none -	very low *no info*	medium
Bi-component wrapper	70% *slight oversized*	low *good preservation of sterility, low protection against impacts*	medium *easy to identify*	high *no overpackaging*	high *dissassembly to open*	8.3 gr / n.a. *lightweight*		very low *no info*	medium
INFUSION LINE *Bi-component wrapper*	70% *slight oversized*	medium *good preservation of sterility*	medium *easy to identify and open*	high *no overpackaging*	high *dissassembly to open*	7.1 gr / n.a. *lightweight*	STERILE EO	low *no info about materials and disposal*	medium
BICARBONATE *Cartridge*	80% *proportionate*	medium *over-protection (focus on usage)*	high *easy to open and connect*	low *mono-material overpackaging (plastic bag or cardboard sheet)*	low *it is not possible to open it*	300-500 gr / 750 gr *heavy*		medium *info about materials, none about disposal*	low
ACID CONCENTRATE *Bag*	90% *proportionate*	medium *good preservation of sterility*	low *easy to connect, difficult to handle*	high *no overpackaging*	low *composite polymer*	43 gr / 3800 ml *lightweight*		low *no info about materials and disposal*	low
Semi-rigid bag	80% *proportionate*	medium *good protection of product*	high *easy to connect, open, and handle*	high *no overpackaging*	low *composite polymer*	50.8 gr / 1000 ml *medium*		medium *info about materials and manufacture, none about disposal*	high
SALINE SOLUTION *Bag*	95% *proportionate*	medium *good preservation of sterility*	medium *quite easy to connect and handle (compact size)*	high *no overpackaging*	low *composite polymer*	22.5 gr / 1000 ml *lightweight*		low *no info about materials or disposal*	low
WASH SOLUTION *Bag*	95% *proportionate*	medium *good preservation of sterility*	low *quite easy to connect, difficult to handle*	high *no overpackaging*	low *composite polymer*	30.1 gr / 2000 ml *lightweight*		low *no info about materials or disposal*	low
COLLECTION BAG *Bag*	n.a. *depending on wash solution*	high *avoid liquid leakages (low performance required)*	medium *quite easy to connect, difficult to handle when full*	high *no overpackaging*	low *composite polymer*	34 gr / 2000 ml *lightweight*	/	low *no info*	medium
FISTULA NEEDLES *Bi-component wrapper*	40% *oversized*	medium *good preservation of sterility*	medium *easy to identify and open*	high *no overpackaging*	high *dissassembly to open*	8.2 gr / 20 gr *medium*	STERILE	medium *info about phtalates, no info about disposal and materials*	medium
CONNECTION/ DISCONNECTION KIT *Bi-component wrapper*	70% *slight oversized*	medium *good preservation of sterility*	medium *easy to open, two types of kit are not easy to identify*	low *contained items have their own pack*	high *dissassembly to open*	5 gr / 35-46 gr *lightweight*	STERILE EO	low *no info about materials and disposal*	medium
ANTI-COAGULANT *Bi-component case*	70% *slight oversized*	medium *good impact protection and preservation of sterility*	low *difficult to open and to handle*	high *no overpackaging*	low *layers are difficult to separate*	1.5 gr / 15 gr *lightweight*	/	low *no info*	low
Hard case	70% *slight oversized*	high *good impact protection and preservation of sterility*	high *very easy to open and handle*	high *no overpackaging*	high *mono-material*	5.5 gr / 4.7 gr *heavy*	/	low *no info*	high
SYRINGE *Bi-component wrapper*	75% *slight oversized*	high *impact protection adequate to the content and good preservation of sterility*	high *easy to open and handle*	high *no overpackaging*	high *dissassembly to open*	2 gr / 15 gr *lightweight*	STERILE EO, LATEX FREE, PYROGEN FREE	low *little info about materials, none about disposal*	medium

analysis that are summarized according to eight criteria which allowed to provide a final score to highlight the most critical categories.
The comparison criteria sum up the three areas of analysis:

1. **Functionality**
- *Filling ratio*: ratio of the volume of product to the total volume of packaging;
- *Level of protection:* adequacy of the level of product protection and preservation;
- *Ease of use:* usability in relation to different users' tasks.

2. **Sustainability**
- *Over-packaging:* use of necessary or unnecessary over-packaging;
- *Ease of disassembly:* easiness of separating different materials for recycling;
- *Packaging weight:* lightness of the pack in relation to the product.

3. **Communication**
- *Standard labels:* use of standard international symbols;
- *Information:* quantity and quality of the information provided through the pack/product.

Overall, the qualitative analysis highlighted some specific issues concerning haemodialysis products. As regards **functionality**, the comparison shows a widespread oversizing of packaging for distribution, that affects their ability to protect products against impacts, as well as their environmental burden, because of the unnecessary consumption of materials. At the same time, many usability issues negatively impact on both the health staff and the patient tasks: the absence of gripping points, the difficulty in handling, and the lack of visual codes make the daily supply process more difficult; disposables and devices require higher cognitive effort especially within the set up of the dialysis, this problem particularly affects the participation of patients in the treatment.
The main issues highlighted concern the **sustainability** of dialysis product. First, the use of connection and disconnection kits results in wasted resources (since many disposables are not used and a further packaging is needed) while it leads to usability problems related to product conservation during the whole treatment. Secondly, the disposal phase has major operational problems about managing the contaminated waste (the bulky system composed of bloodlines, tubing, dialyzer, and infusion line is difficult to handle) and sorting the non-contaminated waste. In particular, many packaging for treatment, such as cartridges and solution bags, are difficult to sort since they cannot be open to being emptied, or this action requires physical effort (and personal motivation to do it). Furthermore, most packaging made of composite materials are difficult to separate for recycling, because of the use of permanent joints and the cognitive and physical effort required to separate different materials.
Finally, the **communication** issues mainly deal with the little information about the product identification, that would allow facilitating supply operations, and the lack of information about materials and waste disposal.

3.1.3 Quantitative comparison of different methods

The quantitative comparison has first taken into account different methods of haemodialysis, performed with different dialysis equipment in the same dialysis unit so as to sort all waste in the same way. The analysis has been carried out in collaboration with the SS Nephrology of San Luigi Gonzaga Hospital (Turin, Italy), and information was collected through on-the-field analysis in their Dialysis Unit.

The analysis looked at the three most important types of haemodialysis treatments:
- **bicarbonate dialysis** (performed with Nikkiso DBB-06)
- **hemofiltration** (performed with Bellco Lynda)
- **haemodiafiltration** (performed with Bellco Formula Therapy)

Table 2 - Quantitative comparison of different treatment methods according to the weight of the collected waste

The analysis has considered two practices of waste sorting, the *careful* practice and the *careless* one, as mentioned in par 3.1.1. All information about materials, product type (according to the five categories defined in par 3.1.1), and the level of contamination have been reported. Finally, the treatment stage in which waste is sorted has been indetified (set-up, start, and end of dialysis - see par. 2.1.1).
The data collected from the analysis of the selected haemodialysis treatments are reported in detailed in Annex I.

The results of the quantitative comparison according to the weight of the collected waste, are summarized in Table 2. Overall, the total amount of **waste produced in each dialysis session may be from 1.9 up to 7.7 kilogrammes**: this result not only confirms the general esteems carried out in previous works (Agar, 2012), but it highlights even larger numbers whether waste sorting is not done properly. If we consider that each patient attends at least 3 sessions per week, the waste produced may be from 304 kg to 1200 kg per patient per year. The **total weight is strongly affected by the emptying of waste** from residual materials (careful practice), as detailed in Table 2: the weight of non-emptied waste can increase by 43% (hemofiltration) to 315% (bicarbonate dialysis). This problem is even more impactful if we consider the non-contaminated fraction, whose "careless" weight can increase by 95% (hemofiltration) to 549% (bicarbonate dialysis). It is important to notice that some product categories significantly affect the environmental impact of haemodialysis regarding waste production (by weight): biomedical devices represent on average the 54% of the waste collected within a session, and the average waste of packaging for treatment is the 31% of the waste production. The **waste sorting practice** influences both categories; in particular, the weight of pack for treatment may double (hemofiltration) or even increase tenfold (bicarbonate dialysis). From a design perspective, it is important to highlight the impact of some specific product categories and how the waste sorting practices can affect the overall weight. Then, it would be essential to give users the possibility to empty residual materials (especially from packaging for treatment) and to encourage them to sort waste properly, facilitating the disposal tasks.
The analysis of materials highlighted that, on

METHOD	BICARBONATE DIALYSIS (HD)		HEMOFILTRATION (HF)		HEMODIAFILTRATION (HDF)	
EQUIPMENT	NIKKISO DBB-06		BELLCO LYNDA		BELLCO FORMULA	
PRACTICE	*careful (gr)*	*careless (gr)*	*careful (gr)*	*careless (gr)*	*careful (gr)*	*careless (gr)*
TOTAL WEIGHT	**1955**	**8106**	**2575**	**3682**	**2691**	**7691**
Pack for treatment	730	6830	786	1320	680	5580
Pack for distribution	93	93	378	952	128	128
Disposables	133	133	180	180	133	133
Biomedical devices	1000	1050	1200	1200	1750	1850
Contaminated	1166	2982	1410	1410	1916	3782
Non contaminated	789	5124	1164	2272	775	3910
Set-up phase	61	61	895	895	97	97
Start phase	149	1915	174	174	149	1915
End phase	1729	6113	1505	2612	2428	5663

METHOD	HD		HF		HDF	
EQUIPMENT	NIKKISO DBB-06		BELLCO LYNDA		BELLCO FORMULA	
	gr	*%*	*gr*	*%*	*gr*	*%*
PLASTICS	**767,5**	**97%**	**1006,4**	**94%**	**740,1**	**95%**
PP	42,2	5%	653,90	65%	55,60	8%
PVC	17,5	2%	38,00	4%	26,80	4%
composite polymers	695,6	91%	212,50	21%	645,50	87%
generic plastics	12,2	2%	102,00	10%	12,20	2%
PAPER	**21,9**	**3%**	**60,22**	**6%**	**34,9**	**5%**
medical paper	21,9	100%	60,22	100%	34,9	100%

Table 3 - Quantitative comparison of different treatment methods according to the materials making up non-contaminated waste.

average, the **96% of non-contaminated waste is made of plastics** (Table 3): in HD and HDF, the 90% is composite polymers, which are composed of two or more layers of plastic materials and are more difficult to recycle. In HF, polypropylene is prevailing, despite the fact that it is often difficult to sort because of the residual materials contained. Despite its low contribution to the total weight, the medical paper is also present in most packaging. Overall, Design should investigate alternatives to the use of composite materials and communicate, by using clear and standard symbols, the materials that made up the product and how to disposed of.

As regards the **economic assessment**, the esteem of disposal costs has been made considering the minimum and the maximum cost applied by waste disposal operators in the Piedmont Region (Italy), where the Dialysis Unit is located.

Table 4 shows how **waste production represents a huge cost for healthcare facilities, ranging from 152.84 euro 3470.49 euro per patient per year**, according to the method of treatment and the operator. On average, a dialysis session in which waste is sorted carefully costs 4.93 euro, but it nearly doubles if the waste is not emptied (careless sorting), rising to 9.55 euro (+194%).

Overall, the economic assessment highlights the **problem of waste emptying** and the **impact of contaminated waste** on the economic sustainability of the medical treatment. Waste sorting can positively influence cost reduction.

METHOD	HD		HF		HDF	
EQUIPMENT	NIKKISO DBB-06		BELLCO LYNDA		BELLCO FORMULA	
PRACTICE	*careful (€)*	*careless (€)*	*careful (€)*	*careless (€)*	*careful (€)*	*careless (€)*
Average cost	**3,9**	**10,7**	**4,7**	**5,0**	**6,2**	**12,9**
Minimum cost	1,0	3,3	1,2	1,5	1,5	3,5
Maximum cost	6,7	18,1	8,2	8,5	10,9	22,2
Contaminated waste (av. cost)	3,6	9,3	4,4	4,4	6,0	11,8
Non contaminated waste (av. cost)	0,2	1,4	0,3	0,6	0,2	1,1

Table 4 - Quantitative comparison of different treatment methods according to the cost of waste disposal

Table 5 - Quantitative comparison of different case studies according to the weight of the collected waste

3.1.4 Quantitative comparison of different case studies

The second step of the quantitative comparison has focused on the same treatment (bicarbonate haemodialysis), performed in three dialysis units, located in different European Countries:

- **SS Nephrology, San Luigi Gonzaga University Hospital**, Italy (performed with Bellco Forumla Therapy)
- **Dialysmottagning 42:AN, Skånes Universitets-sjukhus (SUS)**, Sweden (performed with Gambro ARTIS™)
- **Haemodialyse 1, Frederiksberg Hospital**, Denmark (performed with Gambro AK 200™ ULTRA S)

The analysis has been carried out as for the quantitative comparison of different treatment methods (see par 3.1.3). The assessed criteria are the same, to make the results obtained for each analysis comparable: **waste sorting practice**, **materials**, **product type**, **contamination** or non-contamination of waste, and **treatment stage**.
The comparison of the waste production by weight is shown in Table 5. In the "careful sorting" scenario, the total amounts of waste are quite similar. Waste production at San Luigi Gonzaga Hospital is one-third higher than the others: the lack of on-line water systems within the dialysis unit requires the use of solution bags during the set-up and the end of the treatment. The **use of bags significantly affects the weight of waste** in careless sorting, because the residues contained in the bags usually are not fully emptied. Moreover, the analysis confirms the results highlighted in the comparison of different methods (see par. 3.1.3), underlining the **need for facilitating the emptying of non-contaminated waste**.
Even in this case, the most impactful product categories are biomedical devices and packaging for treatment, both categories aim at performing special tasks within the treatment; thus they require to accomplish higher requirements and use a more performant structure and more resistant materials. In some cases, such as for the dialyzer, the shape is already optimized for the complex therapeutic task the device has to perform.
Design could hardly address this kind of product as regarding material and weight reduction (however, other solutions are possible at the system level, as

METHOD	BICARBONATE DIALYSIS (HD)					
HOSPITAL	SAN LUIGI HOSPITAL (IT)		SUS MALMO (SE)		FREDERIKSBERG H. (DK)	
PRACTICE	*careful (gr)*	*careless (gr)*	*careful (gr)*	*careless (gr)*	*careful (gr)*	*careless (gr)*
TOTAL WEIGHT	**1968**	**6569**	**1442**	**1830**	**1450**	**2701**
Pack for treatment	644	2551	493	670	557	1608
Pack for distribution	152	2796	109	109	113	113
Disposables	123	123	151	151	180	180
Biomedical devices	1050	1100	689	900	600	800
Contaminated	1192	1242	817	1028	722	922
Non contaminated	777	5327	620	802	870	1944
Set-up phase	107	2751	86	86	115	989
Start phase	666	916	111	111	136	136
End phase	1179	2886	1245	1633	1199	1576

a reuse system for blood filters). Conversely, the impact of some products, such as bicarbonate and sodium cartridges, could be effectively reduced by taking into account alternative materials and layouts.

Table 6 gives an overview of the materials that make up the non-contaminated fraction of haemodialysis waste. The whole fraction can be disposed of as urban waste.
In all cases, **plastics represent most of the total waste**, ranging from 84% to 97% (by weight). The main types of plastics vary in each case: at San Luigi Gonzaga Hospital, the use of bags for physiological solutions increases the volume of **composite polymers** (usually multi-layer materials made of nylon, polypropylene, polyethylene, latex, and polyvinylchloride). At SUS Malmö and Frederiksberg Hospital, **polypropylene** is prevailing: however, in most cases, the packaging made of polypropylene contains residual materials that cannot be removed, this negatively affects the overall recyclability of the products. **Medical paper** and, in smaller quantity, **cardboard** is also present in most packaging, despite their low contribution to the total weight.
Overall, the **widespread use of recyclable materials** offers a high potential for recycling non-contaminated waste. However, the qualitative issues of dialysis products make it more difficult to sort them properly for recycling: the analysis of quantitative and quantitative issues aims precisely at comprehensively addressing the problems and potentials of haemodialysis product.

3.1.5 Product requirements

The results of the qualitative (par 3.1.2) and quantitative analyses (par. 3.1.3, par. 3.1.4) allowed to define the most critical aspects regarding haemodialysis products, and the related issues that affect the functionality and sustainability of the treatment. All these issues have been reported on Table 13: all the issues are divided according to the treatment phase and the aspect they are affecting (functionality or sustainability). Each

METHOD	BICARBONATE DIALYSIS					
EQUIPMENT	SAN LUIGI H. (IT)		SUS MALMO (SE)		FREDERIKSBERG H. (DK)	
	gr	*%*	*gr*	*%*	*gr*	*%*
PLASTICS	**717,7**	**97%**	**543,8**	**89%**	**636,9**	**84%**
PE	0,0	0%	57,00	10%	58,70	9%
PP	40,9	6%	443,70	82%	456,40	72%
PVC	19,1	3%	0,00	0%	0,00	0%
nylon	1,7	0%	0,00	0%	0,00	0%
composite polymers	645,6	90%	0,00	0%	68,60	11%
generic plastics	10,4	1%	43,10	8%	53,20	8%
PAPER	**23,0**	**3%**	**63,8**	**11%**	**89,00**	**12%**
cardboard	0,0	0%	42,3	66%	42,30	48%
medical paper	23,0	100%	21,5	34%	46,70	52%
CELLULOSE	**0,0**	**0%**	**0,0**	**0%**	**28,00**	**4%**

Table 6 - Quantitative comparison of different case studies according to the materials making up non-contaminated waste.

critical element is described in detail, together with the relative issue and the product categories involved.
The analysis of international case studies showed that many existing solutions are currently adopted to answer the identified problems: in some cases, solutions are effective while in others they try to provisionally and partially meet the requirements. So, for each requirement, any existing options have been indicated, along with the possible solutions that could improve the products from a design perspective.
Specific guidelines for haemodialysis products have then been defined, starting from the product requirements based on the presented analysis (see chapter 4).

3.2 Equipment

Because of its cost and complexity, the dialysis equipment is designed for a global market and can perform different types of treatment, adapting to different contexts and infrastructures.
For this reason, the research has started from the **analysis of the main equipment present in the market**, then to focus the analysis on a specific equipment.
FRESENIUS 5008, by Fresenius Medical Care, has been chosen as a valuable example of a commonly used dialysis machine.
The analysis of the dialysis equipment has concentrated on components and materials (disassembly analysis), the type and ease of access to the device by different users (accessibility and interaction), and the definition of inputs and outputs (flows analysis).
The study was performed in collaboration with the **team of the San Luigi Gonzaga Hospital** (Department of Clinical and Biological Sciences, University of Torino) and the team of the **Department of Mechanical and Aerospace Engineering (Politecnico di Torino**). Technicians from **ACTEM S.r.l. (partner of Fresenius Medical Care**) provided technical advice on the equipment.

3.2.1 Existing solutions of haemodialysis equipment

OPERATION PRINCIPLES

The dialysis equipment is an artificial kidney that performs most kidney functions for patients with chronic renal failure (cf. the principles of the haemodialysis treatment on par. 2.1.1).
The equipment aims at creating and monitoring the dialysate, which is the fluid that allows cleansing the blood from toxins while getting electrolytes, pH, and minerals concentration to the proper level.
A common issue of patients with renal failure is water retention: the equipment removes the water in excess from the patient's blood, according to the set quantity. Lastly, the equipment has to monitor the blood flow within the extracorporeal circuit.

SUPPLY

	CRITICAL ELEMENTS	ISSUES	PRODUCT: PACKAGING	PRODUCT: DISPOSABLES	EQUIPMENT	TREATMENT	EXISTING SOLUTIONS	POSSIBLE SOLUTIONS
Functionality	**Problems of management of secondary pack within small warehouses** (packaging are bulky, devoid of points of support, and it is difficult to pick up the products)	Supplies should be divided into several stores and repositioned every day	● *Pack for transport*			●	no	> Functional improvement of packaging > Design of logistics and warehouse storage systems
Functionality	**Staff must make a physical effort** to pick up and move the products for daily therapies.	Pain associated with the use of hands and fingers under stress	● *Pack for distribution* *Pack for treatment*			●	Use of trolleys	> Reduction in size and weight of packaging and products > Optimizing daily supply procedures
Sustainability	**Short life cycle of secondary packaging**, especially pre-assembled kit and pack with few primary pack inside	High consumption of primary resources and large volumes of waste to be disposed	● *Pack for transport*				Reusing undamaged boxes in offices, using new labels created specifically (Malmö SUS)	> Charging systems aimed at a more efficient storage
Sustainability	**Oversize of secondary packaging**, often due to the use of standard boxes	Waste of space during transportation and storage	● *Pack for transport*				Design of new packaging (eg. Gambro's cartridges packaging)	> Design for reuse and customization > Design of more flexible standard pack

TREATMENT

	CRITICAL ELEMENTS	ISSUES	PRODUCT: PACKAGING	PRODUCT: DISPOSABLES	EQUIPMENT	TREATMENT	EXISTING SOLUTIONS	POSSIBLE SOLUTIONS
Functionality	**Need for space to lay and leave products for the end of treatment** (eg. disconnection kit)	Need to use a transport trolley or to place the products on the machine			●	●	Use of small spaces present on the equipment, even if not especially designed	Predisposition of systems for containing and supporting products
Sustainability	**Oversize of primary pack**, especially bags and overpackaging	Waste of material resources and waste of space during storage	● *Pack for distribution* *Pack for treatment*				no	> Study of specific solutions > Packaging adaptable to different formats
Sustainability	The **AVF connection/disconnection kits** often include accessory products that, if not used, cannot be stored	New products, that may still be usable, must be thrown away	● *Pack for distribution*	●		●	Study of the real needs and creation of specific kits (eg. Frederiksberg Hospital)	> Customization of kits > Multipacks
Functionality	The **connection of the bloodline, tubing and bag system requires additional effort** for nursing staff	Pain associated with the use of hands and fingers under stress			●	●	Semi-automation of the procedure of bloodline set-up	> Automation of procedures > Different layouts of machine components
Functionality	In some cases the **connection component between fistula needle and bloodline is difficult to separate** due to the heat of blood	Problems during patient's disconnection		●	●		Auto set-up of bloodiline and peristaltic pumps	Evaluate the use of alternative materials
Functionality	The **overpackaging represent a further effort** for nursing staff (fingers, wrists and hands are prone to muscle / bone pain over time)	Pain associated with the use of hands and fingers under stress	● *Pack for distribution*				Use pliers to force disconnection	> Easy-opening systems > Reduction of overpackaging to open
Functionality	**Difficulty in removing adhesive labels** for the compilation of patient records (if required by the hospital - eg. Malmö SUS)	Low usability for the completion of the reporting on the treatment	● *Pack for distribution* *Pack for treatment*		●	●	no	> Automatic identification of the product > Digital reporting/possibility to print data on patients and treatment

DISPOSAL

	CRITICAL ELEMENTS	ISSUES	PRODUCT: PACKAGING	PRODUCT: DISPOSABLES	EQUIPMENT	TREATMENT	EXISTING SOLUTIONS	POSSIBLE SOLUTIONS
Functionality	**The automatic system of emptying bags requires more than 20 minutes** to complete the process (eg. Gambro Artis)	Often the staff does not have time to wait for the system to finish emptying	● *Pack for treatment*		●		no	> Design automatic systems for faster emptying > Allow manual emptying

Sustainability	**Residual fluids are difficult or impossible to empty** (acid concentrate, saline solution, priming solution)	Increased weight of waste and disposal costs. Possible problems in recycling	● *Pack for treatment*		●		> The machine empties the bags from liquids (it takes considerable time) > Manual emptying of liquids (special precautions for the acid solution)	> Design automatic systems for faster emptying > Allow manual emptying
Sustainability	**Residual materials are difficult or impossible to empty** (bicarbonate)	Increased weight of waste and disposal costs. Possible problems in recycling	● *Pack for treatment*		●		no	> Make the cartridge openable after use > Design breakage areas in disposable pack
Functionality	**Lack of space in the wards for waste collection**	The distance from the recycling bins discourages waste sorting				●	Vertical set of recycling bins	Design of waste compactors to reduce volumes and optimize recycling bins
Sustainability	**Recurring errors in waste sorting**	Problems in recycling	● *Pack for distribution* *Pack for treatment*	●	●		Customized placards (Frederiksberg Hospital) and manual (Malmo SUS) for waste sorting	> Make materials clearly recognizable > Design for quick disassembly
Sustainability	**Different materials are difficult to recognise** in the disposal stage (little use of product label)	Difficulties in disposal and increase of unsorted waste	● *Pack for distribution* *Pack for treatment*	●			no	Improve the communication about disposal and end of life
Sustainability	**Different materials are often difficult to separate and properly recycle**, especially multi-material packaging	Difficulties in disposal and increase of unsorted waste	● *Pack for distribution* *Pack for treatment*	●			no	> Prefer mono-material packaging > Promote material separation through shapes, connections and visual communication
Sustainability	**Wide use of composite polymers that are difficult to recycle**	Difficulties in disposal and increase of unsorted waste	● *Pack for treatment*	●			no	Evaluate the use of alternative materials
Sustainability	**The pre-assembled kits for home hemodialysis can't be separated at end of life**	Difficulties in disposal and increase of special hazardous waste	● *Pack for treatment*	●	●	●	no	Make in-center machine easier to use even by non-expert users

Table 7 – Product requirements

Overall, it is possible to divide the machine operation into three main tasks:

1. **Manage and monitor the extracorporeal blood circulation.** The equipment continuously pumps blood from the patient's fistula into the tubing set to reach the dialyzer. Patient's pressure is checked upstream and downstream the peristaltic pump. Before the blood enters the dialyzer, the heparin pump releases an anticoagulant to avoid blood clotting. The blood enters the dialyzer, where the equipment maintains a pressure gradient across the membrane to ensure the right flow of compounds from the blood to the dialysate, and vice-versa. After blood filtration, an air trap removes any air bubbles before the blood is returned to the patient. Furthermore, the equipment monitors the blood pressure and the oxygen saturation throughout the treatment.

2. **Mix and monitor the dialysate flow**. In some cases, the dialysate can be premixed to be directly used. However, the equipment is usually responsible for creating the dialysate by mixing bicarbonate solution, acid concentrate, and warm deionized water (purified by reverse osmosis) to the proper concentration. During the whole treatment, fresh dialysate is pumped through the dialyzer. The pressure and conductivity of the used dialysate bath are continuously monitored, and special sensors detect any air bubbles. The dialysate can be purified and reused again within the same treatment, before being disposed of as black water. A heat exchanger recovers dialysate heat.

3. **Sterilize the internal circuits**. After each treatment, the equipment must be sterilized. The cleansing process can be done by thermal sterilization (hot water flows through the closed system to flush away all impurities) or chemical sterilization (chemicals are entered into the circuit and are run within the system).

EXISTING SOLUTIONS

The goal of the benchmarking analysis is to define the most common haemodialysis machines, to find a representative case study to analyse in detail (Table 8). The comparison started from identifying the most important manufacturers and the related machines. For each machine, the methods performed and the main features were reported; moreover, it has been indicated if it was a **"compact" system** (mainly used for home haemodialysis) or a **"full" system** (able to efficiently perform one or more type of dialysis treatments). It was also reported which a**ncillary products** are produced by the manufacturer, to understand which machines are designed together with the disposable products to perform the treatment, and which ones are designed to be compatible with the existing products.

The benchmarking analysis highlighted that most machines are designed for **in-centre haemodialysis** (14 out of 18 are full-system equipment) and can perform a broad range of dialysis treatments (Table 9). Regarding shape, **all machines are large-sized** and have a narrow and elongated shape, including a wide touchscreen monitor for managing the treatment parameters. From an operational point of view, in most cases, the **priming process is automatized**, and all machines are compatible with products from different brands. Compact-system machines (4 out of 18) are small-sized and have no monitor so that they take up the least amount of space in a home environment. They only perform haemodialysis or, in some cases, hemofiltration, and are designed to be easily set up by non-expert people.

Table 8 - Benchmarking analysis of the existing haemodialysis machines

COMPANY	MACHINE	TREATMENTS	MAIN FEATURES	ANCILLARY PRODUCTS
ASAHI KASEI Japan	**MDS-101** F	- Hemodialysis	Good accessibility to the inside of the machine.	- dialyzer - bloodline - needle set
BELLCO Italy	**FLEXYA** F	- Hemodialysis - Hemofiltration - Hemodiafiltration - Single Needle - Mid-Dilution - PHF - BD (SN, DN)	Simplicity and automation. The widest possible range of treatments.	- dialyzer and filters - Fistula needles - bloodlines and tubing systems - acid concentrate - water treatment"
	FORMULA THERAPY F	- Hemodialysis - Hemodiafiltration - Hemofiltration	Accurate and flexible, with a wide range of treatments.	
BRAUN Germany	**DIALOG IQ** F	- Hemodialysis - Hemofiltration	System intelligence in medical devices (data exchange)	- dialyzer and filters - fistula needles - bloodlines and tubing systems - concentrates and solutions - disinfectants - water treatment
	DIALOG+ F	- Hemodialysis - Hemofiltration - Hemodiafiltration - Single Needle	Three basic device configurations and many treatments available.	
FRESENIUS Germany	**5008/5008S** F	- Hemodialysis - Hemodiafiltration - Paediatric dialysis - Mixed HDF	ONLINE concept to ease the labour-intensive priming and post-processing steps.	- dialyzer and filters - fistula needles - bloodlines and tubing systems - concentrates and solutions - disinfectants - water treatment - therapy support (Body Composition Monitor)
	4008S F	- Hemodialysis - Single-needle - Ultrafiltration and sodium profiles	cardioprotective haemodialysis; cost-efficiency.	
	2008/2008K@HOME (USA only) C	- Hemodialysis - Single-needle - Home Hemodialysis	Fresenius Clinical Data Exchange (CDX). Home dialysis.	
GAMBRO/BAXTER USA	**ARTIS PHYSIO SYSTEM™** F	- Hemodialysis - Hemodiafiltration	Individualized Quality-assured Dialysis.	- dialyzer and filters - fistula needles - bloodlines and tubing systems - concentrates and solutions - disinfectants - water treatment

	AK 200™ ULTRA S	- Hemodialysis - Hemodiafiltration - Hemofiltration	On-line HDF/HF treatments.	
GAMBRO/BAXTER USA	**AK 96™/ AK 96™ SELF-CARE** C	- Hemodialysis - Home hemodialysis	Compact; cost-efficiency. Fully integrated set-up.	
	PHOENIX® F	- Hemodialysis	No risk of cross-contamination between patients; low-volume design.	
NIKKISO Japan	**DBB-27** F	- Hemodialysis	Compact	- dialyzer - bloodlines and tubing systems
	DBB-05 F	- Hemodialysis - Hemofiltration - Hemodiafiltration - Single Needle	More treatment options, highly functional and value enhanced model	
	DBB-06 F	- Hemodialysis - Single Needle	Easy to read for better operations	
	DBB-07 F	- Hemodialysis - Hemofiltration - Hemodiafiltration - Single Needle - Acetate free biofiltration	Newly developed for high quality therapies	
NX STAGE USA	**SYSTEM ONE** C	- Hemodialysis - Hemofiltration - Home hemodialysis	Simplicity, flexibility and portability without compromising safety.	- dialyzer & filters - fistula needles - bloodlines and tubing systems - dialysate - portable water treatment - eHealth support
	SYSTEM ONE S (+ NxView Simplicity) C	- Hemodialysis - Hemofiltration - Home hemodialysis	Wider ranges of therapy options are available.	

F FULL SYSTEM C COMPACT SYSTEM

HAEMODIALYSIS EQUIPMENT		
TYPES	**Full system (14/18)**	**Compact system (4/18)**
FEATURES	- wide range of treatments - high quality - wide monitor for setting parameters - big dimensions - compatible with different products (and brands) - automation of priming	- 1-2 types of treatments - cost-efficiency - small smonitor or no monitor - small dimensions - use of specific products - easy to set up
APPLICATION	- Hemodialysis - Hemofiltration - Hemodiafiltration - Single Needle treatments - Other special treatments	- Home hemodialysis - Home hemofiltration
ANCILLARY PRODUCTS	- All producers manufacture their own filters and tubing systems - Biggest producers have all types of ancillary products - Many producers don't provide bicarbonate concentrate - There are several compatible ancillary products for the most used machine	

Table 9 - Results of the benchmarking analysis

In all cases, companies manufacture filters and tubing systems for their machines, while different suppliers produce the other ancillary products.

Overall, the benchmarking identified **7 global manufacturers** and only **8 machines** that are able to perform the three most important type of dialysis treatment (haemodialysis, hemofiltration, and haemodiafiltration).
Among these, Fresenius Medical Care agreed to make an equipment available for the disassembly analysis, while also providing technical support during the entire study. Therefore, the research focused on the **case study of Fresenius 5008**, that has been analysed in detail through a disassembly analysis.

3.2.2 Equipment assessment through a disassembly analysis

The chosen method to analyse the haemodialysis equipment is based on a well-defined methodology, which has already been applied to several projects concerning the home environment and household appliances (Fiore et al., 2016). The method combines the approaches of **Design By Components** (Bistagnino, Virano, & Marino, 2008) and **Design for Disassembly** (Bogue, 2007): the disassembly deeply affects the end of life of a product, by increasing or hampering the possibilities of reusing or recycling the product and its components.
From a system thinking perspective, this approach can **go further the end of life, focusing on the whole life cycle**. The exploration of the components (materials, connections, operation, layout) and the interaction of the user(s) with the product (needs and procedures), allows improving usability, maintenance, and disassembly. Systemic Design shapes the product starting from the relationship between the components and the users, taking into account the material flows that occur within a specific context (inputs and outputs). So the application of a methodology based on Systemic Design enables to understand the main environmental and functional issues of a complex product, so as to identify its actual requirements and define possible solutions to solve them.

The complex nature of a biomedical equipment exceeds many other products, from a technical, regulatory and ethical point of view. The analysis of this kind of machine must face many challenges: first, it is a product that is not commonly used in the daily life, so designers need to **acquire specific**

technical skills and lexicons to understand its functioning. Secondly, biomedical companies spent many years developing, testing and patenting the **components** of the medical equipment, which are therefore **not easily replaceable** with other solutions. Thirdly, every modification of the equipment affects the c**omplex system of ancillary products** that are needed within the treatment. Lastly, **a medical device takes from 3 to 7 years before being placed on the market** (Fargen et al, 2013; Christin, 2012), this is not only due to its design complexity but also because every change requires new medical testing and approvals. The more it will change, the longer it will take to fulfil all the conditions and get on the market. For these reasons, the equipment analysis, unlike other sectors, aimed at reaching a better understanding of components and material flows to identify layout and functioning requirements, while **leaving the current components unchanged**.

When dealing with other products, the analysis takes into account the product as a whole. The complexity of medical equipment requires a first step to **divide the product into several macro-components** according to their function. Then each macro-component is individually analysed. Fresenius 5008 has been divided into nine macro-components (Figure 9), according to their function and position.

Electrical macro-components:

1. *Monitor*. It includes the touchscreen monitor, the movable arm which allows to move it, the alarm system, and the card reader to identify patients and staff.
2. *Computer*. It contains the main electronic system which controls the operation of the equipment.

Blood circuit macro-components:

3. *Extra-Corporeal Blood Circuit Module (EBM)*. It is responsible for the blood circulation within the tubing system; it includes blood pumps, heparin pump, bloodline clamps, blood flow monitors, and pressure monitors.

Hydraulics macro-components:

4. *Hydraulics Back + Front*. It represents the biggest hydraulics macro-component and it contains several components aimed at creating the dialysate bath and managing the blood-filtering procedure.
5. *Hydraulics Left Door*. It manages the supply of bicarbonate.
6. *Hydraulics Bottom left*. It contains the ultrafiltration pump, and it is responsible

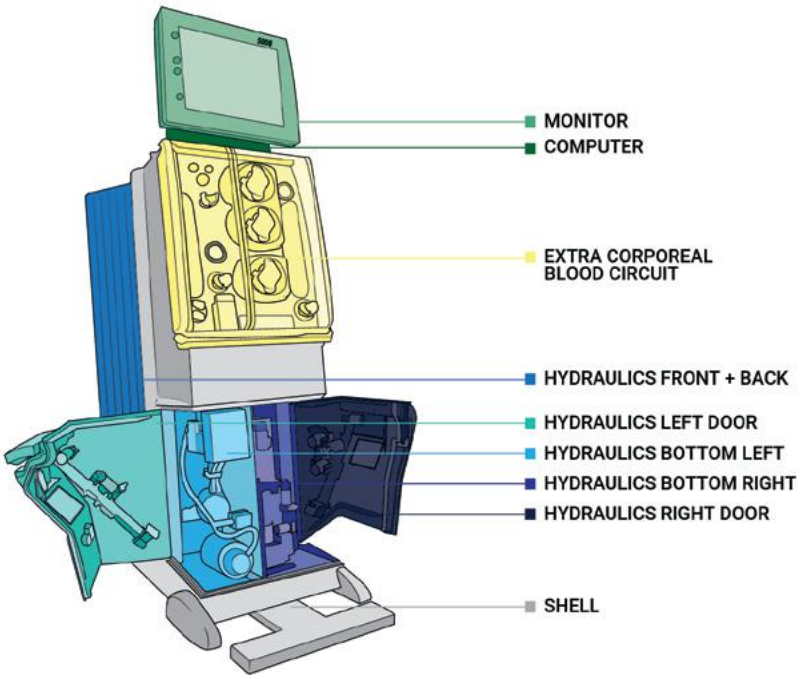


Fig. 9 - Macro-components of Fresenius 5008

for pumping the concentrates in the mixing chamber.

7. *Hydraulics Right Door*. It manages the supply of acid concentrate.
8. *Hydraulics Bottom right*. It includes the dosing and the mixing chamber, which are aimed at mixing the concentrates and the purified water.

Protective macro-components:

9. *Shell*. It includes all the components aimed at containing the other macro-components and providing structural rigidity and strength to the equipment.

The detailed analyses of the macro-components are included in Annex I.

DISASSEMBLY ANALYSIS

In the first part of the analysis, each macro-component has been completely disassembled. Each sub-component has been identified by an identification code that designates its function and the sequential number (e.g. CD1 = Conductivity Cell n. 1; or H02 = Hydraulics component n.2).

The Disassembly Analysis (Figure 10) aims at reaching some important goals:

- **Full understanding of the equipment operation** and the components which make it up.
- **Identifying the components that are easier or more difficult to disassembly**, especially focusing on the type of joints (reversible or irreversible). All tools needed for disassembly are reported since they can contribute to making disassembly more difficult. The ease of disassembly is graphically represented through a basic colour coding (green – easy, orange – medium, red – hard) that allows identifying the most critical components, while the tools are represented with the help of icons.
- **Defining the material composition of the dialysis equipment**, so as to understand the easiness of separating different materials for recycling. A summary table shows, for each component (identified by its code), the materials that make it up and their relative

ANALYSIS CRITERIA

EASE OF ASSEMBLY

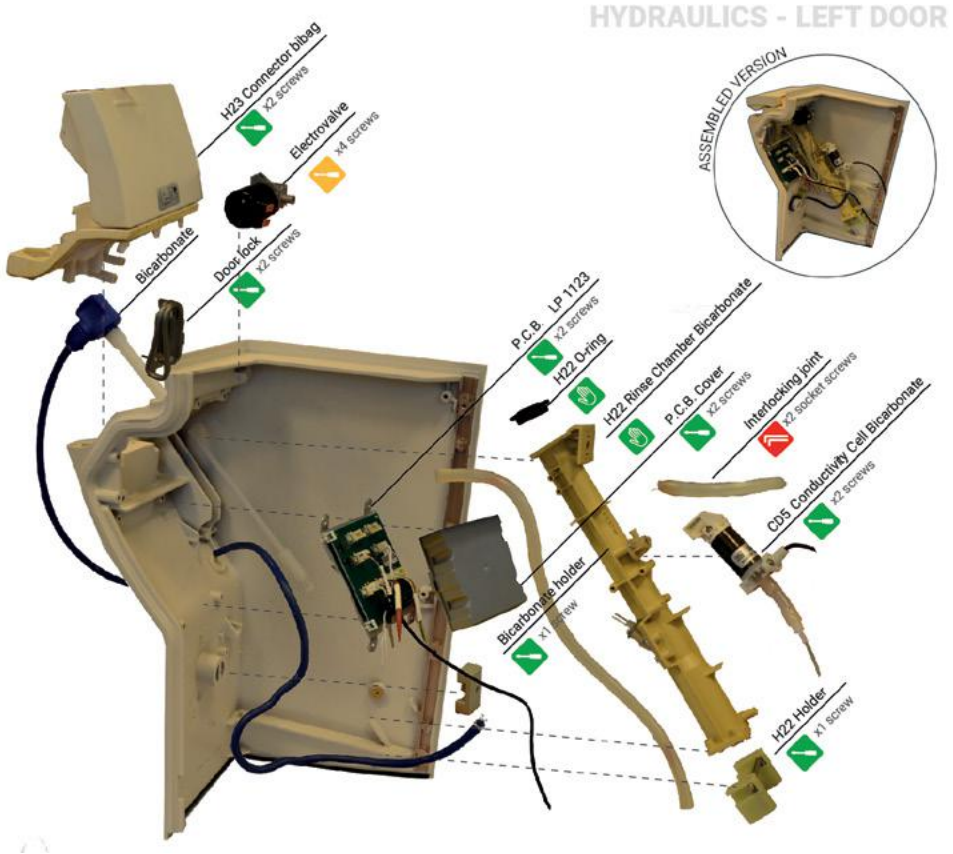
- easy
- medium
- hard

DISASSEMBLY TOOLS

- by hand
- screwdriver (11)
- hex key (2)
- wrench
- hammer
- tongs (2)

WEIGHT AND MATERIALS

COMPONENT	gr	material
Door	1366	PUR
Door locker	60	metal
H23	608	plastic mix + metal
LP1123	108	WEEE
LP1123 cover	43	PP
Electrovalve	170	WEEE
H22	198	plastic + metal
H22 Holder	45	PA66 + metal
O-ring	4	rubber (EPDM)
CD5	90	WEEE
Bicarbonate inlet	135	plastic mix + rubber
Bic. inlet holder	11	plastic
TOTAL	2838	



CATEGORY	WEIGHT	MACRO-COMPONENT	WEIGHT
	gr		*gr*
BLOOD CIRCUIT	15,976	EBM - inner	7,653
		EBM - outer	8,323
ELECTRONICS	18,001	COMPUTER	11,237
		MONITOR	6,764
HYDRAULICS	42,587	HYDRAULICS RIGHT DOOR	4,328
		HYDRAULICS BOTTOM RIGHT	4,671
		HYDRAULICS LEFT DOOR	2,838
		HYDRAULICS BOTTOM LEFT	4,909
		HYDRAULICS BACK	21,402
		HYDRAULICS FRONT	4,439
HYDRAULICS	26,201	SHELL	26,201
		TOTAL	**102,765**

Table 10 - Weight assessment of the equipment macro-components

weights. This allows defining which are the single-material components and the multi-material ones, and which are not recyclable or have to be separately sorted (e.g. WEEE). So it is possible to understand which materials make the equipment up and in what quantity.

Overall, the Disassembly Analysis identified the most critical issues regarding environmental sustainability, considering both the maintenance of the equipment (ease of replacement, ease of separation of sub-components) and the disposal at the end of its useful lifespan (ease of disassembly different components and materials).
First of all, the presence of **several types of fasteners** make the disassembly more difficult: interlocking is often combined with screw fastening, clamps and other interlocking elements are very hard to remove. The use of **different screws** requires several tools, and this is due to the lack of standards for suppliers.
Moreover, components are grouped into units that take time to be disassembled, because of the high number of screws and fasteners. Lastly, the **little information about materials** does not support technicians in recycling faulty or deteriorated components. The overall weight of the equipment is 102.7 kg: as shown in Table 10, the **hydraulics macro-components** account for the 41%, requiring most of the space and the weight of the equipment.

Fig. 10 - Example of the disassembly analysis of a macro-component

As regards materials (Table 11), there are **few mono-material components** (31% in weight, mainly made in PUR, ABS, Iron, and Aluminium) that are mostly shell parts and cover elements.
The major part of components is made of **composite materials or different materials jointed together** (25%) and **WEEE** (44%), that have to be disposed of apart.
All these qualitative and quantitative issues has contributed to define the equipment requirements (par. 3.2.3).

MATERIAL CATEGORY	WEIGHT		MATERIALS	WEIGHT
	gr	*%*		*gr*
PLASTICS	23,607	23%	PUR	19,297
			PP	955
			PE	50
			PES	40
			ABS	2,824
			PC	430
			Other plastics	11
COMPOSITE/MIXED POLYMERS	25,340	25%	-	-
METALS	8,481	8%	IRON	5,570
			ALUMINIUM	2,587
			OTHER METALS	324
WEEE	45,337	44%	-	-
			TOTAL	**102,765**

Table 11 - Weight assessment of the materials making up the equipment

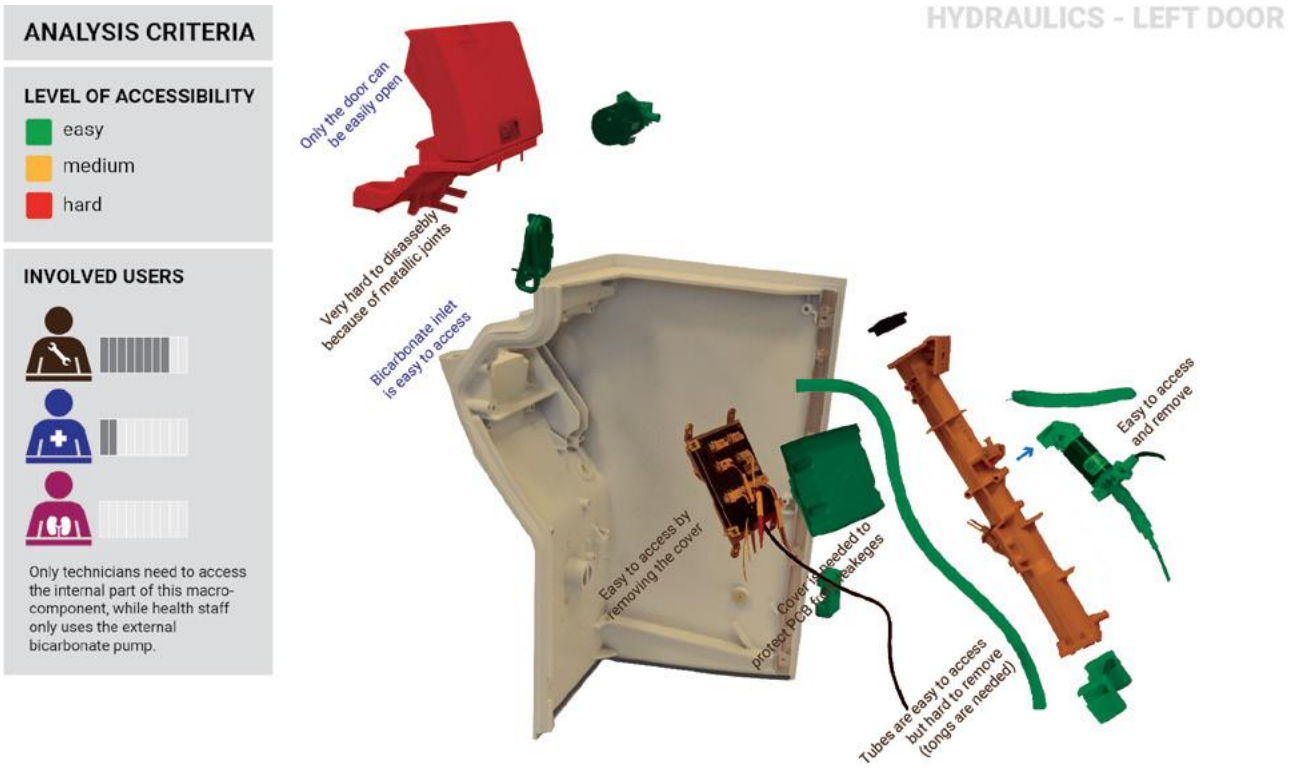
Fig. 11 - Example of the accessibility analysis of a macro-component

ANALYSIS OF ACCESSIBILITY AND INTERACTION

The second part of the analysis aims at defining the ease of access to macro- and sub-components by different users (technicians, health staff, patients).

As shown in Figure 11, the colour coding is the same of the Disassembly Analysis (green – easy, orange – medium, red – hard). However, it does not identify one single component but groups of components according to their function. The analysis of accessibility, carried out during disassembly, is verified by the on-the-field analysis that takes into account treatment routines (healthcare staff and patients) and routine preventive maintenance (technicians). The comparison allows **understanding the frequency and the use of different groups of components**. This analysis aims at establishing a hierarchy regarding accessibility to functional components, by comparing the component functionality with the ease of access. The difficulties in gaining access to some components that health staff must use every day represent a design problem to solve. Conversely, the difficult access to some delicate internal components improve machine safety and must be taken into account also in future projects. Previous works have been considered to integrate the analysis, aiming at addressing all the possible interaction issues related to the equipment. Most factors of patient injury are due to clinical issues, such as poorly implemented policies and procedures (Garrick, Kliger, & Stefanchik, 2012). However machine design flaws can also affect nurses' operations and, consequently, patient safety: in particular, the inadequate equipment disinfection and (Holley, 2006) a poorly designed human-machine interface (Kliger, 2015) can have a negative impact on patient outcome and safety.

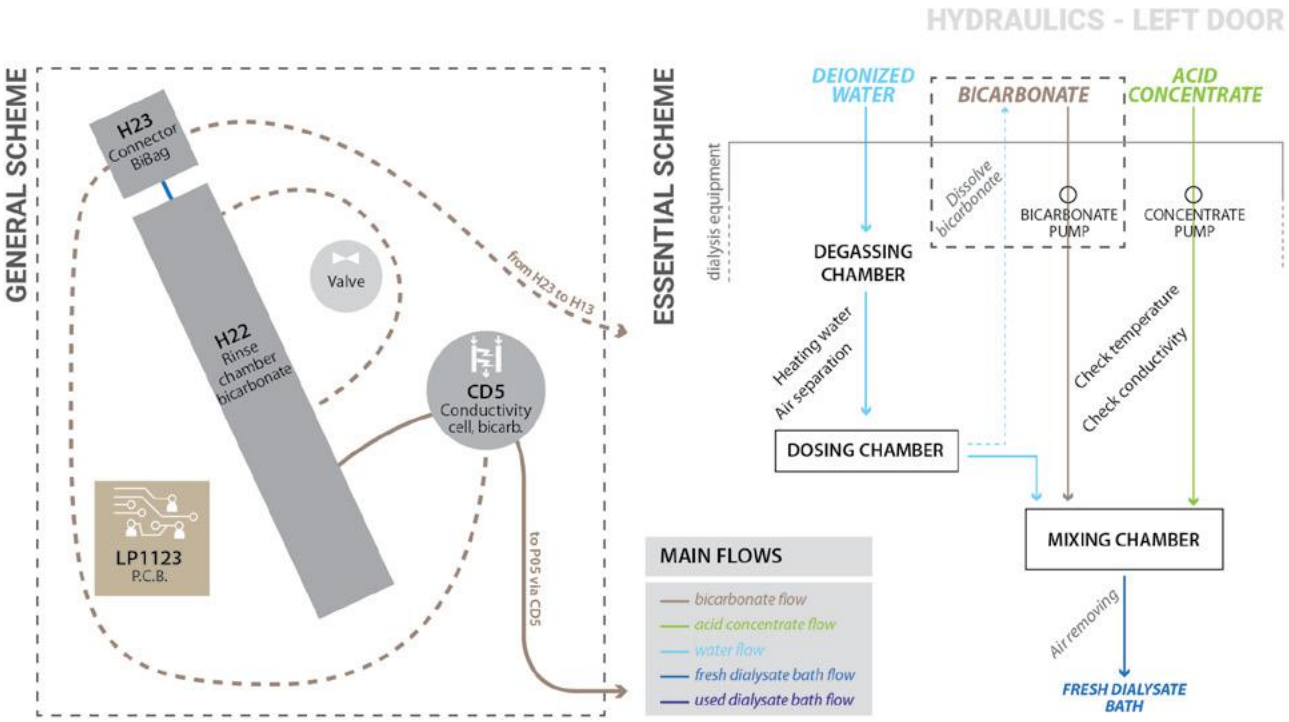
Fig. 12 - Example of the analysis of the input-output flows



Overall, **the accessibility problems mainly affect maintenance**. Many internal components are not easily accessible because of the complexity of layout and the position of screws. The use of protective foams does not provide effective protection to electrical components and makes them more difficult to access.

ANALYSIS OF INPUT-OUTPUT FLOWS

The analysis of the inputs and outputs of the process aims at highlighting critical issues and potentialities from the points of view of



environmental sustainability and usability. The analysis is usually carried out through the creation of a **general scheme**, which sums up flows and functions of the product. Then, an **essential scheme** is designed to simplify the product features, stressing the main components and flows. When dealing with medical equipment, the definition of general and essential schemes (Figure 12) is possible but considerably more complex; therefore, two intermediate steps are needed. Individual general schemes are defined for each macro-component, adopting the alphanumeric codes used in the Disassembly Analysis. This visualization shows the current layout of components, allowing designers to gain a better understanding of the current situation and share it with the other members of the design team. Then, it is possible to define an essential scheme for each macro-component, going beyond the original layout. The general and essential schemes of all macro-components are included in Annex I.

The sum of all the essential schemes is an **overall essential scheme** of the medical equipment, which integrates the functions of the ancillary products (Figure 13).

In some macro-components, ancillary products are external to the equipment: for example, the Extra-Corporeal Blood Circuit Module employs filters and arterial-venous bloodlines that, because of technical and sanitary issues, have to be disposable. The equipment manages these single-use components through peristaltic pumps and temperature sensors. The scheme goes beyond the current layout and shape of the equipment to **highlight the essential flows and components that make up the equipment**.

This representation allowed identifying specific problems of layout and usability. Indeed, the position of some components forces the pathway of the hydraulics flows, at the same time, the component layout is often in contrast to the logical and natural flow of inputs-outputs. This kind of problems is probably due to settled design habits, that lead designers not to assess alternative layout solutions.

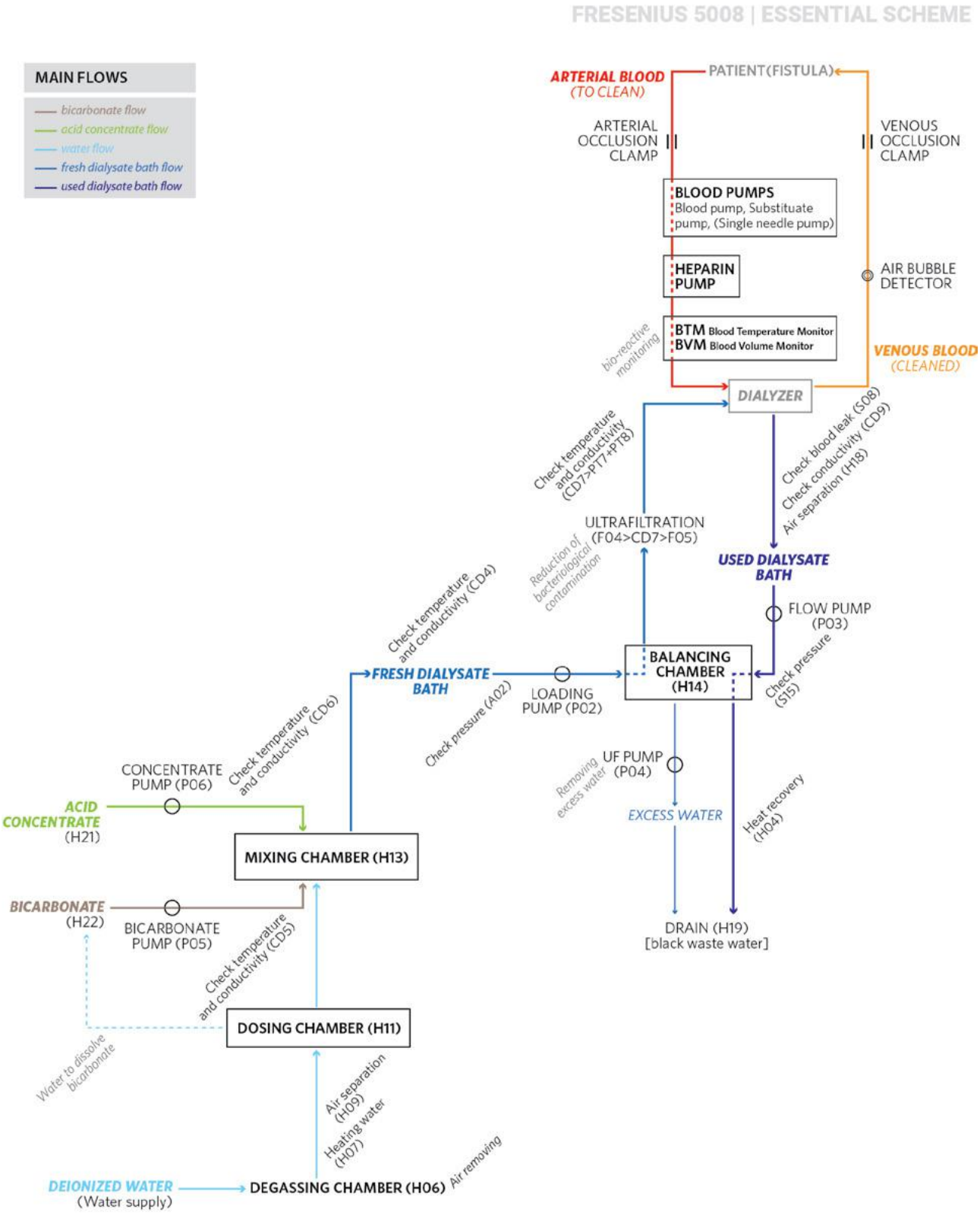
3.2.3 Equipment requirements

The disassembly analysis (par 3.2.2) identified the principal issues that affect the functionality and sustainability of the haemodialysis equipment.

As for the product requirements, all the issues have been identified and divided according to the treatment phase, including also the maintenance of the equipment. Moreover, issues can affect three areas: technical functionality, sustainability, and usability (Table 12).

Each critical element is described in detail, together with the related **issue**, and the **system items involved**. The case studies analysis showed that many **existing solutions** had been already adopted to answer the identified problems: in some cases, these **solutions** are effective while in others they partially meet the requirements. Further options have been presented.

Fig. 13 - The overall essential scheme of FRESENIUS 5008


FRESENIUS 5008 | ESSENTIAL SCHEME
MAIN FLOWS
bicarbonate flow
acid concentrate flow
water flow
fresh dialysate bath flow
used dialysate bath flow
ARTERIAL BLOOD (TO CLEAN)
PATIENT (FISTULA)
ARTERIAL OCCLUSION CLAMP
VENOUS OCCLUSION CLAMP
BLOOD PUMPS
Blood pump, Substituate pump, (Single needle pump)
HEPARIN PUMP
AIR BUBBLE DETECTOR
bio-reactive monitoring
BTM Blood Temperature Monitor
BVM Blood Volume Monitor
VENOUS BLOOD (CLEANED)
DIALYZER
Check temperature and conductivity (CD7>PT7+PT8)
Check blood leak (S08)
Check conductivity (CD9)
Air separation (H18)
ULTRAFILTRATION (F04>CD7>F05)
Reduction of bacteriological contamination
USED DIALYSATE BATH
FLOW PUMP (P03)
Check temperature and conductivity (CD4)
FRESH DIALYSATE BATH
LOADING PUMP (P02)
BALANCING CHAMBER (H14)
Check pressure (A02)
Check pressure (S15)
Removing excess water
UF PUMP (P04)
EXCESS WATER
Heat recovery (H04)
CONCENTRATE PUMP (P06)
Check temperature and conductivity (CD6)
ACID CONCENTRATE (H21)
MIXING CHAMBER (H13)
BICARBONATE (H22)
BICARBONATE PUMP (P05)
Check temperature and conductivity (CD5)
DRAIN (H19) [black waste water]
DOSING CHAMBER (H11)
Water to dissolve bicarbonate
Air separation (H09)
Heating water (H07)
DEIONIZED WATER (Water supply)
DEGASSING CHAMBER (H06)
Air removing

SUPPLY AND SET-UP

	CRITICAL ELEMENTS	ISSUES	PRODUCT: PACKAGING	PRODUCT: DISPOSABLES	EQUIPMENT	TREATMENT	EXISTING SOLUTIONS	POSSIBLE SOLUTIONS
Sustainability	**Difference of supply according to the dialysis unit organisation** and technologies/supply management of bicarbonate, acid concentrate (and NaCl, where needed)	The equipment shall be adaptable to on-line system, as well as feed systems and single dose products	● *Pack for transp*		●	●	The equipment includes components that allow to adapt it to different systems, which are often not used	> Design the equipment according to a Design by Components logic > Make it customizable
Functionality+ Sustainability	**Main use of single-use products,** especially for bicarbonate and acid concentrate	Greater physical effort in product handling and equipment set-up + greater waste of residual materials	● *Pack for distribution* *Pack for treatment*		●	●	Centralised on-line system	> Optimization of weights and volumes of single-use products and packaging > Encourage the choice of a centralized on-line system
Functionality	**Effort required from staff to set-up the equipment** with hand and fingers strain	Risk of occupational diseases	● *Pack for treatment*		●		Partial automation of bloodlines set-up	> More tiring actions (patient connection/disconnection) shall be automized > Imporve pack and product usability
Functionality	**Low interactivity of patients,** that can only check their own weigth and blood pressure, and set up few parameters	Obstacle to the spread of home or semi-assisted dialysis	● *Pack for treatment*		●	●	There are some devices for home dialysis but are poorly effective	> Equipment and products should be easily operated by less expert users

TREATMENT

	CRITICAL ELEMENTS	ISSUES	PRODUCT: PACKAGING	PRODUCT: DISPOSABLES	EQUIPMENT	TREATMENT	EXISTING SOLUTIONS	POSSIBLE SOLUTIONS
Functionality	**Need of space for all personal items and for products needed at the end of the treatment** (e.g. disconnection kit)	Need of trolleys or bearing components of the equipment			●	●	Use of small spaces present on the equipment, even if not especially designed	> predisposition of systems to hold and place personal and medical objects
Functionality	**Need of space to connect the patient to the equipment** and check the proper functioning of the treatment steps	Need for operating space of sufficient size even in small dialysis units	● *Pack for distribution* *Pack for treatment*				Vertical equipment to help reduce machine space by the bedside	> layout innovation
Functionality	**The connection of products/pack to the equipment is not optimal** for health staff, in particular bicarbonate and acid concentrate	Transportation systems alongside the bed and discomfort in connection phases	● *Pack for distribution*	●		●	none	> Improve pack and product design > Improve equipment design
Functionality	Ineffectiveness of systems for home dialysis: **non-specialized users and patients need to use the in-center machines**	The complexity of set-up reduces the number of patients suitable for home treatment			●	●	Training of the most experienced patients in the use of existing machinery	Design a better interaction of in-center machines
Usability	**Using outdated interfaces**	More possibilities for error, less autonomy of the patient			●	●	no	Design a more effective UI, even for non-expert users (home dialysis)
Usability	**Entertaiment is delegated to the ward or to the patients** through personal devices (e.g. TV in the dialysis room, personal tablets or smartphones)	Boredom and impatience of the patient during the treatment		●	●	●	no	> Incorporate entertainment systems into the machine > Allow the connection of personal devices
Usability	The patient and the medical staff **look at the monitor screen from different heights**	The patient's view is penalized		●		●	Use of a movable arm which can not be adjusted in height	> Redesign the functionality and the layout of the display system
Usability	**Continuous view of the blood** during the whole treatment by the patient	Lack of choice and possible apprehension	● *Pack for distribution*				no	> Design alternative solutions available to the bloodlines and tubing system

MAINTENANCE

	CRITICAL ELEMENTS	ISSUES	PRODUCT: PACKAGING	PRODUCT: DISPOSABLES	EQUIPMENT	TREATMENT	EXISTING SOLUTIONS	POSSIBLE SOLUTIONS
Functionality	**The components that are most subject to wear and breakage are placed in the lower part of the machine** (due to the risk of leaks of the hydraulic system)	It is required a greater effort in maintenance and replacement operations			●		Where possible, it is provided a lift truck for the technicians	Design the layout of the components with a special view to maintenance

Usability	**Machine can not be elevated** during maintenance	Uncomfortable and wrong postures in maintenance operations			●		no	Evaluate the use of alternative materials
Functionality	**Inaccuracies in the self-diagnosis system** of the machine	Possible errors or difficulties in maintenance			●		Registration of frequent errors and improvement in subsequent releases	Registration of frequent errors and improvement in subsequent releases
Sustainability	**Difficult to remove and replace some components** (heat exchanger, occlusion clamps, etc.)	Difficulties in maintenance operations and disposal			●		no	Communicate the necessary information for maintenance and disposal
Sustainability	**Components are grouped in bigger units** that have to be removed and replaced together	Difficulties in recycling and possible disposal of working components			●		no	> Design different combinations > Allow to separate sub-components for recycling
Functionality+ Sustainability	**Internal layout of components is often not effective** (bad screw position, problem in accessibility)	Difficulties in maintenance operations and disposal			●		no	Redefine internal layout taking into account specific maintenance needs
Functionality	**Tubing layout is not optimal** and creates obstacles to access to hydraulics components	Difficulties in maintenance operations			●		no	Redefine internal and tubing layout taking into account specific maintenance needs
Functionality	**Use of protective foams** that have not a well-defined position and can create access problems	Difficulties in maintenance operations			●		no	> Alternative protections of electrical parts > Design a better use of protective foams

DISPOSAL

	CRITICAL ELEMENTS	ISSUES	PRODUCT		EQUIPMENT	TREATMENT	EXISTING SOLUTIONS	POSSIBLE SOLUTIONS
			PACKAGING	DISPOSABLES				
Sustainability	**Residual fluids are difficult or impossible to empty** (acid concentrate and saline solution)	Health staff does not have time to wait for the systme to end	● *Pack for treatment*		●		no	Design automatic systems for faster emptying
Sustainability	**Residual materials are difficult or impossible to empty** (bicarbonate cartridge)	Increased weight of waste and disposal costs. Possible problems in recycling	● *Pack for treatment*		●		> The machine empties the bags from liquids (with medium to long timescales) > Manual emptying of liquids	> Automatic systems for faster emptying > Make the manual emptying easier
Sustainability	**Many groups of components are difficult to disassembly** (fixed on plastic support by using screws)	Waste may be more difficult to recycle or not be recycled at all	● *Pack for treatment*		●		Component manual separation	> Prefer interlocking systems > Group components with similar lifecycle
Sustainability	**Different materials are difficult to recognise** in the disposal stage (little use of product label)	Difficulties in disposal				●	Use of labelling, but on a few components	> Wider use of labelling > Communicate the end of life and disposal
Sustainability	**Different materials are often difficult to separate and properly recycle**	Difficulties in disposal	● *Pack for treatment*	●	●		no	> Make materials clearly recognizable > Design for quick disassembly
Usability	**Different types of tools are needed to disassembly the components**: this is not due to real needs but because components are provided by different manufacturers or because some components are placed in a non-optimal way.	Waste may be more difficult to recycle or not be recycled at all	● *Pack for distribution* *Pack for treatment*	●			no	> Prefer interlocking systems > Standardize the requirements for connecting options in the whole supply chain
Sustainability	**Wide use of polymers that are difficult to recycle** also for the shell and components that are not in contact with fluids (PUR e PES)	Waste may be more difficult to recycle or not be recycled at all	● *Pack for distribution* *Pack for treatment*	●			no	> Prefer, if possible, the use of alternative materials that are more easy to recycle
Sustainability	**High production of WEEE** still working (e.g. electrovalves)	Increase in special hazardous waste	● *Pack for treatment*	●			Possible regeneration of some components	> Promote regeneration
Functionality+ Sustainability	**Many components are full of residual fluids** and need to be emptied before disposal	Difficulties in disposal	● *Pack for treatment*	●	●	●	no	> Design a system that allows the emptying of machine

Table 12 – Equipment requirements

3.3 Treatment

In-centre medical treatments involve a broad and heterogeneous group of direct and indirect users (see par. 2.2.2). When focusing on the dialysis therapy, **three main users** are directly involved in the treatment: **patients**, **nurses** and **physicians**. Each of them specifically deals with the products and the equipment, as well as the context. System items can enhance users' tasks or, conversely, negatively affect their behaviours.
The assessment of treatment routines allows defining the relations among users and between users and the other system items. The goal of the analysis is not to evaluate the routine and suggest organisational changes, but to **understand the main behavioural issues** that could be addressed through the design of products and machines.
Although many actions are globally required to set and operate the equipment, treatment routines can vary according to the place and the local standards. Therefore, the treatment assessment has been carried out in all the **three case studies**, analysing the dialysis routines in Italy (San Luigi Gonzaga Hospital), Sweden (SUS Hospital), and Denmark (Frederiksberg Hospital).
Haemodialysis differs from other chronic noncommunicable diseases, such as diabetes or heart disease, because CKD patients are highly dependent on the medical equipment and they need daily or weekly treatments throughout their lives or until they receive a kidney transplant. Despite dialysis has always been considered a passive treatment regime, today there are several possibilities for home and in-centre patients to get involved in the treatment and play a more active role in their own care. Therefore, the treatment analysis has taken into account both clinicians and patients' roles, with a special focus on patient empowerment towards limited-assistance and self-care. Technicians and indirect users were not included in the treatment analysis since they do not directly interact with products and equipment during the therapy. Patients' families have also been excluded from the assessment because, in hospital haemodialysis, they are absent and play a very marginal role in the therapy.

3.3.1 Treatment assessment through a routine analysis

A specific method has been defined to describe and compare the haemodialysis routines of the three case studies. Customer journey mapping techniques are commonly used in business (Rosenbaum, Otalora, & Ramírez, 2017) and have effectively found application in healthcare to improve the quality of the "***patient's journey***" (Curry, McGregor, & Tracy, 2006). In this case, the purpose was to visualize and compare the treatment "journey" of different users, highlighting their behaviours toward products

Fig. 14 - The dialysis unit at Frederiksberg Hospital during the set-up of the treatment

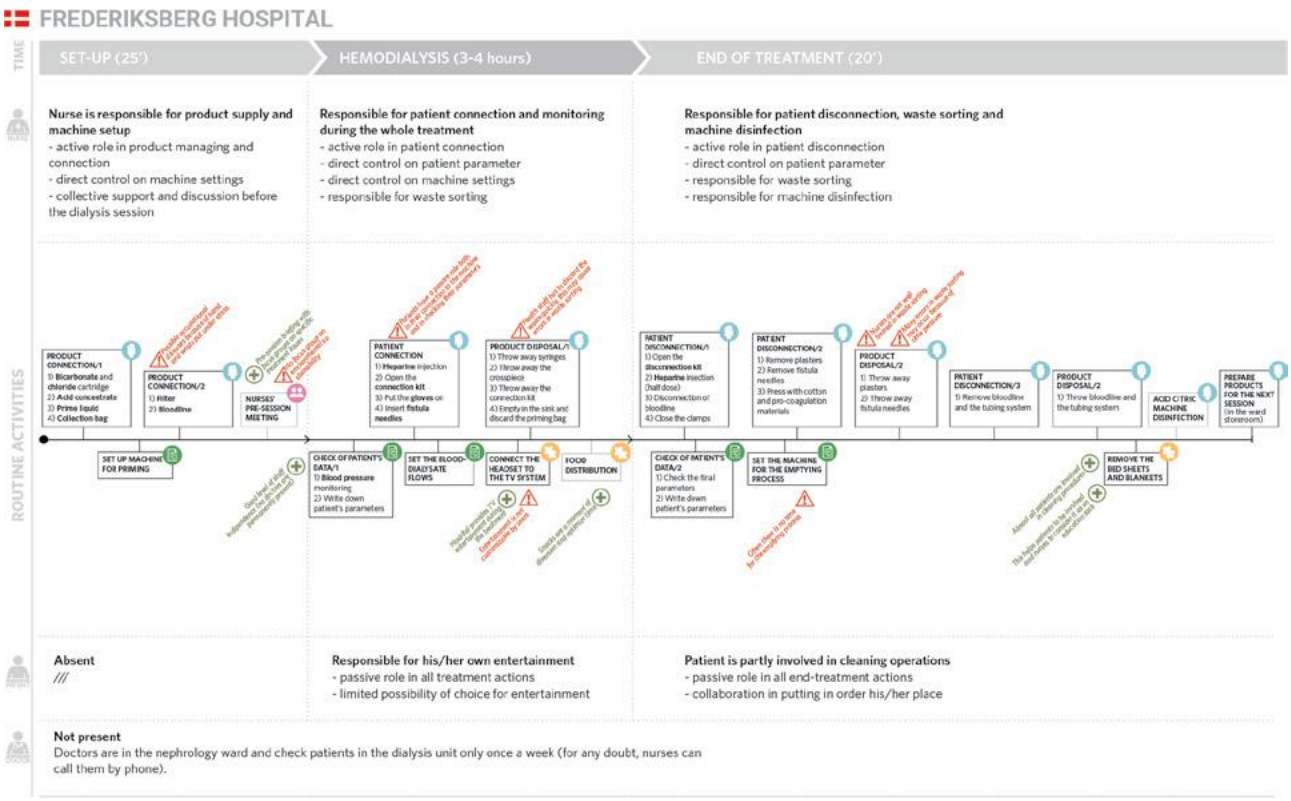
Fig. 15 - Example of the routine analysis applied to the Swedish case study.

and equipment, considering the therapy from an environmental sustainability perspective. So, the mapping tool has been used to describe the treatment through different levels of analysis.

On-field observation (Figure 14) allowed to collect the data, by spending two full-time days for each case study: the actions of nurses, patients, and physicians have been monitored and recorded, and informal interviews with all the stakeholders were used to understand the routines of all the stakeholders involved.
The data collected have been visualized through a **specific map that combines three levels of analysis** (Figure 15):

1. **Routine Activities**. The actions carried out during the whole treatment are divided into four categories. Manual actions include the physical activities to manage the disposable products for connecting the patient to the machine and for managing the treatment (including disposal). Digital actions/checking concern cognitive operations that deal with setting and monitoring parameters. Staff interaction includes planned social actions for sharing issues and opinions, especially regarding environmental sustainability. Patient empowerment concerns planned procedures to involve patients in their own care and make the therapy more acceptable and comfortable.
2. **Users' role**. The tasks and the active/passive role of the three categories of users (patients, nurses, and physicians) are described concerning the three phases of a dialysis session (set-up, dialysis, and end of treatment).
3. **Strengths and weaknesses**: Potentials and criticalities are directly shown on the map through a visual code based on colours and icons. The code helps to highlight the most critical activities and phases immediately.

The treatment analyses of the three case studies are included in Annex I.
The comparison of the three case studies (Table 13) revealed many issues that design can contribute to improving. First, **nurses' activities involve physical and mental strain**, due to the daily product supply, the equipment set-up, and the need of handwriting information about the therapy. **Time pressure** may cause errors both in



	SAN LUIGI HOSPITAL - **ITALY**	SUS HOSPITAL - **SWEDEN**	FREDERIKSBERG HOSPITAL - **DENMARK**
ROUTINE ACTIVITIES			
MANUAL ACTIONS	**Patient connection**: - Additional effort because priming is not processed automatically - Most used products are stored in the dialysis room **Waste sorting**: - Good training in waste sorting (self-initiative) - Waste sorting bins are present in each dialysis room - Additional effort because of priming bags to empty **Cleaning:** - Made by health workers	**Patient connection**: - Standard routine and automatically priming - Products to prepare for the next session (in the ward storeroom) **Waste sorting**: - Good training in waste sorting (hospital initiative) - Waste sorting bins are in the ward - Time pressure may cause errors in waste sorting **Cleaning:** - Mainly made by nurses	**Patient connection**: - Standard routine and automatically priming - Products to prepare for the next session (in the ward storeroom) **Waste sorting**: - Poor training in waste sorting - Most waste are not sorted - Waste sorting bins are out of the dialysis room **Cleaning:** - Made by nurses together with patients
DIGITAL ACTIONS/CHECKING	**Machine setting**: - Fast procedure through experience (interface is not user-friendly) - Priming requires digital and physical actions **Checking and taking note**: - All notes are handwritten - Staff don't take note of production batchesv	**Machine setting**: - Fast procedure through experience (interface is not user-friendly) - Priming requires only digital setting **Checking and taking note**: - All notes are handwritten - Production batches and specific data on products are handwritten or adhesive label are pasted on the medical record book. - Data registered on patient electonic card are used for treatment setting	**Machine setting**: - Fast procedure through experience (interface is not user-friendly) - Priming requires only digital setting **Checking and taking note**: - All notes are handwritten - Staff don't take note of production batches - Data registered on patient electonic card sometimes are used for treatment setting
STAFF INTERACTION	**Mutual support**: - There are no plans for collective or interactive moments (that are informal) **Relationships with doctors**: - Nurses daily assist doctors during patient examining	**Mutual support**: - Each nurse double check the patient connection of another collegue **Relationships with doctors**: - Nurses ask doctors only for doubts/emergency	**Mutual support**: - Collective brefing before each dialysis session **Relationships with doctors**: - Nurses call doctors by phone only for doubts/emergency
PATIENT EMPOWERMENT	- Few TVs are present in the dialysis room: - Entertainment is not customizable	- Some TVs are present in the dialysis room - Entertainment is not customizable	- Each patient can use a TV, connecting his/her own headset - Entertainment is limited byt customizable - Snacks are distributed during each session
USERS			
PATIENT	- **Passive role** in all treatment actions - No possibility to choose entertainement	- **Passive role** in all treatment actions - No possibility to choose entertainement	- Passive role in all treatment actions but **possibility to move to limited-care or self-care dialysis units** - **Active role in cleaning** operations - Limited possibility to choose entertainement
NURSE	- Responsible for **patient connection, product supply** and **waste sorting** - Patient's health is mainly checked by doctors (**limited autonomy**)	- Responsible for **all the treatment operations** and **patient monitoring** - He/she daily share doubts and issues with doctors (**good autonomy**)	- Responsible for **all the treatment operations** and **patient monitoring** - He/she must make his/her own decisions (**full autonomy**)
DOCTOR	- **Always present** during the treatment - **Daily interaction** with **all** patients	- Limited presence during the treatment - **Daily interaction** with **some** patients	- Absent during the treatment - **Weekly interaction** with **all** patients
STRENGTHS AND WEAKNESSES			
STRENGTHS	- **Occasional training on quality** aspects of dialysis - **Strong belief that waste sorting is important** - Less stringent treatment routines (**autonomy**)	- **Good autonomy of nurses** - Very stringent treatment routines (**safety**) - **Periodical training on different topics** about dialysis and healthcare - Special **training on environmental** issues - **Environmental awareness** is supported by the hospital (ISO 14000 standard)	- **High autonomy of nurses** - Good **indipendence of patients** - Less stringent treatment routines (**autonomy**) - **Focus groups on different topics** about dialysis issues
WEAKNESSES	- **Low autonomy of nurses** and high control by doctors - **Low indipendence of patients** - Less stringent treatment routines (**error risks**) - Environmental awarness is a self-initiative, poorly supported by the hospital	- **Low indipendence of patients** - Very stringent treatment routines (**lack of flexibility**) - Many **checklists to fulfill by hand** - Enviromental standard requires **frequent reports and a huge effort** from environmental coordinators	- **No focus group on environmental** issues - **Lack of environmental awareness** (poorly supported by the hospital)

Table 13 - Comparison of the treatment analyses

SUPPLY AND SET-UP

	CRITICAL ELEMENTS	ISSUES	PRODUCT: PACKAGING	PRODUCT: DISPOSABLES	EQUIPMENT	TREATMENT	EXISTING SOLUTIONS	POSSIBLE SOLUTIONS
Functionality	**The connection of products/pack to the equipment requires physical strain**, especially where machine priming is not automatized.	Physical effort in product handling and equipment set-up + risk of occupational diseases	● *Pack for transp*	●	●	●	Partial automation of bloodlines set-up	> More tiring actions shall be automized > Improve pack and product usability
Functionality	Nurses need to **manually check and take note of all parameters** and, in some cases, all data and code of the disposable devices.	Physical and cognitive workload for nurses.	● *Pack for distribution* *Pack for treatment*			●	Packaging for distribution includes adhesive labels to stick on the patient's book	> Digitalize the procedure > Use QR code or other digital-based system that can be scanned
Functionality+ Sustainability	**Time pressure** may increase the risk of errors, both in procedures and in waste disposal.	Safety risks + environmental risks				●	none	> Product design should ensure a safe connection and set-up > Improve ease of disassembly
Functionality	**Most patients play only a passive role** in the set-up of the treatment.	Obstacle to patient empowerement toward home or semi-assisted dialysis			●	●	Training of the brightest patients for home or self-assisted dialysis	> Facilitate set-up procedures > Make information clearer to understand > Improve the machine interface (customization)

TREATMENT

	CRITICAL ELEMENTS	ISSUES	PRODUCT: PACKAGING	PRODUCT: DISPOSABLES	EQUIPMENT	TREATMENT	EXISTING SOLUTIONS	POSSIBLE SOLUTIONS
Functionality	**The connection of patient to the equipment requires physical strain**.	Risk of occupational diseases	● *Pack for treatment*	●	●	●	none	> Improve pack and product usability
Functionality	**Entertaiment is delegated to the ward or to the patients** through personal devices (e.g. TV in the dialysis room, personal tablets or smartphones)	Boredom and impatience of the patient during the treatment (decrease in comfort).			●	●	Vertical equipment to help reduce machine space by the bedside	> layout innovation

DISPOSAL

	CRITICAL ELEMENTS	ISSUES	PRODUCT: PACKAGING	PRODUCT: DISPOSABLES	EQUIPMENT	TREATMENT	EXISTING SOLUTIONS	POSSIBLE SOLUTIONS
Sustainability	Health staff has to **discard the waste quickly**.	Time pressure may cause errors in waste sorting	● *Pack for distribution* *Pack for treatment*	●		●	none	> Incorporate entertainment systems into the machine > Allow the connection of personal devices
Sustainability	**Waste often are not emptied properly,** even if the machine is able to automatically empty the tubing system and the concentrate bags.	Increased weight of waste and disposal costs. Possible problems in recycling.	● *Pack for treatment*	●	●	●	> The machine empties the bags from liquids (with medium to long timescales) > Manual emptying of liquids	> Automatic systems for faster emptying > Make the manual emptying easier
Sustainability	The **lack of recycling bins at the bedside** discourages a proper waste sorting.	Waste may be not be recycled, especially if made of different components to separate.				●	Ward recycling bins	> Design a more compact bin-sort system > Provide at least one bin for most common waste (e.g. plastics)

Table 14 - Treatment requirements

treatment set-up and in waste sorting: products and equipment must take into account this work condition. In hospital haemodialysis, nurses play a leading role but the presence of the doctors directly affect their autonomy, limiting their freedom and decision-making abilities. If the role of nurses may vary depending on the hospital, the **role of patients is always passive**: their contribution to the treatment is very limited as well as their awareness and decision power. **Entertainment** is a key issue in chronic treatments which require 3-4 hours per session: in most cases, there is little attention to this aspect and patients must provide for self-entertainment or they might opt for the limited and not customizable offer delivered by the hospital. In all cases, environmental awareness is considered as an essential aspect to promote, but often sustainable initiatives are poorly supported by the hospitals. Even in the hospitals more committed to environmental aspects, sustainable behaviours, such as proper waste sorting, are deeply connected to personal commitment.

3.3.2 Treatment requirements

All the criticalities highlighted within the routine analysis (par 3.3.1) has been divided according to the treatment phase and described more in detail (Table 14). Each issue involves the treatment and other system items, that can contribute to increasing the problem. Each case study showed

specific solutions that could be implemented in the other dialysis units (in Table 14 they are listed as "existing solutions"). In many cases, these solutions only partially meet the requirements or are not sufficient at all; therefore, new possible solutions were identified to improve the issues highlighted.

3.4 Local environment

The analysis of the local environment has been carried out in parallel with the product, equipment, and treatment analyses, focusing on the contexts in which the haemodialysis system is located. In this case, the comparison of the three international case studies was essential to assess and highlight the influence of the context on the healthcare system.
The **organizational analysis** aims at providing an overview of different approaches to Sustainable Healthcare, analysing environmental strategies both at the macro (Region) and the micro level (hospital and dialysis wards). The complexity and interdisciplinarity of healthcare systems require a multi-level analysis that takes into account different aspects which affect the implementation of environmental sustainability strategies. Health stakeholders and their responsibilities and tasks were considered to define a methodology that could be applied to different contexts and countries.

The analysis has been carried out considering two levels of the organization, each of which shows specific criteria of analysis:

- **Regional organization for Sustainable Healthcare**: analysis of national/regional policies and regional organization. It focuses on defining the regional management organization, and the organizational figures responsible for environmental sustainability in health care.
- **Implementation of Sustainable Healthcare strategies**: analysis of the practical application of macro-strategies, focusing on the responsibilities and tasks of the key stakeholders (Region, Hospital, Ward/Unit), and their role in promoting and implementing environmental strategies and sustainable procurement.

The combination of these two levels allows comparing macro-strategies and regional organizations concerning Sustainable Healthcare but, at the same time, it makes it possible to verify their implementation and effectiveness at a more specific level. The goal of the analysis is not to classify countries/hospitals but to highlight common weaknesses and limits to the developments of Sustainable Healthcare, underlining the existing good practices and solutions that can be shared at international level.

The analysis has involved the three European regions in which the dialysis case studies are located:

4. **Piedmont Region** (Italy) > San Luigi Gonzaga University Hospital;
5. **Skåne Region** (Sweden) > SUS Hospital;
6. **Hovedstaden Region** (Denmark) > Frederiksberg Hospital.

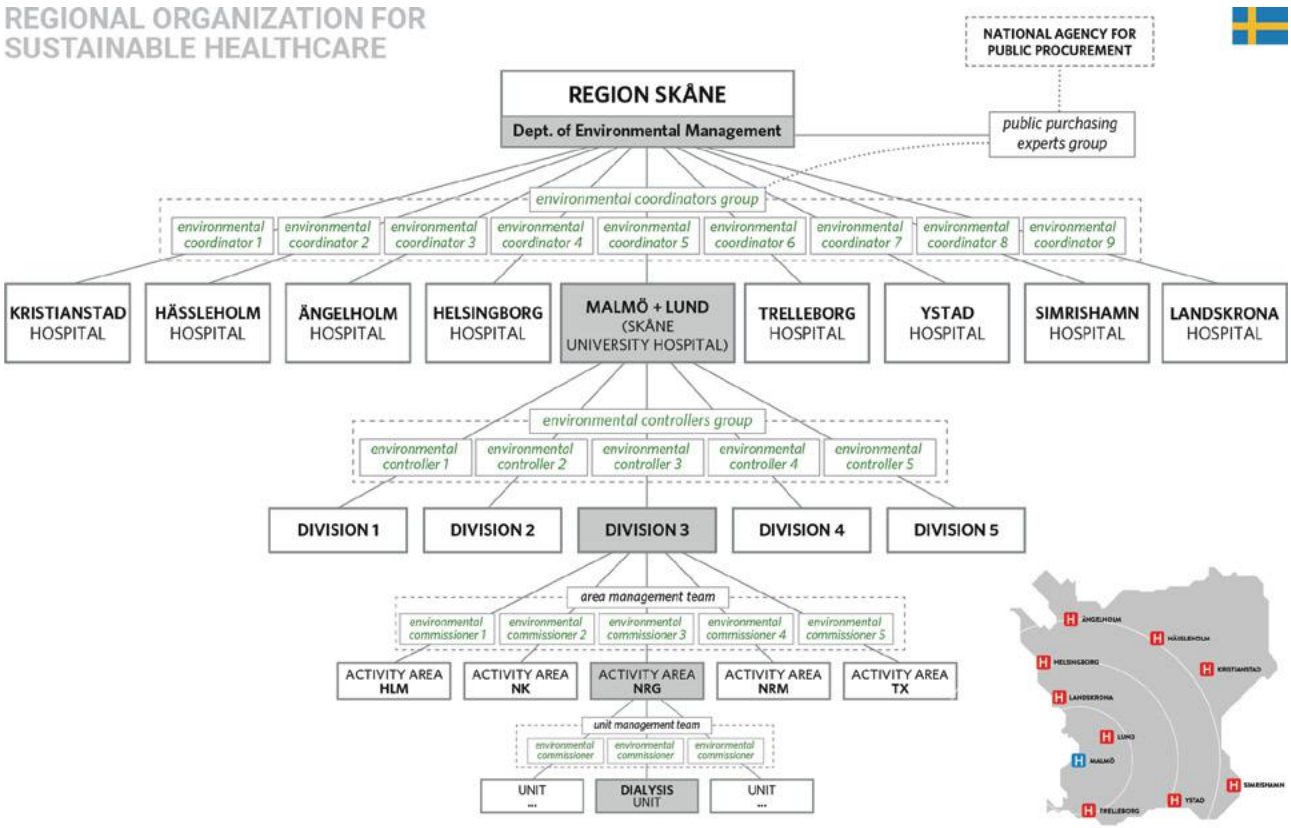
Even if the three regions are slightly different regarding their area and population, the selected hospitals are similar in size, and they all have small-medium dialysis units that can be compared relating to the implementation of environmental strategies and the complexity of the organization.

3.4.1 Regional organization for Sustainable Healthcare

The cross-case analysis compares the organisational structure of the regions as regards environmental sustainability and health care.
Data has been collected through the **official information channels** (regional websites and published documents), and through **qualitative interviews** with regional and hospital managers and, if present, with the environmental

Fig. 16 - Example of the analysis of regional organization for Sustainable Healthcare

coordinators of hospitals and units.
Figure 16 shows an example of the analysis of regional organization: the organizational structure is represented by a diagram, which focuses on the hospital being considered. Special text-boxes give detail of the **managers/coordinators** that are responsible for environmental sustainability in the different levels of the organization. If needed, external bodies (such as the National Agency for Public Procurement) are indicated.
The comparison (Table 15) showed **different levels of complexity** and the **inconsistent presence of environmental managers/coordinators** within the organisational hierarchy. Indeed, each region has a regional department that is dealing with environment and environmental sustainability; Skåne (Sweden) and Hovedstaden (Denmark) also have specific hospital managers, called "environmental coordinators," which are responsible for interacting with their regional department and monitoring the implementation of environmental strategies.
At the hospital level, the case studies show **different organisational structures**. Skåne has a complex organisation: there is an environmental controller for each hospital division (which groups different areas), then an environmental commissioner for each activity area (which put together various units according to the medical topic), and an environmental controller for each unit/ward. Hovedstaden and Piedmont have a similar structure, where each hospital is divided into departments or units. In Hovedstaden, the hospital environmental coordinator is responsible for implementing the regional environmental strategies in all the units. In Piedmont, the unit managers have to implement the regional strategies, even if they have no background or training in environmental topics.
The **presence of environmental coordinators** for each level of organization **is crucial to translate environmental strategies into practice**. The hospital environmental coordinator constantly relates to the regional department, and his/her role is important to implement long-term strategies. The presence of a staff member trained in environmental sustainability is significant to achieve environmental goals and promote sustainable behaviours. The unit environmental commissioner is the point of reference for



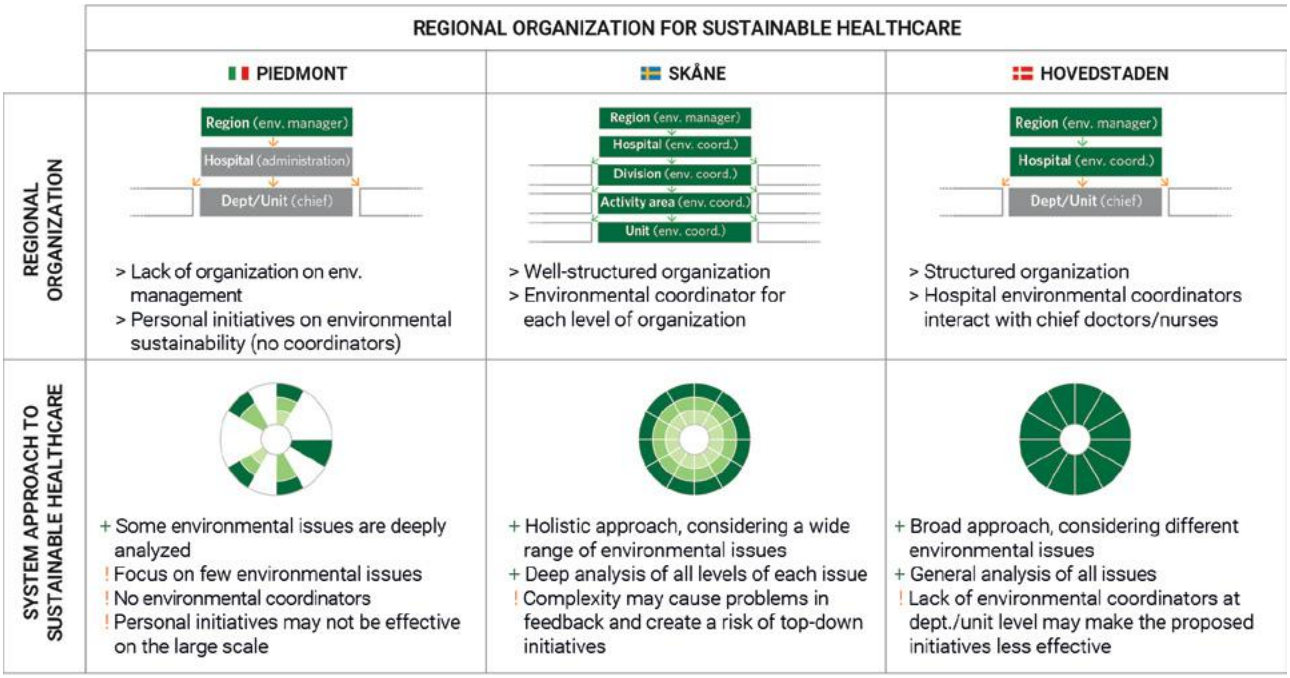


Table 15 - Cross-case comparison of the regional organization

employees and patients and can solve daily issues and doubts with environmental matters. At the same time, the **organizational complexity** may lead to top-down initiatives, making it difficult to propose and discuss bottom-up ideas, and to encourage shared responsibility and cooperative efforts among staff and patients. Conversely, a less complex organization can increase horizontal communication and promote self-initiatives.

As regards the overall approach of the regional organization to Sustainable Healthcare, the analysis defined **three different models**. In Piedmont, some environmental issues are deeply investigated while others are ignored, and the environmental awareness can vary according to different hospitals since it is based on personal commitment. In Hovedstaden, there is a broad approach to sustainability: a wide range of environmental issues are addressed, but through very general measures, without specifying any of matters in detail. Finally, Skåne is trying to applying a holistic approach to sustainability, addressing environmental issues at all levels of the organization, from region to unit. This approach is however not without problems, mainly due to organizational complexity, but the attention to sustainability in all the interwoven sectors of healthcare is essential to promote Sustainable Healthcare.

3.4.2 Implementation of Sustainable Healthcare strategies

The second part of the analysis has compared the **environmental tasks and goals of the organization stakeholders** that are present in all the case studies: **region, hospital,** and **unit**. The goal is to understand the differences between different organizations as regards stakeholders' tasks, decision-making power, and their role in implementing environmental strategies. A special focus on **sustainable products purchase** was needed since Green Public Procurement is essential to encourage the sustainable design of new products.
Figure 17 shows an example of the analysis of Skåne Region: the tasks of each stakeholder are defined in detail, and the arrows highlight the possibility of feedback and direct interaction among the levels of the organization. **Decision-making power** and

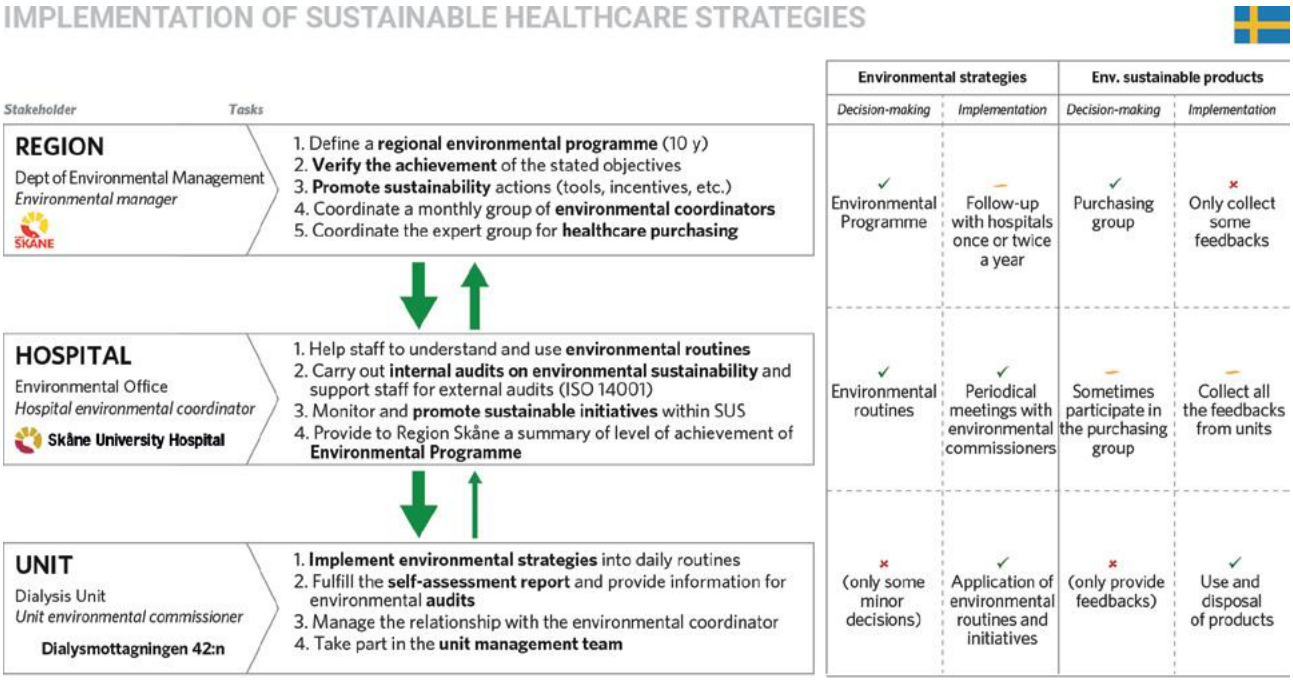


Fig. 17 - Example of the analysis of the implementation of Sustainable Healthcare strategies

implementation ability are described through specific observation and symbols.
The results of the comparative analysis are reported in Table 16. In all cases, regions are responsible for defining the environmental programme and the related goals to achieve. In Skåne and Hovedstaden, hospitals receive a specific set of environmental routines or guidelines to implement in their units, which are then verified and discussed through periodical or occasional meetings with the regional managers. In Piedmont, besides the mandatory regulations, hospitals have to promote occasional projects that aim at reaching the environmental goals set by the region. The hospital feedback is limited to the occasional projects. At unit levels, in Skåne and Hovedstaden the staff have to implement the environmental routines, translating into practice the guidelines and projects that regions are promoting. So, despite the global attention to sustainability, **units** are aimed at implementing regional and hospital strategies, but they **can only take minor decisions**. Conversely, in Piedmont the Unit Head can promote self-initiatives that deeply commit the staff; at the same time, the lack of environmental awareness can lead to a total indifference toward sustainability issues and activities.
As regards Sustainable Product Procurement, the decision-making power of units (that involve the end users of products) is extremely limited. There are **no official procedures to allow the staff to ask for more sustainable products** to test, but they can only provide feedbacks, if required, on the products provided by the regional or hospital purchasing group. In Skåne, hospital environmental coordinators can sometimes take part in the regional purchasing group: in those cases, they can discuss the most impactful products for the hospital. However, specific problems concerning minor products can not be discussed at any level of organisation.

The overall results of the two steps of analysis confirm the outcomes of the previous analyses (par. 3.3, 3.2, and 3.1). The effects of Green Public Procurement can be extremely positive: currently, new technologies and products for waste management are improving recycling, even if the adoption of eco-innovative solutions is not always possible. The **slow pace of change in public procurement** and the **rigidity of supply**

		ENVIRONMENTAL STRATEGIES			SUSTAINABLE PRODUCT PROCUREMENT		
		PIEDMONT	SKÅNE	HOVEDSTADEN	PIEDMONT	SKÅNE	HOVEDSTADEN
REGION	DECISION-MAKING	✓ Environmental Goals (no holistic programme)	✓ Environmental Programme	✓ Environmental Programme	n.a.	✓ Purchasing group	✓ Purchasing group
	IMPLEMENTATION	– Follow-up with hospitals (occasional)	– Follow-up with hospitals once or twice a year	– Follow-up with hospitals 3-4 times a year	n.a.	× Only collect some feedbacks	× Only collect some feedbacks
HOSPITAL	DECISION-MAKING	– Promotion of occasional projects	✓ Environmental routines	✓ Environmental guidelines (especially for waste)	n.a.	– Sometimes participate in the purchasing group	× Provide feedback to region
	IMPLEMENTATION	– Top down implementation of projects	✓ Periodical meetings with environmental commissioners	– Occasional meetings with head nurse or physician	n.a.	– Collect all the feedbacks from units	– Collect some feedbacks from units
UNIT	DECISION-MAKING	✓ Indipendent initiatives and research	× (only some minor decisions)	× (few minor decisions)	× Supply is decided at regional level	× (only provide feedbacks)	× Possibility to order new products to test (usually focus on quality)
	IMPLEMENTATION	✓/× Discretionary waste sorting	✓ Application of environmental routines and initiatives	– Discretionary application of environmental guidelines	– Possibility to ask for more sustainable features	✓ Use and disposal of products	✓ Use and disposal of products

Table 16 - Cross-case comparison of the implementation of Sustainable Healthcare strategies.

categories make the introduction of innovative products more difficult (e.g. a company providing new solutions for integrated rubbish boxes must be able to participate both the tendering procedures for the garbage bins and the garbage bags). Current practices of public procurement may be an obstacle to design new systemic solutions that integrate different system items.

In all cases, the **focus on product quality** is rarely connected to environmental sustainability, and the staff involved in environmental issues do not have much say in the matter of product purchasing. Many environmental strategies, such as waste sorting, are effective only where an official (or unofficial) environmental coordinator encourages and provides daily support to people in achieving sustainability goals. Although **staff autonomy** is necessary to promote personal development and sense of initiative of individuals, a **higher organization is needed to solve long-term environmental issues**. Indeed, the subjectivity of initiatives may lead to excellent results (because of personal awareness), but it is not reliable and effective on a large scale.

3.5 The current system

The analysis of the system highlighted a complex network of relationships existing between the users and the system items (Figure 18).
Design has to deal with both material and immaterial flows. On the one hand, the system is consuming an **enormous amount of resources** (raw materials, chemicals, energy, and water) that are transformed into a **significant quantity of waste** (urban waste, infectious waste, and used dialysate). Both the inputs and the outputs of the system impact on the local environment and are affected by it: several regional stakeholders are aimed at dealing with the management of material flows, from purchase to disposal. Concerning the haemodialysis treatment, they are indirectly dealing with the therapy. Therefore, **indirect users are responsible for the inputs and outputs of the system**, and there are no established channels of communication that could ensure ongoing and multi-directional information flows with the direct users.
Health staff, technicians, and, to a lesser extent, patients communicate each other about health and treatment concerns. In many cases, the environmental awareness leads to self-initiatives and personal commitment, but it is very difficult to share bottom-up ideas with regional and hospital managers. In particular, procurement managers could play a key role in matching the users' requirements to the producers' supply, but currently, end users have **no possibility to dialogue** with them.
Despite their interwoven systemic nature, the **system items are usually designed separately**. Treatment routines are established regardless of the type of products and equipment that users will adopt. Products and equipment are often designed separately by different manufacturers; standard and, frequently, inefficient design solutions allow them to fit different contexts of use, but they can not respond to all the system requirements. Finally, the local environment deeply affects the dialysis system, but one-way communication and the rigidity of traditional hierarchies could restrain innovation towards a more sustainable system.

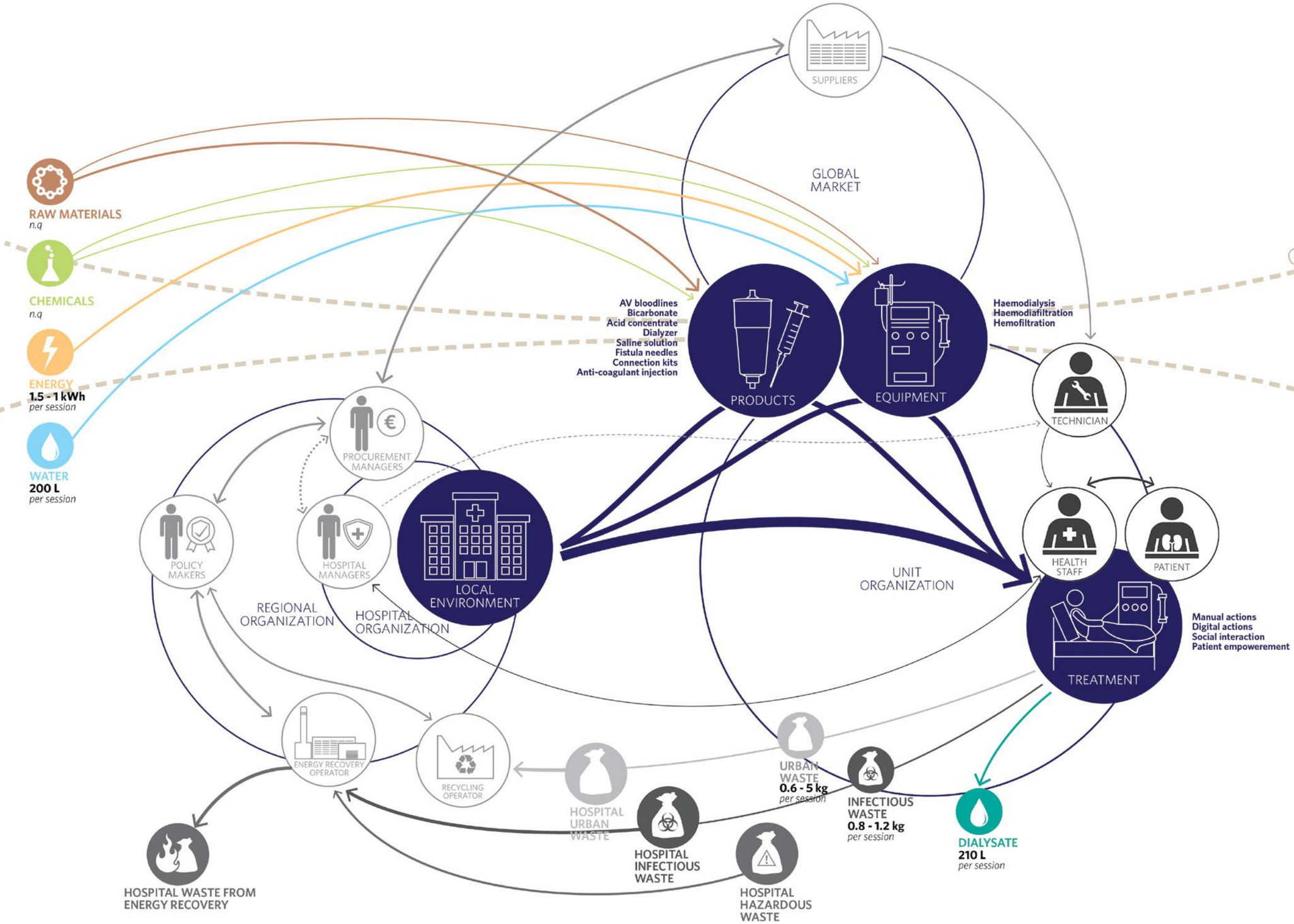


Fig. 18 - Map of the current haemodialysis system

Chapter 4

Ecoguidelines for haemodialysis

Design guidelines for improving the environmental sustainability of dialysis

"[...] Science and technology are being placed at the hub of our decision making pathways, while they can only provide information and knowledge about the world and not about what is desirable to be done to the world. So while technology tells us what is possible we do need to look at design with its participative and integrating methods to find out what is desirable and valuable for a sustainable future."

(Ranjan, 2012)

4.1 Definition of Design Ecoguidelines

The analysis of the system has led to define a broad set of requirements, starting from the problems and potentials that the analyses of the items have defined. Requirements address the environmental sustainability and the functionality of haemodialysis from a design perspective, starting from the main design issues. In addition to problems and requirements, specific solutions have been highlighted: a set of existing or possible alternatives has been identified for each issue.
The Requirements Summary Tables are undoubtedly a long-established and frequently used tool for designers, but the consultation is complex and misses a hierarchical relationship between the requirements.
A further step was needed to summarize the results of the analysis of the system and **provide a comprehensive overview of design issues in haemodialysis** and chronic treatments. The design guidelines focus on the main problems identified by the analysis and provide clear and **practice-based guidance for designing innovative products, services, and systems toward environmental sustainability and user-centricity** in dialysis treatments.
In most cases environmental sustainability can only be achieved through the coordinated design of different elements: many guidelines address issues that do not involve one item only. The system items involved are clearly indicated.
As was pointed out in the methodology section (cf. par. 2.2.5), the guidelines address the design of products, equipment, and treatment. The analysis of local environment was aimed at outlining the context in which the treatment takes place and its direct and indirect influence on product and equipment design. The organizational analysis allowed underlining the challenges and boundaries of design for Sustainable Healthcare. Therefore, no specific guidelines have been defined regarding the local environment.

4.2 Product and equipment guidelines

The definition of Product and Equipment Guidelines brings along the challenge to maintain a systemic approach while addressing the design of a single product or a set of products. For this reason, guidelines combine different aspects, addressing both the issues related to the product and those that require a system-level intervention. Given the novelty of this domain, it is advisable not to take the established guidelines of Design for Sustainability for granted. So first, the **"generic guidelines" for the sustainable design of products** (Table 17) **and equipment** (Table 19) have been summarized. Because these guidelines provide general design indications, they do not apply only to the healthcare systems, and it is not possible to indicate which system items they involve. So each generic guideline may refer to the product only or may involve the system as a whole. Then the study has focused on defining the **"specific guidelines" that directly address the medical sector and the haemodialysis system** (Table 18, Table 20). These guidelines may involve the product, the equipment, and the treatment, as they specifically address the healthcare systems.
In order to facilitate reading and comprehension, the guidelines have been divided into seven categories, which refers to **common strategies of Design for Sustainability** (Vezzoli & Manzini, 2007). Each category addresses a particular aspect of the product design, without losing a systemic vision of the problem. The reference to existing categories allows the designer to deepen the criticalities highlighted through the existing literature, or to seek for specific tools adopted by other areas to pursue that type of design intervention.

1| REDUCTION

The approach to product reduction is not a simple decreasing in the weight and volume of a product, which implies an inherently worsening of its functionality: **design for reduction means to rethink the way the product is intended to be** (Braungart, McDonough, & Bollinger, 2008).
The concept of reduction should become a

requirement of the project. It does not only mean reducing the size of a product but rethinking it in a different way so that its physical characteristics allow a reduction in weights, dimensions, and thicknesses of materials (Rashid, Evans, & Longhurst, 2008). Designing for reduction allows **designing formally and typologically innovative products**, where customization and configurability lead to dematerializing the product.
The reduction affects not only the product but the entire production system behind it: design for reduction **positively involves all stages of the life cycle** from supply to production, promoting an approach that enhances sustainability and functional effectiveness toward dematerialization.

2 | MATERIALS

Choosing a material is the result of an assessment that takes into account the qualitative and functional characteristics of the product.
The material must first **meet the performance required by the product** and a**nswer the regulatory requirements** of the product category. The sustainability of a material cannot, therefore, leave out of consideration the **application of use** (Muenchinger, 2011).
The natural origin of a material and its biodegradability do not necessarily make it more sustainable: its **effectiveness**, its **durability** in relation to the life cycle of the product, and the **easiness of sorting** are essential elements that enhance the sustainability of the product.
Undoubtedly, some materials are more easily recyclable than others and, where the performances are equal, they improve the end-of-life management. Whenever possible, these materials should be preferred, and their management can be facilitated by planning the relationship between the components (design for **disassembly**) or by designing products from a perspective of **upcycling**, so that materials can be reprocessed for use at the same level of application (Bakker, Wever, Teoh, & de Clercq, 2010).

3| TECHNOLOGY

Technology can be a useful tool to address the environmental and social problems of products, services, and systems. This is not just about adopting new technologies for the sector of the product concerned, but it implies **thinking of an innovative use** of the existing ones.
Again, usability is a fundamental aspect: the **focus on user's needs** allows to choose the most appropriate technologies to facilitate users' tasks and boost system sustainability (Thackara, 2005).
Digitization combines greater usability and dematerialization of products and communication media. The pervasiveness of mobile devices makes it possible to exploit technologies that the user has already become familiar with, to propose new purposes. The designers have to identify the most suitable applications and technologies, considering the sustainability of the entire system.

4| FLEXIBILITY

Product flexibility is the *"degree of responsiveness (or adaptability) for any future change in a product design"* (Palani Rajan et al., 2003). **A flexible product fully fits the needs of different users and adapts itself to the change of these needs over time**. The primary goal of design for flexibility is to maximize usability and to promote the standardization of components, aiming at enhancing the freedom of use. **Flexibility** and **seriality** are not antithetical aspects, but the perfect match to meet the needs of the users and the local environment within a global marketplace. Standardization allows improving the adaptability and interactivity of products.
Flexibility enables to address different users, places, and times through the same product or system: products that offer multiple features and customization options can adapt to different users, **maximizing usability** and **optimizing the use of resources** (Van Nes & Cramer, 2005). The possibility to update and customize a product also provides **space and time flexibility**: these are important features that can improve product sustainability in a global context.
Lastly, the design for flexibility should avoid the risk of making the use more complicated: multi-functionality must pursue the **simplicity of use**, that is essential to ensure the long-term usability of complex products.

5| USABILITY

Design thinking directs to user-focused problems, aiming at selecting tools and methods that can be useful for bringing **innovative solutions, starting**

from the social, cultural, and operational needs of users. User-centricity is the primary focus of every design intervention.
From a systemic point of view, attention can not be limited to the end user who will principally utilize the product, but designers must consider **all the stakeholders involved in the system**. The product system includes a number of direct (users, technicians) and indirect users (buyers, managers, waste operators, and others) that a user-centered design approach should take into consideration. Facilitating use does not only mean ensuring a user-friendly interaction but **responding to the real needs of users** involved in the different stages of the life cycle (Money et al., 2011).
Usability is a **search for simplicity**; it means to focus on what is actually significant. Simplicity is not trivialization or deprivation but is the response to the real needs of users (Maeda, 2006). The more complex the product is, the more it is necessary to act for the simplification of use: **the primary purpose of design is to simplify complexity**, avoiding unnecessary physical and cognitive efforts.
Usability also improves environmental sustainability, acting to **prevent rapid obsolescence**. On the one hand, it seeks for essential shapes and graphics, avoiding semantic obsolescence, on the other hand, usability enhances the flexibility and upgradeability of products and technologies, fighting effectively against the rapid technological obsolescence of digital and physical artefacts.

6| LIFE CYCLE

Designing for the life cycle means extending the life of the product and its components, considering new secondary uses. **Facilitating maintenance** allows extending the life cycle of the product and updating it according to users' needs. **Reusing and recycling** enable the waste to become a resource for a new life cycle that exploits the properties of the material/product beyond its end of life.
Approaches such as Design for Disassembly propose guidelines and design techniques to facilitate the recycling of the product and its components (Harjula et al, 1996). Fastening systems, breakage areas and specific design solutions can enhance the exploitation of the components that make up the system.
Further attention to maintenance and **upgrading** is needed to design the product in a lifetime extension view. These goals are achieved by expanding the focus from the end user to a comprehensive user-centricity that considers all the users involved in the system, including the tasks and goals of the maintenance technicians. Shedroff (2009) rightly points out that *"component replacement is part of a product's serviceability or maintenance, including easy care by the user or owner and easy and effective care by service people. Serviceability requires some systems thinking and a great deal of understanding about how users and other customers work with the product (and the system in which they work)."*
Overall, the design of the relationships between different components determine the sustainability and, at the same time, the usability of the product.

7| INFORMATION

The product is effectively sustainable over the long term if it can promote a permanent change not only in the production process but also in the user who utilizes it. The communication of the product and through the product is crucial to **creating awareness in the user, throughout the whole life cycle**. Packaging and products must promote sustainable behaviours so that the user can **correctly purchase, use, and mange the end-of-life of the product** (Scudieri & Gill, 2008). Providing information in an honest, clear, and effective way is the main focus of communication for sustainability. The packaging and the product should communicate their origin, their use, the materials that make them up, and their end-of-life. The choice of **universally understandable words and symbols** helps to make the communication effective: the use of standard icons to indicate materials and their recyclability makes end-user communication more effective.
Information transparency builds trust, sensitivity, and attention in the end user.

PRODUCT | GENERIC GUIDELINES

		PRODUCT	SYSTEM
	MAIN GUIDELINE: **Design the packaging concurrently with the product, adopting a concurrent design approach to avoid additional environmental problems and costs during transport, storage, use and disposal.**	●	●
REDUCTION	**Designing packaging and products with a view to optimization of space and raw materials, reducing volume and thickness.**	●	
REDUCTION	 **Optimize size and volumes** Avoid unnecessary oversizing, especially in secondary packaging.	●	
REDUCTION	 **Optimize materials** Reduce thicknesses and prefer lighter protective solutions, in order to minimize the use of materials	●	
MATERIALS	**Preferring recycled, recyclable or biodegradable materials (where possible in accordance with the regulations and product requirements), facilitating post-consumer waste collection.**	●	
MATERIALS	 **Prefer the use of materials that are easy to recycle** Avoid, if possible, the use of composite materials and composite polymers.	●	
MATERIALS	 **Prefer, if possible, the use of materials that are biodegradable or compostable** Avoid the use of plastics and materials difficult to recycle.	●	
MATERIALS	 **Facilitate the sorting of different materials** Avoid permanent joints and, if possible, prefer mono-material packs and products.	●	●
FLEXIBILITY	**Design the product so it can be easily customized and renewed without substantially changing the production processes.**	●	●
FLEXIBILITY	 **Design a packaging adaptable to different types of products** Considering both physical features and communication.	●	●

		PRODUCT	SYSTEM
TECHNOLOGY	**Use of new technologies to improve the sustainability of products.**	●	●
	Use of technologies able to monitor the whole life cycle Increasing product safety and user's consciouness.	●	●
	Use of technologies to provide information about product and end of life Preferring low technologies that don't increase the environmental impact of packs and products.	●	
USABILITY	**Ensure user-friendliness, avoiding unnecessary physical and cognitive efforts**	●	
	Improve the affordance of product/packaging Making it easy to open/close, use and dispose properly of it.	●	
	Guarantee an easy handling During transport, storage and use.	●	
	Design the product seeking simple shapes and essential graphics, so as to prevent rapid semantic obsolescence.	●	
	Prefer simple shapes Take advantage of the shape to strengthen the visual identity and prevent semantic obsolescence	●	
	Prefer simple graphics Reduce and simplify graphcis,preventing semantic obsolescence	●	
LIFE CYCLE	**Design upstream the reuse of packaging and products after the usage phase.**	●	●

		PRODUCT	SYSTEM
LIFE CYCLE	**Reuse for the same or other kind of applications** If it is not possible to reuse the product for the same purpose, explore the possibilities of reuse it in other sectors.	●	●
	Design a product with multiple functionalities, thus extending its life cycle.	●	●
	Add new functions to extend the use of packaging and products Providing functions able to make use and reuse easier.	●	●
INFORMATION	**Design the communication to encourage conscious user choice both in the purchase and in the disposal phases.**	●	
	Provide clear and comprehensive information about product and packaging. Defer to external sources to avoid visual redundancy and confusion.	●	
	Improve the communication of the disposal Provide information about materials and processes to facilitate waste sorting and recycling.	●	

Table 17 - Generic eco-guidelines for designing products and packaging

Table 18 - Specific eco-guidelines for designing products and packaging

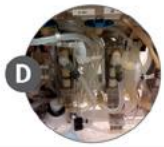
PRODUCT | SPECIFIC GUIDELINES		PRODUCTS	MACHINE	TREATMENT
REDUCTION	(D) **Design the composition of AVF connection kits** Avoid the waste of not used products and/or allow the personalization of the kit according to the treatment method.	● PackDistr		●
	(M) **Avoid or simplify overpackaging** Avoid the use of overpackaging or make it easy to open in order to reduce the effort required to the health staff for open pack/product.	● PackTrans PackTreat		
MATERIALS	(M) **Avoid materials containing phthalates (especially DEHP)** If possible, avoid the use of PVC and other plastics that could cause health and environmental problems.	● PackTreat		●
TECHNOLOGY	(M) **Facilitate data entry procedures to record the products used in the treatment.** Through the packaging itself or thorugh digital procedures.	● PackTrans PackTreat		●
FLEXIBILITY	(D) **Preserve connection kits during the whole treatment** Design the opening/closing system of packs to allow storing the connection kit until the end of the treatment	● PackTrans PackTreat	●	
USABILITY	(D) **Facilitate the set up phase both for HHD and IHD treatments** Avoid the use of pre-assembled kit, designing new systems easy to use even by non-medical staff in HHD treatments.	● PackTreat	●	●
	(M) **Improve movement and handling of secondary packaging** Design secondary pack providing gripping points and facilitating the opening even when stacked.	● PackTrans		
LIFE CYCLE	(D) **Allow the emptying of residual materials** In particular the bicarbonate contained in the cartridges and the solution residuals in the flexible bags.	● PackTreat		
	(D) **Facilitate the end of dialysis phase and the sorting of hazardous waste** Improve the disposal operations of bulky hazardous waste (bloodlines/dialyzer/infusion line).	● PackTreat		●
INFORMATION	(M) **Facilitate the daily procedure of supply made by the health staff** Make each product and type of product easy to identify and pick up.	● PackDistr PackTrans		●

(M) MEDICAL SECTOR (D) DIALYSIS

EQUIPMENT| GENERIC GUIDELINES		MACHINE	SYSTEM
	MAIN GUIDELINE: The shape of the product is determined by: the layout of internal parts; the relationship between the components; the production processes; the optimization of the operation (human-machine interaction).	●	●
MATERIALS	**Minimize the use of materials with a heavy ecological rucksack**	●	
MATERIALS	**Minimize the use of different materials inside the product. If possible, prefer single-material components or materials that are compatible with each other for the recycling.**	●	
MATERIALS	**If possible, prefer recycled, recyclable or biodegradable materials, avoiding composite materials.** Facilitate waste sorting and material recycling.	●	
LIFE CYCLE	**Consider the life cycles of the components and provide for the replacement of some of them during the machine life cycle**	●	●
LIFE CYCLE	**Facilitate maintenance and component regeneration or update.** Design the components layout to extend the life cycle of the machine.	●	●
LIFE CYCLE	**Follow a Design for Disassembly approach (upstream design of the disassembly, predetermination of breaking areas).**	●	●
LIFE CYCLE	**Promote recycling through easy disassembly** Facilitate the disassembly of different components and materials.	●	●
FLEXIBILITY	**Simplify the shape of the machine, preferring the modularity and standardization of its components.**	●	
FLEXIBILITY	**Optimize volume and shape** If possible, prefer the use of modular elements easy to assembly, disassembly and replace.	●	

Table 19 - General eco-guidelines for designing machines

EQUIPMENT | SPECIFIC GUIDELINES		PRODUCTS	MACHINE	TREATMENT
MATERIALS	**Prefer to use plastics that are easier to recycle.** Especially for components that are not in contact with fluids (e.g. shell components).	●		
	Promote recycling through communication. Make materials easily recognizable by using standard labelling and clear indications.	●	●	
FLEXIBILITY	**Make the supply system flexible and context-sensitive** Design a machine that can be customized according to the local supply system (on-line/disposables/multiuse products).	● PackTreat Product	●	●
	Optimize volume and shape of the machine, considering narrow areas in the wards. The machine must be compact, comfortable and available for use also in narrow areas.		●	●
USABILITY	**Enhance the role of patients** Facilitate their involvement in the treatment and allow them to check parameters and procedures in a easy way.	● PackTrans PackTreat Product	●	
	Optimize and facilitate the set-up phase Facilitate the set-up operations both for health staff and for non-expert users (in HHD). Pay special attention to the connection of bloodlines and concentrates.	● PackTreat Product	●	
	Offer entertainment possibilities Create entertainment opportunities for patients during long treatments, through the machine or their personal devices.		●	●
LIFE CYCLE	**Design the machine in a holistic way.** Design the machine together with products and packaging to avoid as many single-use products as possible.	● PackTreat Devices	●	●
	Make the machine easy and confortable to use and access also for technician. Take into account the more common maintenance issues and technicians' needs in designing the shape.		●	
	Design effective protectors for electical parts Design protective components that can be easily removed during maintenance		●	

LIFE CYCLE		PRODUCTS	MACHINE	TREATMENT
	(M) **Facilitate the disassembly of the machine** Simplify the locking system of components (preferring reversible joints) and reduce the number of tools needed for disassembling		●	
	 (D) **Optimize internal layout of components and tubing system** Facilitate accessibility to all components for maintenance and disassembly		●	●
	(D) **Allow the disposable products to be drained rapidly** Design emptying system to avoid residual materials within product and pack waste	● PackTrans PackTreat Product	●	

(M) MEDICAL SECTOR (D) DIALYSIS

Table 20 - Specific eco-guidelines for designing medical equipment

4.3 Treatment guidelines

The routine analysis has allowed establishing the main criticalities of the treatment that affect the design of the products and their end-of-life. The analysis focuses on **four types of routine activities** that characterize the behaviour of users within a hemodialysis treatment (cf. par 3.3.1).
The treatment guidelines start from the analysis results and address the four categories of activity. For each type of activity, the related guidelines are shown, as well as the levels of intervention that is required to address the problems highlighted (product, equipment, treatment).
Unlike the product and equipment guidelines, the treatment guidelines include **only "specific guidelines"** (Table 21) because they especially address the medical sector and the haemodialysis treatment. No generic design guideline takes into account the users' routines and can, therefore, be applied to this case.

1| MANUAL ACTIONS

The guidelines are aimed at **improving the usability and effectiveness of physical activities** to manage the disposable products for setting up the machine and for connecting it to the patient. Special attention is paid to the end of dialysis, in which the majority of waste is sorted: a proper design can enhance better sorting and recycling.

2| DIGITAL ACTIONS/CHECKING:

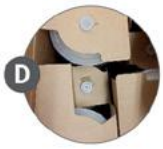
The guidelines concern the **reduction of the cognitive efforts** needed to interact with the digital interfaces: users must set the equipment parameters and monitor the patient parameters throughout the treatment.
Moreover, design can act to improve the data record of patient parameters and the data about products (such as batch codes).

3| STAFF INTERACTION

The guidelines focus on supporting the caregivers to improve their knowledge and skills, by **facilitating mutual participation** in meetings and other planned moments. Design could also enhance the implementation of social actions for promoting environmental sustainability.

4| PATIENT EMPOWERMENT

The guidelines focus on **supporting the patients to promote their autonomy and awareness**. Design can boost patient empowerment regarding the therapy (towards limited-care and self-care) and environmental sustainability.

TREATMENT | SPECIFIC GUIDELINES		PRODUCTS	MACHINE	TREATMENT
MANUAL ACTIONS	 (D) **Facilitate the daily supply of dialysis products** Improve ward and dialysis room storage. Make packaging easier to open and to identify.	● PackDistr PackTrans		●
	(M) **Improve waste sorting** If possible, use a single material. Make materials easy to identify and provide effective waste sorting systems in the dialysis room.	● PackTrans PackTreat Disposables		
DIGITAL ACTIONS/CHECKING	(M) **Minimize time and effort to take notes** Digitize data and notes about packaging and products. Improve the use of patient's electronic card.	● PackTrans PackTreat Disposables		●
	(D) **Design a user-friendly machine interface** Make it possible to customize the interface according to users' needs, to make them more aware of the treatment.		●	
STAFF INTERACTION	(M) **Promote nurse training and autonomy** Simplify the treatment procedures and provide additional information to nurses in order to improve their skills during the treatment.	● Devices	●	●
	(M) **Promote training and focus group about sustainability** To increase personal and collective awareness, according to the knowledge and skills of the staff.			●
PATIENT EMPOWERMENT	(D) **Provide customizable entertainement to patients** Allow to customize entertainement and/or allow patients to connect their own devices (smartphone, tablets, etc.).		●	●
	(M) **Promote patient training and autonomy** Provide information to patients about treatment steps and their personal parameters, to improve their awareness and/or autonomy towards self-care.	● PackTreat Devices	●	●

(M) MEDICAL SECTOR (D) DIALYSIS

Table 21 - Specific eco-guidelines for designing for medical treatments

4.4 Towards a new system

The analysis of the system items provided a comprehensive overview of the current system (cf. par. 3.5), highlighting specific issues concerning the one-way relationships between users, the rigidity of the stakeholders' hierarchy, the indirect management of inputs and outputs, and the compartmentalization of the system items.

The guidelines defined new design strategies to address the system from a holistic perspective: they focused on specific issues while extending each topic to different system items. When thinking of a new system, we should **start from the current situation** and the actual needs related to products, equipment, and treatment. Designers should **support users** in their daily tasks, promoting life-long learning to **increase their skills and personal consciousness**. The focus on needs is fundamental to promote the autonomy of direct users: achieving a greater independence and self-awareness make the users able to **rebuild the network of relations at both the micro and macro level** (Figure 19).
A multi-lateral dialogue can foster sustainable behaviours and increase the attention to environmental concerns. Output and input management can be shared among all the users involved in the system: resource consumption and waste production are common responsibilities that should be approached together. Designing new sustainable solutions can help users to reduce waste upstream but can also act to enhance waste through their employment as new resources for innovative applications, aiming at achieving **environmental, economic and social sustainability**.
Looking forward, the presented system items will deeply change: design should **address products and equipment simultaneously**, conceiving them as a single item in order to optimize resources and functions, and better answer the users' requirements. Treatment will be more rooted in the local environment, with the objective of answering the specific needs of local users and promoting **sustainable strategies tailored to the local socio-technical context**.

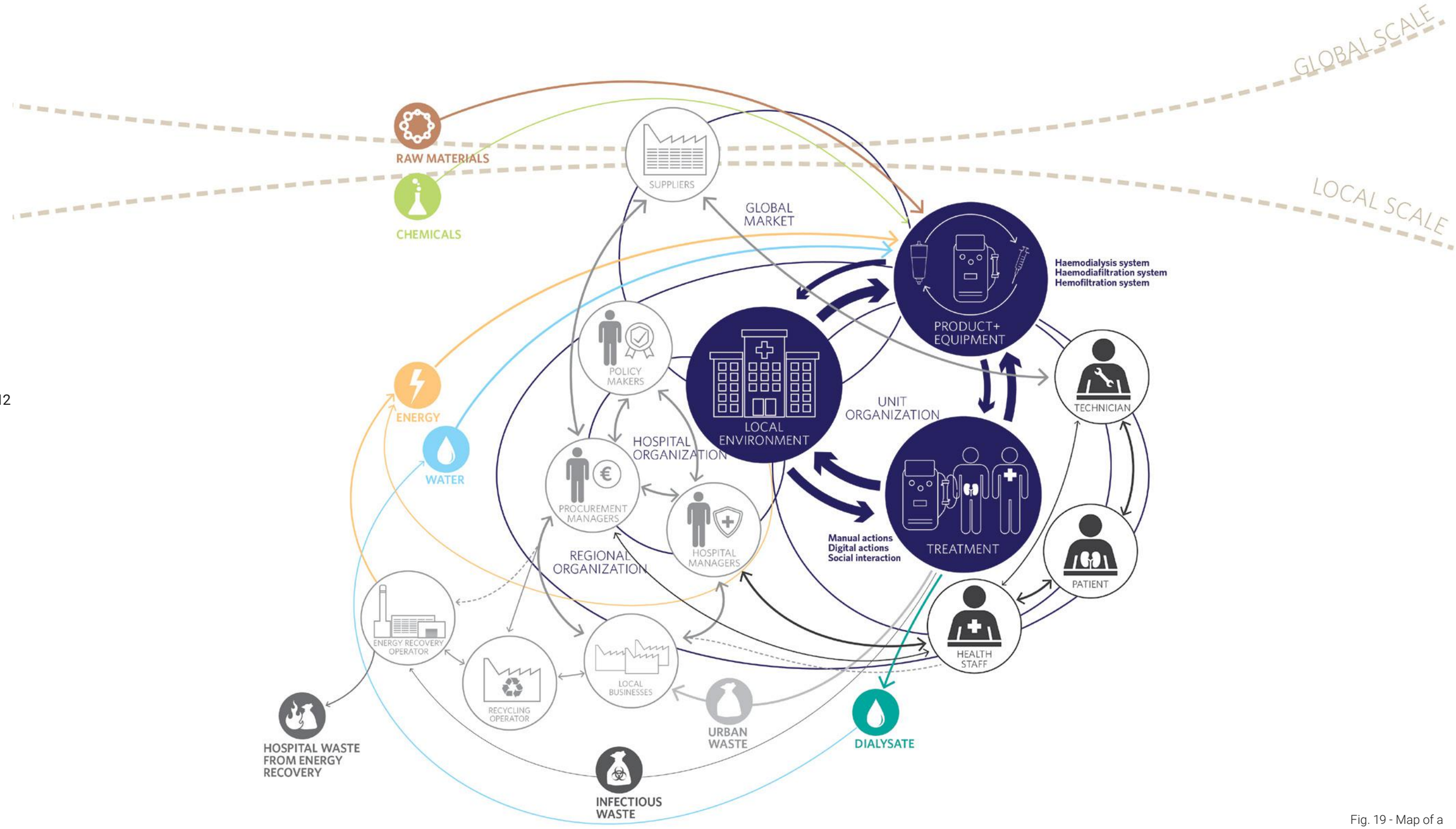


Fig. 19 - Map of a sustainable haemodialysis system

Chapter 5

Design strategies for Sustainable Healthcare

Practice-based strategies for enhancing the environmental sustainability of health treatments

"What we need now is a gaze that includes in its sweep how medicine sits within the Earth system as a whole, a subtle but revolutionary change of perspective from atomistic to holistic and from unbridled to sustainable development. This gaze does not supplant biomedicine. Rather it fits it into a necessarily bigger picture."

(Schroeder, Thompson, Frith, & Pencheon, 2012)

5.1 From Practice to Theory: Designing for Sustainable Healthcare

The present research aimed at answering two primary research questions: first, **how the health system affects the products**, considering how the users interact with them within the system. Second, which are the **most significant environmental impacts of the system and how design can help to address them** by improving the environmental sustainability of medical products, services, and systems, without losing sight of user-centricity.
The study has focused on the analysis of a complex health system, through the case study of haemodialysis, that is particularly representative of chronic noncommunicable diseases.
A specific methodology has been implemented to comprehensively analyse the system, by dividing it into four items: product, machine, treatment, and local environment. Each system item has been analysed, and the main issues have been outlined to define the requirements and, finally, a set of specific guidelines. The requirements highlighted many criticalities that characterize the haemodialysis system and, more generally, the chronic treatments, from an environmental and functional perspective. The guidelines address both the health treatments and the haemodialysis system, stressing the responses that design can provide to address the requirements, thus taking into account the relationships between products, equipment, and treatment, and the influence of local environment.
Thanks to the system analysis and the guidelines deriving from there, the study established some **priority design strategies that could foster the transition towards Sustainable Healthcare**.
These strategies start from **six key topics** emerging from the research.

First, the **optimization of volumes and weights** can reduce resource consumption and the environmental impact of products and packaging during transportation, thereby facilitating the storage. This change would have enormous advantages for the environment, but it would also solve real-world concerns: despite the construction of new efficient buildings and facilities, many hospitals are still located in existing and, often, historical buildings that respond to the healthcare needs of the past. The renovation of these buildings guarantees more safety and efficiency, but spaces are often tight, and the warehouses are frequently not adequate to the needs of the wards. Due to the considerable increase in chronic patients, it is important to design products and equipment that optimize spaces and facilitate access and interaction even under difficult working conditions. If we consider the enormous environmental impact of waste production, the space optimization is also fundamental for waste handling and sorting: recycling bins and other ancillary products should fit the space requirements of hospitals.

The second crucial strand is the **digitization**, which would allow avoiding information overload and reducing packaging while increasing the quantity and effectiveness of information provided to users. Many tasks would be easier and safer thanks to eHealth technologies: product batches and patient data could be recorded on digital patient record, thanks to scanning tools. Digitization can result in environmental benefits by reducing packaging, dematerializing patient record books, and promoting sustainable behaviours. Digital technologies can provide tips and information according to user's habits at the right time, so as to support users when they need it most.

Sustainable Healthcare should promote **life-long learning** and the development of collaborative learning and "learning-by-doing" by means of strategies and tools. Improving the autonomy and the skills of users, both staff and patients, can deeply improve the quality of care and raise people's awareness and understanding of health and environmental issues. A continuous learning helps to reduce human error risks and to promote sustainable behaviours, also through tech tools that provide reminders and suggestions.

Furthermore, designers should promote the **interaction of different media**. Physical products should interact with web-based services to fully respond to user needs, favouring the free interaction and the quick identification and

resolution of any errors. The use of personal devices exploits technologies which users are already familiar with, aiming at creating a tailored care. Design has to work on both levels to provide physical products that are easy to manage and use, and web services that effectively meet the needs and capabilities of users. The appropriation of media is the key to boost an effective media interaction: designers should promote to use the best media type for the communicative purpose, so as to make innovation actually efficient and sustainable.

Moreover, **user involvement** is the crucial goal of design for Sustainable Healthcare. Patients should become protagonists: the move towards home care is essential, but design should follow a gradual pathway allowing patients to gain self-confidence, self-esteem, and a better knowledge about their health. Nurses and health staff are also key users to support in their daily work, by facilitating their tasks and enhancing their professional skills. Today, technicians play an underestimated role: design should take their needs into account and help them to improve their capabilities since they are one of the keys to extending product life cycle.

Lastly, a **flexible design** is needed to provide more sustainable solutions: products cannot be separated from the equipment, and the needs of all users directly or indirectly involved in the treatment must be taken into account. The local environment in which a treatment takes place can deeply affect users' requirements and product development: design must help policymakers and procurement managers to open new paths towards Sustainable Healthcare.

5.2 Design Strategies

The guidelines provided important highlights on haemodialysis issues, by giving practical design suggestions to address this type of treatment. However, the aim of the doctoral work is to address health care and health treatments more broadly: as seen in the previous section, the analysis carried out on the case study enabled to define the emerging trends that will shape health systems and design for healthcare in the next future. Therefore, it is important to transform the answers given to the research questions in a practical tool that can be made available to designers and health stakeholders addressing Sustainable Healthcare.
The Design strategies are **a set of 15 strategies directed to designers and professionals**, that aims at describing the main issues to face in chronic treatments, the role of design in the resolution of these problems, and the relationships among users and system items that should be taken into account. The Design strategies are divided into the **seven categories of Design for Sustainability** which have already been used for categorizing the eco-guidelines (cf. par. 4.2). The categorization allows to include the strategies in an overall framework that designers are familiar with, so as to make them able to seek references for deepening and updating their knowledge about these topics.
All the Design strategies have the same visual organization, to set a common key of the reading. Strategies provide **detailed information on the principal issues and how design can address them, through specific guidelines**. Each strategy is presented in four sections:

1. **System items**: the strategy may involve the design of products, machines, or the whole treatment. The items involved are highlighted, and a short description summarizes the role of design toward each item.
2. **Issues**: the problems observed in chronic treatments are described in detail to share a common base of knowledge and make designers aware of the issues they should address.
3. **Design perspective**: this section describes the role of design in relation to the highlighted issues. The possible strategies to be employed are detailed, so as to provide a starting point for understanding the resulting guidelines.
4. **Design guidelines**: this section provides a short list of the main design guidelines concerning the issues addressed. It gives clear and concrete form to the previous sections, by defining practical suggestions for designing sustainable products, equipment, and systems.

In the following sections, the design strategies are presented according to the related category and in

relation to the system items (product, equipment, treatment) and the direct users (patient, health staff, technician) involved in a chronic treatment.

5.2.1 Reduction

Design for reduction means to **rethink the product and its function**, aiming at reaching a new solution that **minimizes materials, volumes, and thickness** toward dematerialization.
Identified strategies include simplifying packaging and overpackaging and optimizing the volume and shape of biomedical machines. As shown in Figure 20, reduction concerns product and equipment since it is especially aimed at physical artefacts, whose volumes and weights deeply impact the environmental sustainability during transportation and storage. The users affected by a reduction strategy are the technician and, above all, the health staff: in both cases, the lack of optimized layout and the use of bulky packs and unnecessary overpackaging make their daily tasks more challenging. The reduction can decrease the environmental burden of products and facilitate users' routines, ensuring a greater usability.

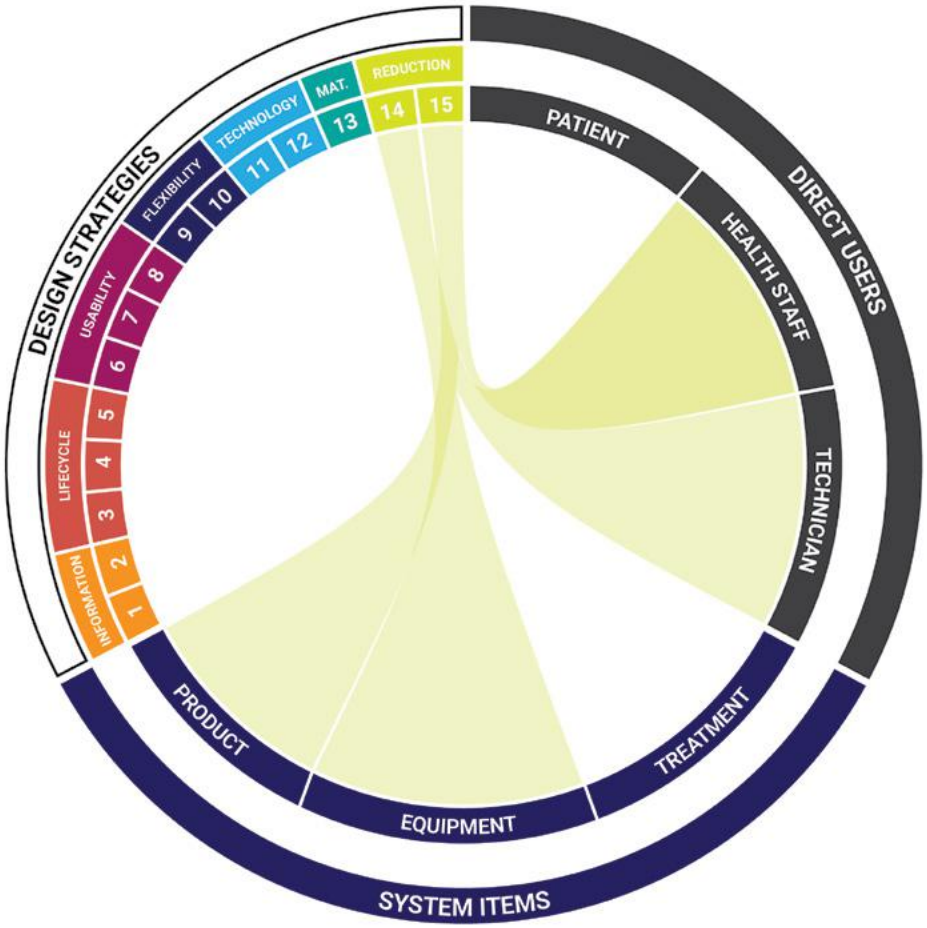


Fig. 20 - Diagram of Design strategies for reduction

AVOID OR SIMPLIFY PACKAGING AND OVERPACKAGING

PRODUCT	●	packaging optimization
EQUIPMENT	○	-
TREATMENT	○	-

ISSUES

Packaging has to protect the biomedical product and to maintain its sterility. So all products have a packaging and packaging for treatment (which directly connect to the machine) has an overpackaging to preserve sterility. In many cases, the packaging is oversized compared with the content and its actual requirements.
Oversizing affects both environmental sustainability and usability: the opening of packages require an additional effort to nurses that may further complicate the daily supply and worsen existing occupational diseases.

DESIGN PERSPECTIVE

Size optimization is the first step to reduce material consumption and improve usability. Packaging volume and weight can be reduced by acting on thickness and lightness while preserving its protective capacity.
Overpackaging may be avoided, preferring other sealing systems that could maintain sterility and facilitate the opening of the packaging.
In all cases, a better opening system could improve usability and optimize recycling.

DESIGN GUIDELINES

- Optimize size and volumes, avoiding unnecessary oversizing.
- Reduce thicknesses and prefer lighter protective solutions, in order to minimize the consumption of raw materials.
- Avoid overpackaging, preferring other sealing systems to ensure sterility.
- Reduce overpackaging and make it easy to open so as to improve usability and recycling.

OPTIMIZE MACHINE VOLUMES AND SHAPE

PRODUCT	○	-
EQUIPMENT	●	flexible design
TREATMENT	○	-

ISSUES

Biomedical machines and devices are often designed for optimal environments, where the space between the hospital beds is adequate to perform supply and set-up operations in a comfortable way.
In actual settings, the areas for treatment operations are narrow, and staff should operate in non-optimal conditions. Product connection and storage may be complex operations because of the context.

DESIGN PERSPECTIVE

Product compactness, lightness, and flexibility are key features to improve usability in non-optimal environments. The internal layout should optimize the outer shape, and the overall weight has to be minimized to improve product handling in narrow areas.
A well-designed location of the connection positions facilitates the set-up operations. Support areas and containers improve the storage of medical products and patient's belongings during the treatment.

DESIGN GUIDELINES

- Optimize machine volumes, considering narrow areas in the wards.
- Reduce weights to improve machine handling.
- Design a flexible location of product connections, so as to allow different configurations according to the local context.
- Provide containers and support areas to enhance product storing within the treatment.

5.2.2 Materials

There is no a material absolutely sustainable, but **the design choice we made in relation to the product makes that material sustainable or not.** This choice must first take into account the application, the fabrication process, and the user's requirements: functionality and environmental sustainability must always be assessed as a whole.
The Design strategy about materials focuses on recycling: the high standards required to products in the health sector make bio-based materials and reuse applications very difficult to implement. At the same time, recycling is the key to reduce the quantity of infectious waste and to increase the environmental awareness of end users. The strategy addresses technicians and health staff, that are directly involved in the management and disposal of products and machines and are responsible for material sorting (Figure 21).

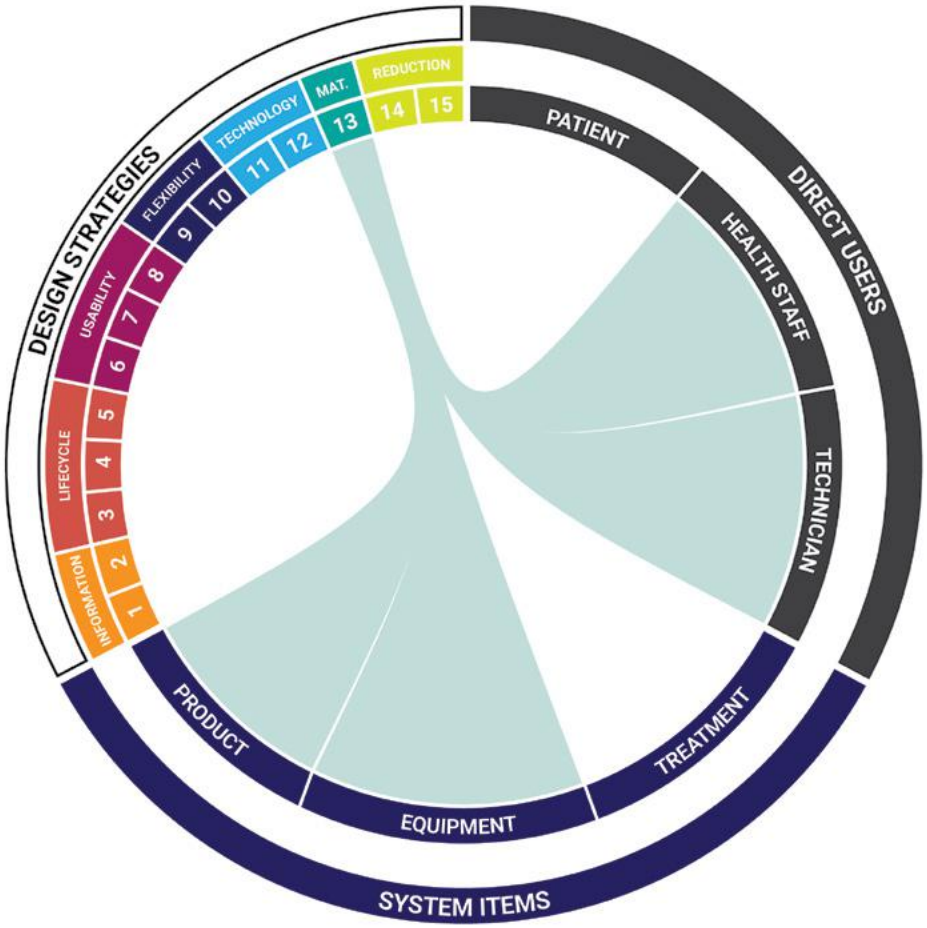


Fig. 21 - Diagram of Design strategies for materials

PREFER MATERIALS THAT ARE EASIER TO RECYCLE

PRODUCT	●	material choice
EQUIPMENT	●	material choice
TREATMENT	○	-

ISSUES

The choice of materials for biomedical products and packaging is particularly challenging. Biocompatibility requirements and medical regulations often lead to choosing composite and high-performance materials. However, some machine components, such as the protective ones, requires less stringent performance: the choice of more recyclable materials is thus possible. Packaging for distribution is usually made of commodity plastics, but it is often coupled with other components and materials, making recycling more difficult.

DESIGN PERSPECTIVE

Design should focus on those components and products that require less stringent requirements, as regards materials. Protective covers and structural components can be designed weighing up alternative solutions to the use of current plastics.
The recyclability of commodities and other recyclable materials must be ensured by allowing an adequate disassembly of packaging and products.

DESIGN GUIDELINES

- If possible, prefer recycled or recyclable materials.
- If possible, evaluate the use of biodegradable materials for packaging for distribution and overpackaging.
- Avoid composite materials, that are more difficult to recycle.
- Prefer commodity plastics that are easier to recycle.
- Communicate the material through standard symbols and proper information.

5.2.3 Technology

Technologies can help users in their daily tasks while reducing resource consumption, waste production, and promoting sustainable behaviours. Design should work to support the conscious use of technologies, **choosing the proper technology according to the actual needs of users.**
The Design strategies for technology focus on digitization through Internet-enabled technologies and patient entertainment. Both aspects are important: digitation and electronic data recording can reduce staff workload while minimizing the risks of errors; digital entertainment can actually improve the care experience of chronic patients, giving them the opportunity to spend their time in a useful and engaging way. Figure 22 shows how both patients and staff benefit from IT technologies, which involve all the system items, with a particular attention to the treatment procedures.

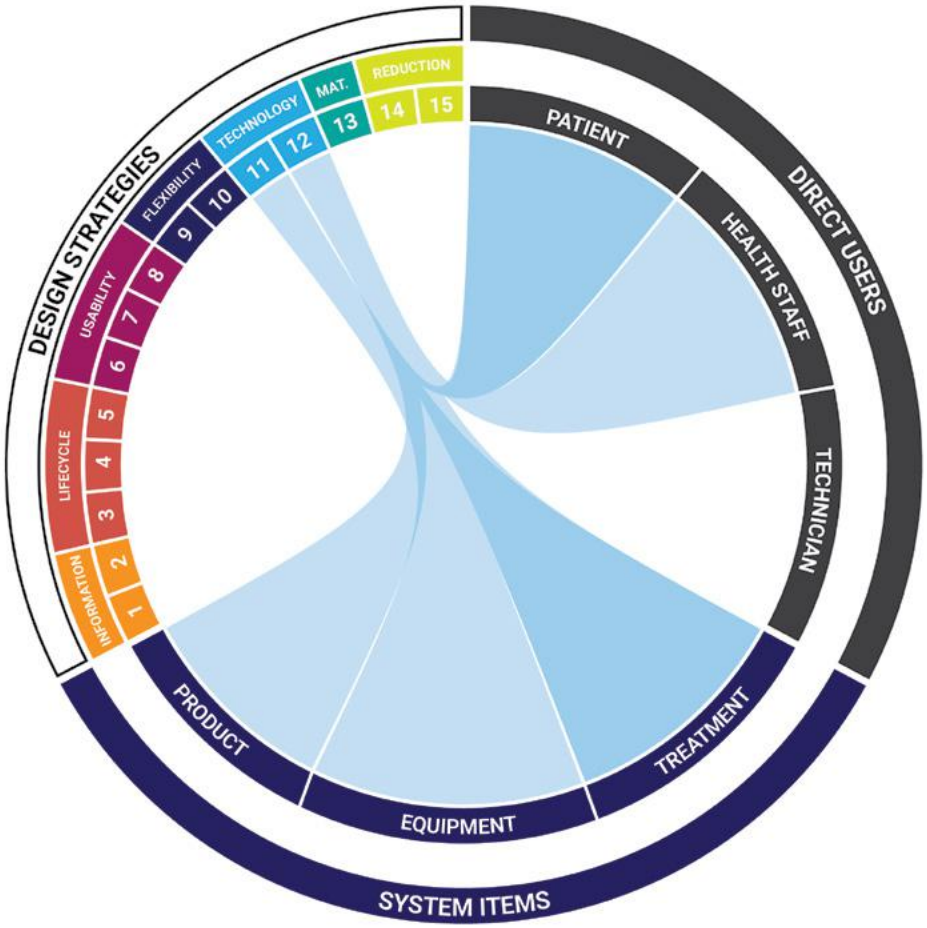


Fig. 22 - Diagram of Design strategies for technology

FACILITATE PRODUCT DATA ENTRY THROUGH DIGITALISATION

PRODUCT	●	internet-enabled packaging
EQUIPMENT	○	-
TREATMENT	●	digital tools

ISSUES

The medical staff must manually take note of the batch data of the main biomedical devices used in chronic treatments. This procedure aims at ensuring the control in case of any health problems, but it slows down and complicates staff work: they have to personally write information (with a greater risk of error) on the patient record book or to remove stickers from the packaging and paste them into the book.
At present, the machines allow to use patients' electronic cards, but their use is limited to automatically setting the therapy parameters, according to the latest treatment performed.

DESIGN PERSPECTIVE

Design can promote the use of digital technologies at a treatment level. The use of digital devices for batch number scanning and product-related information can make staff work faster and more secure. The use of Internet-enabled packaging (with QR codes) can facilitate this task. New "Near Field Communication" and "Bluetooth Low Energy" solutions can be tested towards mobile-engaging solutions.
Packaging design must prevent and follow the upcoming trends in digitization of patient records.

DESIGN GUIDELINES

- Promote the digitalisation of data entry procedures.
- Introduce internet-enabled technologies in packaging design (e.g. QR codes).
- Introduce internet-engaged technologies in packaging design (e.g. Near Field Communication).
- If digitalisation is not possible, provide clear communication of patch number and product information.

ENABLE CUSTOM ENTERTAINMENT SOLUTIONS FOR LONG THERAPIES

PRODUCT	○	-
EQUIPMENT	●	integrated entertaiment; personal devices
TREATMENT	●	internet-based entertaiment

ISSUES

The treatment of chronic disease requires long-term therapies (a dialysis session lasts on average 3-4-hours). There are usually some TVs in the ward, but these are seldom systems for personalization of broadcast programs. Patients carry with them books or personal devices, but equipment systems are not predisposed to facilitate reading or viewing. Often there is no way to recharge the devices. Overall, the entertainment aspect is underestimated, while it could significantly improve the patient's quality of life, allowing him to spend time or even work during therapy.

DESIGN PERSPECTIVE

In this case, Design must focus on the machine. The integration of entertainment solutions is likely to lead to rapid technological obsolescence (given the duration of the chronic machines). Instead, the possibility to connect patient's devices (or devices provided by the hospital) allows to customize the entertainment and, if necessary, repair the components without affecting the treatment.
Charging stations for the devices can be included in the machine, while the ward should provide wi-fi internet to access personalized contents.

DESIGN GUIDELINES

- Insert support elements for personal devices into the machine.
- Provide connection systems for personal devices.
- Provide charging station for personal devices.
- Make a free Wi-Fi connection available for patients.

5.2.4 Flexibility

Design for flexibility aims at creating products, services, and systems that can **meet the needs of different users, adapting to the change of these needs over time**.
The main strategies to enhance flexibility are the integrated design of the system, assessing the relations between products, machines and users, and the adaptability of machines to different infrastructural solutions. Flexibility involves all the users and all the system items (Figure 23). Special attention is paid to the equipment, that must adapt to different treatments, users, infrastructures, and environments during its long lifetime. Technicians are directly involved in the maintenance of the equipment and can act to ensure the update and technical flexibility according to the final application.

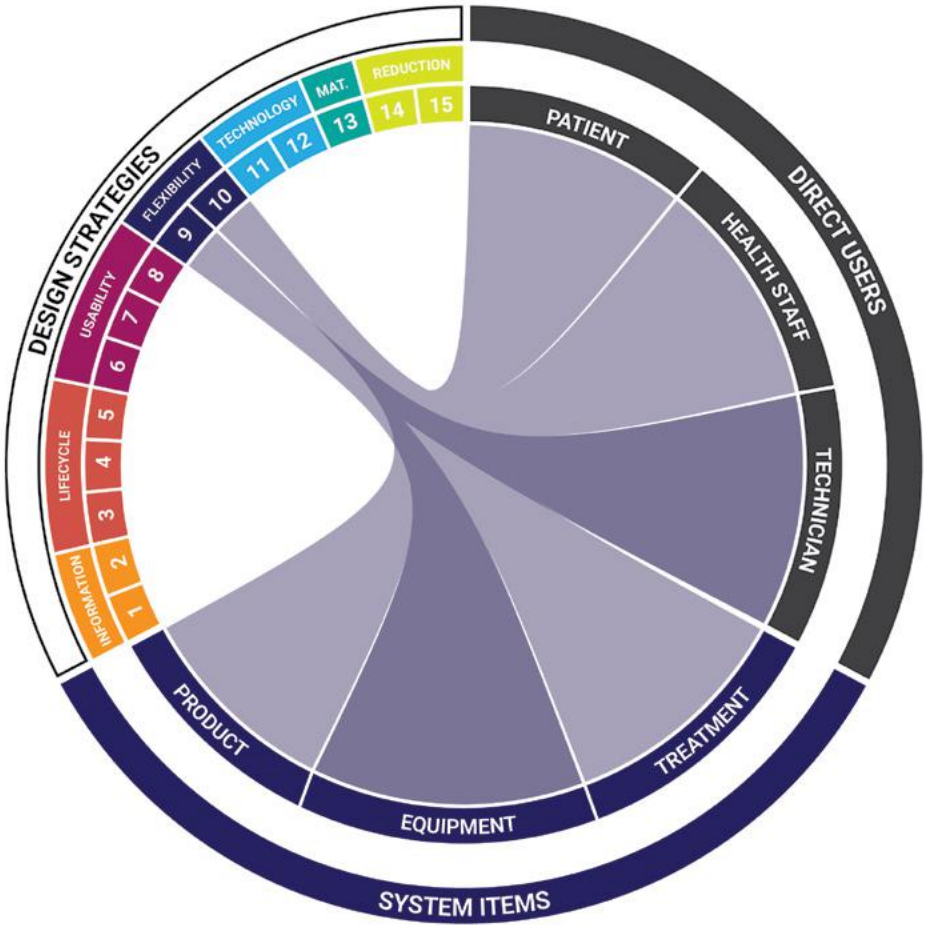


Fig. 23 - Diagram of Design strategies for flexibility

DESIGN THE MACHINE TOGETHER WITH THE DEVICE SYSTEM

PRODUCT	•	design together with the equipment
EQUIPMENT	•	design together with the products
TREATMENT	•	promote integrated solutions

ISSUES

The design of medical products and packaging often seems to be detached from the machinery. This problem leads to product oversizing, waste of resources, and lower usability when setting up the machine and connecting the patient.
At the same time, some sustainable solutions (such as the reuse of some devices) are not applicable if we design only the machine or only the products, but it requires an integrated design.

DESIGN PERSPECTIVE

The primary objective is to propose an integrated design of the device and machine system. Particular attention should be paid to optimizing the connection and the set-up phases.
More sustainable solutions can be evaluated to reuse, where possible, devices, simplify tubing systems, standardize components and products.

DESIGN GUIDELINES

- Integrate design processes of the machine and device system.
- Address users' tasks from a holistic perspective.
- Implement sustainable solutions, considering the whole treatment.

DESIGN FLEXIBLE CONNECTIONS FOR DIFFERENT INFRASTRUCTURAL SOLUTIONS

PRODUCT	○	-
EQUIPMENT	●	design for flexibility
TREATMENT	○	-

ISSUES

Biomedical machines are designed for a global market, so designers have to consider the wide variety of infrastructural requirements between different hospitals. In some cases, the department is equipped with on-line systems for water supply or other treatment solutions. In other cases, different types of disposable products are needed. This means the machine must have several components for connecting ancillary products: depending on the department, only one type of connection will be used, and the others will remain unused.

DESIGN PERSPECTIVE

The design of the machine must meet the needs of a global marketplace, which is a necessary factor to consider because of the cost and technological know-how required to create an effective treatment system. The design can adopt flexible solutions that allow the machine to be tailored to suit the needs of each department: from the component design that offers on-site personalization, to the creation of new connection systems that can adapt to different types of supply.

DESIGN GUIDELINES

- Design for multiple supply systems.
- Design a component-based solution to customize the machine according to the final user.
- Provide a flexible solution for product connection.

5.2.5 Usability

Usability arises from the **identification of user-focused problems** and aims at **providing solutions to solve them**.
Designing for usability means to answer the social, cultural, and operational needs of users. Usability and sim-plicity come together: design must simplify the use of complex products and systems, such as biomedical devic-es and healthcare systems.
Strategies for usability (Figure 24) consider all the users and address maintenance and upgrade, patient's autonomy, and product supply and handling. These aspects include all the system items because design must include usability in different ways and applications.

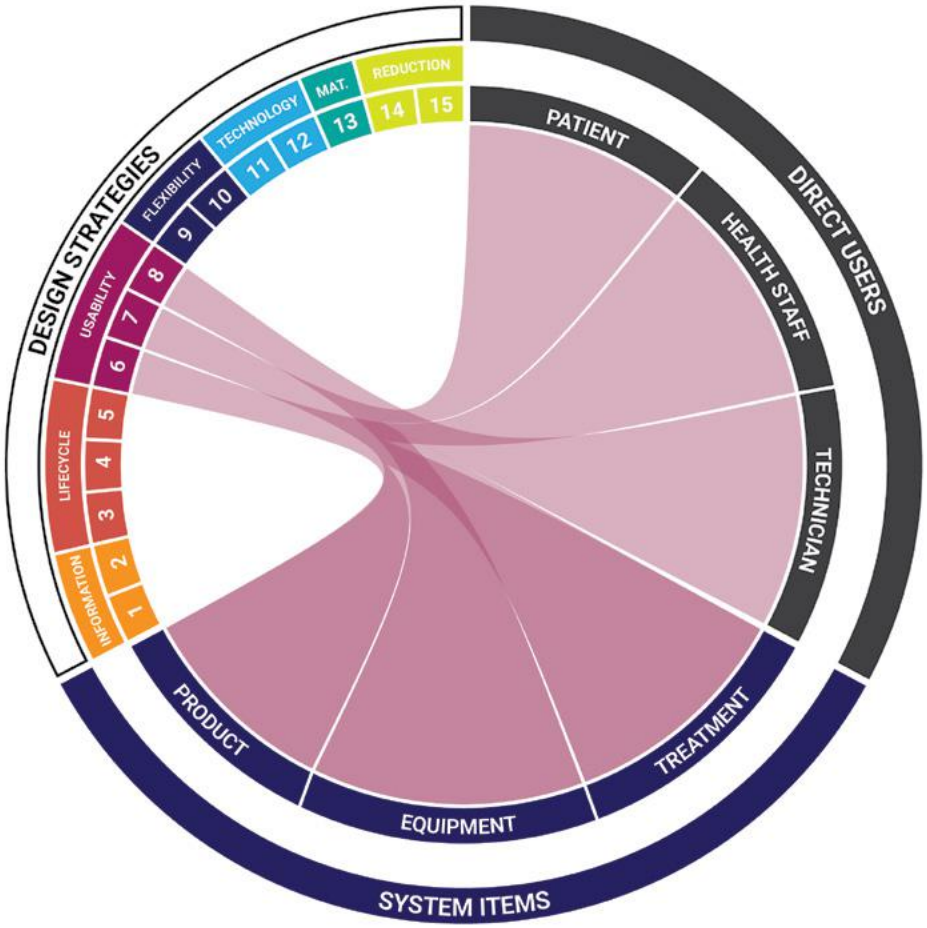


Fig. 24 - Diagram of Design strategies for usability

CONSIDER MAINTENANCE AND UPGRADE WHEN DESIGNING THE MACHINE

PRODUCT	○	-
EQUIPMENT	●	design for maintenance
TREATMENT	○	-

ISSUES

When thinking about user-centered design, the attention is given to the final user who, in medical treatments, is the caregivers or the patient. Although biomedical machines can be repaired and regular maintenance is provided, these operations do not take into account the ergonomic and cognitive needs of the technicians. The need to adopt awkward and uncomfortable positions is frequent, no visual design helps identify components, and the internal layout often does not facilitate repair.

DESIGN PERSPECTIVE

Designers must pursue a user-centred approach that takes into account all the users who operate within the system, including maintenance technicians.
The layout of components must consider not only routine maintenance but also occasional repair and system upgrades. The shape of the machine must facilitate maintenance, allowing the technician to working in a comfortable position. The use of color codes and visual systems for component identification can help users in repair work and maintenance operations.

DESIGN GUIDELINES

- Consider technician as final users of the products.
- Consider the need for ergonomics of technicians during maintenance operation.
- Design the component layout according to ordinary and extraordinary maintenance.
- Adopt a communication strategy to identify components and facilitate maintenance.
- Design the digital interface to facilitate the identification and reparation of system failures.

ENHANCE THE ROLE OF PATIENTS

PRODUCT	•	user-friendly products and systems
EQUIPMENT	•	digital and physical interfaces
TREATMENT	•	promotion of patient awareness

ISSUES

In hospital therapies, patients often play a very limited and passive role in receiving the therapy. The staff performs all operations, from personal parameter control to machine set-up, to data reporting, to product management. Today, it is commonly recognized the importance of an active role of patients and, if possible, patients should turn in-center care into home care. Current equipment and routines do not promote a progressive enhancement of the role of the patient: nowadays, selected patients are included in special training programs for limited-assistance care or home care.

DESIGN PERSPECTIVE

Design can promote greater autonomy and awareness in all patients, including those who have to undergo in-center therapy. Easy-to-use interfaces and products and a clear communication of information and procedures can considerably increase patients' independence.

Training for home care can begin right away, providing progressive and continuous information to understand better what the patient is experiencing. The simplest actions can be carried out autonomously by all patients, such as monitoring their personal parameters.

DESIGN GUIDELINES

- Allow patients to check therapy parameters and procedures in a easily understandable manner.
- Provide tools to self-check and report personal parameters (such as weight and blood pressure).
- Provide clear information to patients about the steps of the therapy, so as to train them in order to enhance self-care.
- Facilitate the use of products and their connection to the equipment, towards a home-led perspective of care.

FACILITATE THE DAILY PROCEDURE OF PRODUCT SUPPLY

PRODUCT	●	secondary and primary packaging
EQUIPMENT	○	-
TREATMENT	●	digitalization

ISSUES

In most chronic treatments, disposable products are needed to medicate the patient or to connect it to the machine. Some products should be specifically selected according to the patient's clinical background. Therefore, the health staff has to prepare the required products before each treatment session, based on patient records. This operation is often hampered by the inadequacy of the warehouses created within the ward. Even the design of primary and secondary packaging does not facilitate this process. The manual selection of products also carries a higher risk of errors.

DESIGN PERSPECTIVE

Design can act on two levels: on the one hand, the design of secondary packaging can facilitate product selection through an easier opening and an adequate communication. Primary packaging should also help to identify the contained product and make supply operations easier.
On the other hand, the use of digital technologies for supporting the selection process can avoid errors in product supply and speed up the staffing tasks.

DESIGN GUIDELINES

- Design secondary packaging to facilitate the opening and closing, even when stacked.
- Design secondary and primary packaging to allow easy identification of their contents.
- Support the supply process thorugh an effective communication (labels, symbols, colors, typing).
- Promote digitalization to allow immediate identification of products thorugh tactile and optical digitizers.
- Organize the arrangement of products by evaluating the most common daily supply scheme.

5.2.6 Lifecycle

Designing for the life cycle means **extending the life of the product and its components, enabling maintenance and upgrading and planning secondary uses**.
The strategies deal with material sorting and the disassembly of packaging, products, and machines. The possibility to properly separate materials and components is essential for designing secondary uses and enhancing waste, by turning them into resources for other systems. The role of health staff in waste sorting determines the recoverability of waste since infectious and hazardous waste must be treated separately. Technicians are responsible for maintenance and upgrading, so they play a fundamental role in lifecycle extension. Design can help making products and machines easier to disassembly, but users must act for promoting waste enhancement (Figure 25).

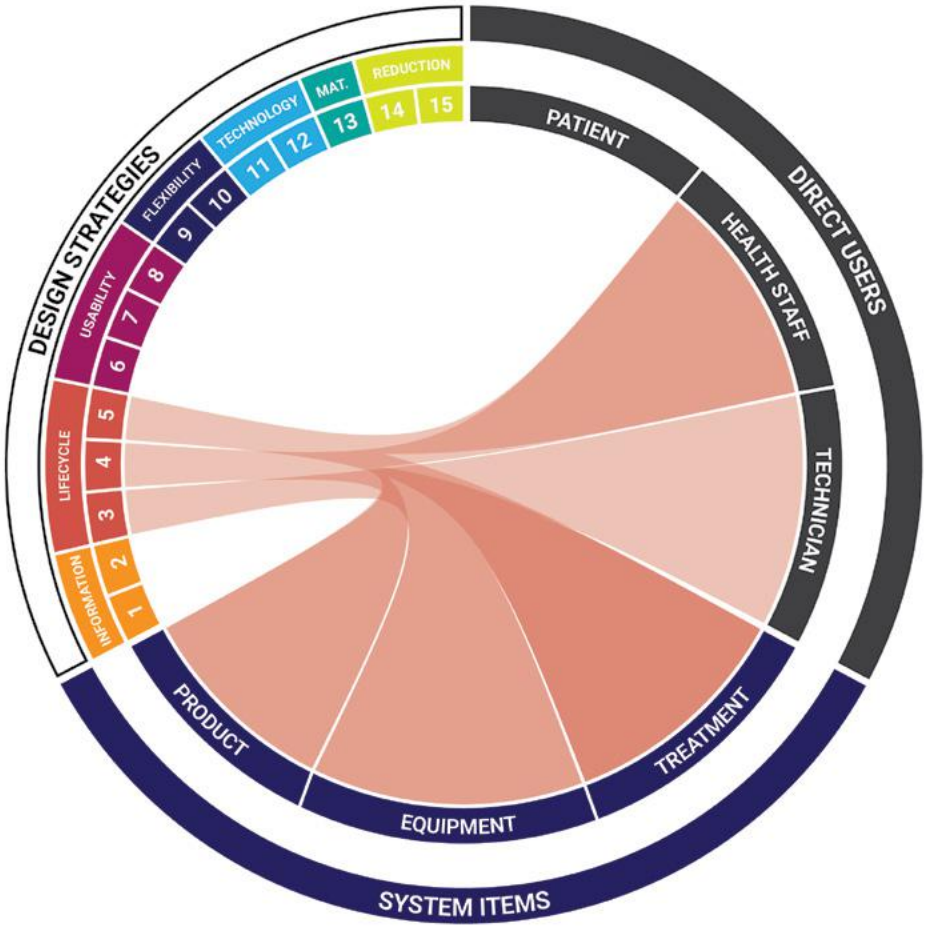


Fig. 25 - Diagram of Design strategies for lifecycle

FACILITATE USERS TO SORT COMMON WASTE AND HAZARDOUS WASTE

PRODUCT	●	waste types
EQUIPMENT	○	-
TREATMENT	●	waste collection bins

ISSUES

It is often difficult to make a clear distinction between hazardous and common waste, as well as between the different materials that comprise the common waste fraction. This is mainly due to:

- difficulties in distinguishing different materials when disposal is carried out under time pressure;
- difficulties in handling bulky waste;
- difficulties in separating components;
- lack of information about materials;
- different waste collection bins are not placed directly next to the treatment area.

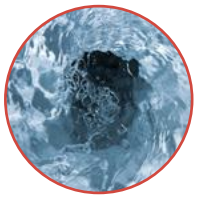
DESIGN PERSPECTIVE

Design should aim at improving the disposal operations, by making waste handling easier and waste sorting faster and more intuitive. Labels, closing parts, bonding systems, and composite and multi-material pack are key elements to take into account. The main goal is to design product and packaging that are readily recognisable, whose components are easy to separate and sort. At the same time, hazardous waste must be clearly identified to minimize the special waste fraction. Besides the products, the placement of sorting bins must be improved.

DESIGN GUIDELINES

- Make hazardous waste easy to identify with the aid of communication and position.
- If possible, group together the hazardous waste, so as to create a distinct block of waste. Provide also gripping points to improve handling.
- Prefer using one single material, or help users to separate different materials since the opening of the packaging/product.
- Prefer to use clearly recognisable symbols (standard pictograms) to indicate materials.
- Design an effective placement of the waste collection bins close to the bedside, so as to facilitate users in the disposal phase.

ALLOW THE EMPTYING OF RESIDUAL MATERIALS



PRODUCT	•	opening systems
EQUIPMENT	•	opening systems
TREATMENT	•	training on waste sorting

ISSUES

In many medical treatments, bags, cartridges, and other devices still contain non-pharmaceutical residual fluids (e.g. saline solution) or materials (e.g. bicarbonate) at the end of the treatment. The presence of liquid or solid waste within packaging can negatively affect recycling and increase the overall weight of waste. In some cases, hospitals encourage staff to empty the devices, but their design does not ease the operation. In other cases, as in dialysis, the machine can automatically empty the devices, but this procedure is time-consuming, and staff often can't wait for it.

DESIGN PERSPECTIVE

Design can effectively contribute to solving this issue, working both at product and machine levels. As regards products, the emptying procedure can be facilitated through the design of opening systems, as well as by predetermined breaking points. If a machine is present, it can help users by quickly automatically emptying the device or by exploiting the breaking points to open it. In all cases, emptying is an additional action, and appropriate reasons must be provided to users, through proper training.

DESIGN GUIDELINES

- Provide opening systems to empty packaging/devices at the end of the treatment.
- Predetermine breaking points to allow users opening packaging/devices at the end of the treatment.
- If fast automatically emptying is not possible, machines could be designed to help users in opening the packaging/devices.
- Motivate users in emptying the packaging/devices, thorugh specific training and visual manuals.

FACILITATE THE DISASSEMBLY OF MACHINES AND COMPLEX PRODUCTS

PRODUCT	○	-
EQUIPMENT	●	designed for disassembly
TREATMENT	●	training on waste sorting

ISSUES

Biomedical machines and complex devices consist of several components that are mainly made of composite materials or different materials joined together. Often WEEE is fastened together with polymer components, making them harder to separate and recycle. Many sub-components are assembled by the external suppliers, which use their own type of screws and bolts; therefore, several tools are needed for disassembling, despite there are few types of fastenings. Problems in accessibility negatively affect maintenance and disassembly, making component separation more difficult.

DESIGN PERSPECTIVE

The methods of Design for Disassembly address the accessibility issues to improve disassembly for maintenance and recycling.
Mono-material components should be preferred, where possible. The choice of the fastening type is important to facilitate the separation of elements made of different materials and to reduce the number of tools needed. Overall, a careful design of the internal layout, considering maintenance and end of life operations, can enhance the upgrade, repair, and recycling of machines and complex products.

DESIGN GUIDELINES

- Prefer mono-materials components.
- Prefer materials that are easier to recycle.
- Simplify the fastening system of components, preferring reversible joints that allow separating different materials.
- Choose common fastenings, so as to reduce the number of tools for disassembling.
- Optimize the internal layout, facilitating access to all the components for maintenance and disassembly.

5.2.7 Information

Communication is crucial to **creating awareness in the user, throughout the whole life cycle**.
Packaging and products must promote sustainable behaviours concerning their purchase, use, and end-of-life.
Design strategies focus on communicating environmental sustainability through the product and enhancing users' training and autonomy. As shown in Figure 26, all users are affected by information, that aims at encouraging the effective presence of information on products and equipment, and using new technologies to provide personalized information to patients and health staff.

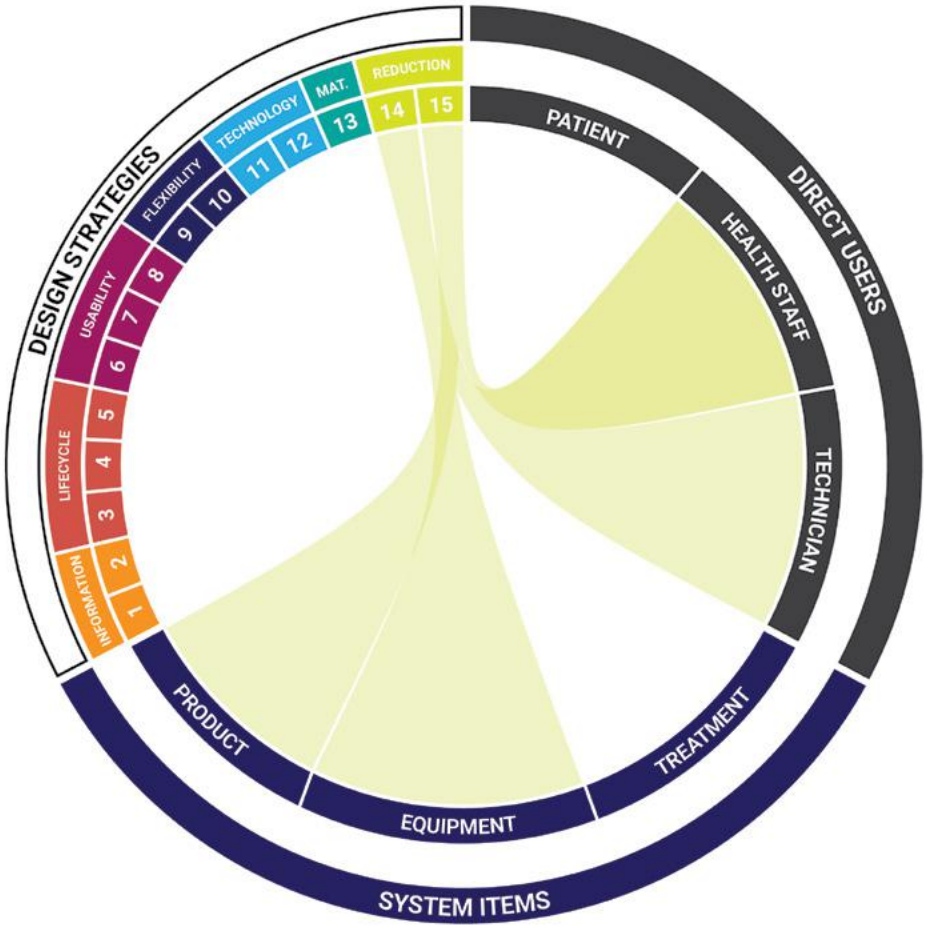


Fig. 26 - Diagram of Design strategies for information

PROMOTE ENVIRONMENTAL SUSTAINABILITY THROUGH COMMUNICATION

PRODUCT	•	communication and labels
EQUIPMENT	•	communication through the interface
TREATMENT	•	informative documents

ISSUES

Users' awareness is the key to promoting an all-encompassing commitment to sustainability that lasts over time and positively affects all daily activities. Resources invested in promoting sustainable behaviours vary considerably from hospital to hospital and from country to country. In some cases, environmental managers coordinate the sustainable initiatives, in other cases, it is a free personal choice. Products and machines provide a way to communicate useful information to improve the environmental (and economic) sustainability of health treatments. However, this kind of communication is completely missing today.

DESIGN PERSPECTIVE

Users' behaviours can effectively improve the sustainability of medical treatments: from the attention to resource consumption (energy, water, chemicals) to the choice of products with a low environmental impact, to a correct waste recycling. The effectiveness of these behaviours is based on the user's awareness. Products can provide clear information to facilitate recycling, and communication can highlight the environmental impacts and advantages of products. Information documents should be designed specifically for each user to support their daily routines.

DESIGN GUIDELINES

- Provide information about the environmental impacts of products.
- Make materials easily recognizable by using standard labelling and clear indications.
- Provide informative documents for promoting sustainable behaviours within daily routines.
- Provide information through the equipment interface.

PROMOTE USERS' TRAINING AND AUTONOMY

PRODUCT	○	-
EQUIPMENT	●	fully costumizable interfaces
TREATMENT	●	promoting autonomy

ISSUES

Improving patient autonomy and knowledge is definitely one of the main challenges for healthcare. However, the current scenario shows a deficit of training also among professional caregivers. Machines, in particular, offer a considerable potential for interacting with users, but this potential today is limited to communicating data about patients and the ongoing treatment. Professional training is left to personal initiative or training programs promoted by hospitals.

DESIGN PERSPECTIVE

Product and equipment design can act to improve the autonomy of all users, whether they are patients or caregivers. Customizable interfaces allow the machine to interact individually with different users, providing specific information according to their tasks. In this way, it is possible to increase the knowledge and skills of users, by correcting wrong habits, reducing the risk of human errors and promoting virtuous behaviours.

DESIGN GUIDELINES

- Simplify the treatment procedures to enhance users' autonomy.
- Provide additional information to health staff to improve their skills during the treatment.
- Provide suggestions based on individual behaviours
- Design fully customizable interfaces to allow individual interaction

5.3 Conclusions

Design research, as seen in the literature review (cf. chapter 1), is bringing a valuable contribution in different domains of health care, focusing on need identification and usability and aiming at boosting care and self-care innovations. The moving to home care and the improvement of care quality and usability are important steps to help the health systems to cope with the emerging health needs of long-term and noncommunicable diseases, as well as the need of increasing their financial sustainability. However, the principle of Sustainable Healthcare has been primarily pursued from an economic and a social point of view. One of the main challenges health systems will face in the future is to identify new pathways to reach a comprehensive sustainability. The environmental impact of health treatments is unbearable, and more and more health stakeholders are advocating for new environmental policies and initiatives. Although the contribution of Design research is still limited, it has the potential to improve the sustainability of products, services, and systems, by creating new solutions to address the emerging health issues.

Traditional design disciplines have focused on health care from an individual perspective, but the complexity, versatility, and wickedness of Sustainable Healthcare require a holistic approach.

The present research is set in the wider framework of Systemic Design (SD): the SD approach allows including environmental sustainability into the design process, considering environment as a cross-item of the system which dialogues with the other stakeholders. Design must focus on the set of interrelationships within the system to address the sustainability issues without losing sight of the other items. Thus, a systemic approach to health care enables to address environmental sustainability in multi-stakeholder and multi-environment systems, while maintaining the focus on patient empowerment and user-centred care.

The application of SD to a complex medical treatment, such as haemodialysis, highlights important strategies to move toward a more sustainable and resilient system:

1. **Relationships among users improve the system.** The final goal of the design process is to improve user's experience through improving the relationships among users and between the user and the system items. The starting point is the identification of the actual needs according to the user's tasks and role within the health treatment. Answering those needs means to enhance the autonomy, awareness, and self-confidence of users: patient empowerment is a key challenge for health systems, but all direct and indirect users should be enabled to take an active part in the system. Individual empowerment is necessary, but not a sufficient condition to boost sustainability. Design should focus on relationships to promote a direct and mutual dialogue between users. Nowadays, health hierarchies led to one-way communications that are hampering the implementation of bottom-up initiatives and the general raising of environmental awareness. Design should enhance direct participation, by bringing into permanent communication direct users (patients, physicians, nurses, technicians) and indirect users (hospital administrators, procurement managers, policymakers).

2. **Considering material flows from a circular perspective.** SD analyses material flows to enhance the waste of health processes, by transforming them into resources for other systems. Despite the focus on outputs, the design process should involve all the stages of the product lifecycle, acting both upstream of the production and downstream of the health treatment. Material reduction and resource optimization are important strategies to prevent waste production and rethink products and services in a different way. Design should give preference to local resources and technologies, to promote the development of the territory and extend the supply network on the local scale. However, medical treatments cannot be set apart from the global market: SD should consider international manufacturer and suppliers to promote a global awareness concerning the sustainability and flexibility of products and services. The attention to outputs is also linked to a broader perspective

of circular economy. The creation of local and global networks allows finding new solutions to manage waste and turn them into new resources for innovative industrial applications.

3. **Integrated vision of products and services.** The traditional view of product and service design cannot tackle the complexity of health care. The design of a medical device cannot ignore the relationships between the other devices, the users, and the local environment. Today, we have several suppliers that provide ancillary products based on common standards: conceiving a product as a stand-alone item inevitably leads to a lack of usability and sustainability. Design should focus on products considering them as small parts of a wider system. The relation between products and medical equipment is essential: they can not be regarded as different goals of the design process, but rather should be designed as a single integrated system. This approach leads to rethinking the product itself, moving towards dematerialization and service-based systems. New technologies can significantly promote this shift, but their effectiveness relies on the need identification: Product Service System must first of all answer the actual requirements of the users involved in the system.

4. **Sustainability as a cross-item feature of the system.** Environmental sustainability always embeds economic and social aspects, representing a pervasive and flexible feature of the system. Therefore, policies can not address environmental sustainability through a top-down sectoral approach: all the system items must be addressed in a coordinated and complementary way, involving direct and indirect users. Policies can expedite moving from current understanding to a new approach to health care, but the systemic nature of sustainability must be acknowledged. Design should support policymakers to broaden their perspective on sustainability, moving from the product to the system and promoting users' awareness, that represents the first goal to achieve towards Sustainable Healthcare.

5.4 Contribution to knowledge

This thesis work deepens the knowledge of design thinking in relation to the healthcare field, providing a collection of theories and approaches that are addressing design topics in different healthcare domains. The doctoral research contributes to knowledge on Systemic Design (SD), strengthening the theoretical approaches to SD through increasing the body of empirical evidence. The goals achieved provide a valuable contribution to the emerging field of Sustainable Healthcare, addressing the environmental sustainability of complex systems from an integrated perspective.
This thesis work has a value for the research community, policymakers, procurement managers, and healthcare stakeholders and organizations promoting Sustainable Healthcare. In detail, the contribution of this research can be classified into four achievements:

1. **Fieldworks**. The research is based on extensive fieldwork, carried out on three international case studies. On-field analysis has focused on waste production, users' routines, and environmental organization. Each case study has involved qualitative interviews and discussions with a range of health stakeholders, such as regional policymakers, environmental coordinators, academics, company managers, and clinicians. The data collection and analysis represent an empirical contribution to the body of knowledge on design for Sustainable Healthcare.
2. **Methodology**. The research is based on a strong theoretical background and original field examinations. Although the analysis has focused on a significant case study, such as chronic haemodialysis, the implemented methodology can be applied to a wide range of health treatments. Indeed, it provides a valuable methodological path to analyse the individual system items (product, equipment, treatment, and local environment) in connection to the whole system. The research outcomes provide practice-based design strategies to address SD in complex health systems.

3. **Knowledge**. This thesis work responds to calls in the scientific literature for a greater understanding of the role of design research towards Sustainable Healthcare. The analysis of chronic treatment from a design perspective can, therefore, be considered a novel approach to this field. The interdisciplinary collaborations that supported this research has allowed combining different competencies and skills, finding a common language that caters for various audiences and disciplines.
4. **Strategies**. Practical tools and methods are needed to apply SD to real socio-technical systems. Therefore, the final goal of the doctoral research was to provide a practice-based tool for researchers, designers, and stakeholders involved in the design process. The final set of design strategies provides valuable guidance to build up a common background and to include environmental sustainability in the design process.
5. **Interdisciplinary dissemination.** Since Sustainable Healthcare is a new inter-sectoral and interdisciplinary field, the results have aimed at being disseminated to as wide a public as possible. The findings of this research were presented at several design conferences, but have also been published in major medical journals, and presented at informal meetings with companies and healthcare stakeholders. The collaboration with the Nordic Center for Sustainable Healthcare allowed reaching a wide audience of policymakers, companies, and hospitals.

5.5 Limitations and directions for future research

This doctoral dissertation has investigated the emerging field of Sustainable Healthcare from a design perspective, aiming at defining how design strategies can boost the transition towards more sustainable health systems and how these complex systems affect and relate to products, services and stakeholders. The core of this research is the application of the Systemic Design approach to analyse a significant case study, Chronic Haemodialysis, to assess its environmental and functional impacts, understanding how design can face them through a systemic approach. The findings presented (see par. 4.2, 4.3 and 5.2) are not free of a set of limitations due to the research questions and the methodology chosen for carrying out this research. However, the definition of research limitations is essential to guide future research efforts to improve the contribution of Systemic Design to this research area.

5.5.1 Limitations

The investigation of Sustainable Healthcare and the contribution of design to this challenging topic is a complicated effort. Sustainability involves an interwoven set of environmental, social and economic aspects that deeply affect the health system. A single thesis has to choose an aspect to focus on, since the complexity of healthcare sustainability has to be addressed through a broader research, by involving different disciplines and skills. The key goal of this thesis was to deepen the environmental impacts of healthcare systems, in order to start filling a research gap that literature has clearly highlighted. So the research methodology has focused on the analysis of the system, paying special attention to its environmental sustainability: material flows, waste management, and environmental behaviours have been analysed in detail. Significant findings have been provided by assessing the environmental issues of a healthcare system both from a quantitative and qualitative

perspective and through cross-case and cross-national analyses.

However, the first limitation of this analysis derives from its complexity: the vastness and heterogeneity of problems make it difficult to establish a hierarchy of priorities to be addressed. The research identified many significant issues, but it was not possible to define which ones should first be addressed since they could provide increased benefits to the system, if solved. This is a complex issue that can not be solved by an external researcher: it would require a detailed assessment by health stakeholders and clinical, administrative, and organizational experts to understand the consequential impacts of the resolution of one issue to solve the main systemic criticalities. Furthermore, a multi-disciplinary collaboration would be essential to complete this analysis by extending the focus to social and economic sustainability, which have been investigated in a more marginal way compared to environmental sustainability.

The second limitation concerns the analysis of users: the first part of the analysis highlighted different item categories and specific user types (see par. 2.2) that characterised a health system. Because of their environmental impact, items have been investigated in detail, while only direct users (patient, clinician, nurse, technician) have been considered concerning their interaction with products, machines and treatment processes. More work is needed to broaden the scope of the analysis and address the system also from an organisational point of view, deepening the analysis of different stakeholders and the management of various types of services, including Home Dialysis (and the related patients). At present, organisational issues have been taken into account in relation to the environmental sustainability of products and processes, but different task-based roles and functional identities should be investigated in the whole dialysis system to boost innovation in patient-centred healthcare services.

Finally, the dialysis guidelines and the design strategies effectively sum up the results of the analysis of the system and provide practical guidance to interpret and start dealing with the highlighted problems. Since they are an output of the analysis, they carry with them some of the limits of the analysis itself. First, the focus on the selected system items (product, equipment, treatment) and their environmental impacts leads to a lack of guidelines concerning organizational aspects, healthcare policies, and business model solutions. Second, broader and more interdisciplinary studies are needed even in this case to validate the preliminary guidelines and move towards defining higher-order system guidelines.

5.5.2 Directions for future research

All the three mentioned sets of limitations identify a number of areas for improvement that can drive design research in the domain of Sustainable Healthcare.

In the short-term, the outcomes of the present research should be verified and discussed in detail with company stakeholders. Design guidelines and strategies shall be tested through the design of medical devices and services, collaborating with industrial partners to solve existing issues and implementing these preliminary results. Chronic haemodialysis is a significant case study, but other chronic noncommunicable diseases should be examined to define common issues and goals: future research could explore new areas to compare the results.

In the present thesis, the focus on environmental sustainability allowed to go into detail of a specific area of healthcare sustainability, showing the potentialities of design research in this sector and, in particular, demonstrating the need for a Systemic Design approach to the topic. Sustainable Healthcare is a wicked problem (see par. 2.1) that requires a systemic perspective to be challenged: even focusing on the environmental priorities, it is not possible to address the product design without including machines, treatments, and local environments in the analysis. Future works must enlarge the boundaries of the present analysis going into depth with the organisational analysis and the economic assessment: which

business models are affecting the management of chronic diseases? Which factors are hampering the sustainable innovation in this field? How can Sustainable Healthcare be effectively promoted? The answer to this research questions needs a multi-disciplinary approach that should involve different stakeholders (academics, companies, public healthcare, health organisations, patient associations) in complex structured research projects. Indeed, the research topic could be faced through medium-term European projects that would be able to create a heterogeneous partnership working on this multi-faceted topic.

In the long-term, Systemic Design research should be able to move towards system flourishing, by addressing the complex system of hospital and home care. Design should provide new business models and new products and services, based on an integrated and comprehensive view of Sustainable Healthcare. Obviously, before reaching this goal, intermediate steps are needed to deepen the knowledge about this field that is still unexplored from a design perspective. The dialogue which has developed with several healthcare stakeholders during this doctoral research has shown how it is first necessary to lay the foundations for raising the consciousness of sustainability as an integrated feature of healthcare products and services. The practical experience has demonstrated that there is still a long way to go but Design and system thinking could attract attention toward sustainability and have a key role to play in the transition towards Sustainable Healthcare.

bibliography

References

CHAPTER 1 - STATE OF THE ART

Agar, J.W.M. (2012). Personal viewpoint: Hemodialysis-Water, power, and waste disposal: Rethinking our environmental responsibilities. *Hemodialysis International*, 16, 6-10.

Agha, L. (2014). The effects of health information technology on the costs and quality of medical care. *Journal of Health Economics*, 34(1), 19-30.

Alvaro, C., Wilkinson, A.J., Gallant, S.N., Kostovski, D., & Gardner, P. (2016). Evaluating intention and effect: the impact of Healthcare Facility Design on patient and staff well-being. *Health Environments Research and Design Journal*, 9 (2), 82-104.

Amadi-Obi, A., Gilligan, P., Owens, N., & O'Donnell, C. (2014). Telemedicine in pre-hospital care: a review of telemedicine applications in the pre-hospital environment. *International Journal of Emergency Medicine*, 7 (1), 29-40.

Antonovsky, A. (1979). *Health, Stress and Coping*. San Francisco, USA: Jossey-Bass Publishers.

Asdrubali, F., Baldinelli, G., Bianchi, F., & Sambuco, S. (2015). A comparison between environmental sustainability rating systems LEED and ITACA for residential buildings. *Building and Environment*, 86, 98-108.

Balbus, J. et al. (2016). Enhancing the sustainability and climate resiliency of health care facilities: A comparison of initiatives and toolkits. *Pan American Journal of Public Health*, 40 (3), 174-180.

Banos, O. et al. (2015). Design, implementation and validation of a novel open framework for agile development of mobile health applications. *BioMedical Engineering Online*, 14 (2), S6.

Bitterman, N. (2011). Design of medical devices-A home perspective. *European Journal of Internal Medicine*, 22(1), 39-42.

Braun, D., Barnhardt, K. (2014). Critical thinking: Optimal outcomes through end user involvement in the design of critical care areas. *Critical Care Nursing Quarterly*, 37 (1), 33-40.

Breton, E.R., Fuemmeler, B.F., & Abroms, L.C. (2011). Weight loss-there is an app for that! But does it adhere to evidence-informed practices? *Translational Behavioral Medicine*, 1(4), 523-529.

Bresó, A. et al. (2016). A novel approach to improve the planning of adaptive and interactive sessions for the treatment of Major Depression. *International Journal of Human Computer Studies*, 87, 80-91.

Brown, T. (2008). Design thinking. *Harvard Business Review*, 86 (6), 84-92+141.

Burrows, A., Gooberman-Hill, R., & Coyle, D. (2015). Empirically derived user attributes for the design of home healthcare technologies. *Personal and Ubiquitous Computing*, 19(8), 1233-1245.

Busse, R., Blümel, M., Scheller-Kreinsen, D., & Zentner, A. (2010). *Tackling Chronic Disease in Europe: Strategies, Interventions and Challenges (Observatory Studies Series)*. Copenhagen, DK: World Health Organization.

Bussone, A., Stumpf, S., & O'Sullivan, D. (2015). The role of explanations on trust and reliance in clinical decision support systems. In *Proceedings - 2015 IEEE International Conference on Healthcare Informatics*, ICHI 2015, Dallas, USA (pp. 160-169).

Cai, H., Toft, E., Hejlesen, O., Hansen, J., Oestergaard, C., Dinesen, B. (2015). Health professionals' user experience of the intelligent bed in patients' homes. *International Journal of Technology Assessment in Health Care*, 31(4), 256-263.

Cama, R. (2009). *Evidence-Based Healthcare Design*. Hoboken, NJ: John Wiley & Sons.

Chenven, L., & Copeland, D. (2013). Front-line worker engagement: greening health care, improving worker and patient health, and building better jobs. *New solutions: a journal of environmental and occupational health policy*, 23 (2), 327-345

Cheung, M. (2012). Design Thinking in Healthcare - Innovative Product Development through the iNPD Process. *The Design Journal*, 15(3), 299-324.

Chiarini, A., Vagnoni, E. (2016). Environmental sustainability in European public healthcare: Could it just be a matter of leadership? *Leadership in Health Services*, 29(1), 2-8.

Clemens, T. et al. (2014). European hospital reforms in times of crisis: Aligning cost containment needs with plans for structural redesign? *Health Policy*, 117/1), 6-14.

Commission of the European Communities (2008). *Proposal for a directive of the European Parliament and of the Council on the application of patients' rights in cross-border healthcare* (No. 2008/0142 COD). Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0414:FIN:EN:PDF

Connor, A., Lillywhite, R., & Cooke, M.W. (2011). The carbon footprints of home and in-center maintenance hemodialysis in the United Kingdom. *Hemodialysis International*, 15(1), 39-51.

Cui, Y., Miao, Z. (2012). Green methods in medical environment design. *Advanced Materials Research*, 450-451, 843-846

Davis, J.N., Spaniol, M.R., & Somerset, S. (2014). Sustenance and sustainability: Maximizing the impact of school gardens on health outcomes. *Public Health Nutrition*, 18(13), 2358-2367.

De Ana, F.J., Umstead, K.A., Phillips, G.J., & Conner, C.P. (2013). Value driven innovation in medical device design: A process for balancing stakeholder voices. *Annals of Biomedical Engineering*, 41(9), 1811-1821.

Dellifraine, J.L., & Dansky, K.H. (2008). Home-based telehealth: A review and meta-analysis. Journal of Telemedicine and Telecare, 14 (2), 62-66.

DELOITTE (2016). *Global health care outlook. Battling costs while improving care.* Retrieved from https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Life-Sciences-Health-Care/gx-lshc-2016-health-care-outlook.pdf

Department of Economic and Social Affairs (2015). World Population Ageing – Highlights. New York: United Nations.

Design Research Society. *History of the Design Research Society*. Retrieved March 7, 2016 from http://www.designresearchsociety.org/index.php/about/history

Dilani, A., & Armstrong, K. (2008). The "salutogenic" approach- designing a health-promoting hospital environment. *World Hospital Health Service*, 44(3), 32-5.

Dobkin, B.H., & Dorsch, A. (2011). The promise of mHealth: Daily activity monitoring and outcome assessments by wearable sensors. *Neurorehabilitation and Neural Repair*, 25(9), 788-798.

Dombrowski, M., Smith, P., & Buyssens, R. (2017). Designing alternative interactive techniques to aid in prosthetic rehabilitation for children. *Advances in Intelligent Systems and Computing*, 483, 647-655.

Dorst, K. (2011). The core of 'design thinking' and its application. *Design Studies*, 32(6), 521-532.

Ekelanda, A.G., Bowes, A., & Flottorp, A. (2010). Effectiveness of telemedicine: A systematic review of reviews. *International journal of medical informatics*, 79:736–771

European Commission (2016). Joint Report on Health Care and Long-Term Care Systems & Fiscal Sustainability. Luxembourg: Publications Office of the European Union.

Evans, S., Hills, S., Grimshaw, L. (2010). *Sustainable systems of social care*. London: Social Care Institute for Excellence.

Evans, S., Hills, S., & Orme, J. (2012). Doing more for less? Developing sustainable systems of social care in the context of climate change and public spending cuts. *British Journal of Social Work*, 42(4), 744-764.

Fairbanks, R.J., & Caplan, S. (2004). Poor interface design and lack of usability testing facilitate medical error. *Joint Commission journal on quality and safety*, 30 (10), 579-584.

Fausset, C., & Harley, L. (2014). Designing home health technologies for older adults: The human systems integration approach. *Biomedical Instrumentation and Technology*, 48(5), 361-365.

Fearis, K., & Petrie, A. (2017). Best practices in early phase medical device development: Engineering, prototyping, and the beginnings of a quality management system. *Surgery (United States)*, 161 (3), pp. 571-575

Fiordelli, M., Diviani, N., & Schulz, P.J. (2013). Mapping mhealth research: A decade of evolution. *Journal of Medical Internet Research*, 15(5), e95.

Fung, C.H., Igodan, U., Alessi, C., Martin, J.L., Dzierzewski, J.M., Josephson, K., & Kramer, B.J. (2015). Human factors/usability barriers to home medical devices among individuals with disabling conditions: In-depth interviews with positive airway pressure device users. *Disability and Health Journal*, 8 (1), 86-92.

Furniss, D., Masci, P., Curzon, P., Mayer, A., & Blandford, A. (2014). 7 Themes for guiding situated ergonomic assessments of medical devices: A case study of an inpatient glucometer. *Applied Ergonomics*, 45 (6), 1668-1677.

Garg, A.X. et al. (2005). Effects of computerized clinical decision support systems on practitioner

performance and patient outcomes: A systematic review. *Journal of the American Medical Association*, 293(10), 1223-1238.

Gale, N., & Sultan, H. (2013). Telehealth as 'peace of mind': embodiment, emotions and the home as the primary health space for people with chronic obstructive pulmonary disorder. *Health & Place*. 21, 140–147.

Gerteis, J., Izrael, D., Deitz, D., LeRoy, L., Ricciardi, R., Miller, T., & Basu, J. (2014). *Multiple Chronic Conditions Chartbook*. Rockville, MD: Agency for Healthcare Research and Quality.

Golembiewski, J.A. (2016). Salutogenic Architecture in Healthcare Settings. In: M.B. Mittelmark et al. (eds.), *The Handbook of Salutogenesis*. Cham, CH: Springer, ch.26.

Goodman, B., & East, L. (2014). The 'sustainability lens': A framework for nurse education that is 'fit for the future'. *Nurse Education Today*, 34, 100-103

Goodman-Deane, J., Ward, J., Hosking, I., & Clarkson, P.J. (2014). A comparison of methods currently used in inclusive design, *Applied Ergonomics*, 45(4), 886-894.

Green, L.A., Nease, D., Jr., & Klinkman, M.S. (2015). Clinical reminders designed and implemented using cognitive and organizational science principles decrease reminder fatigue. *Journal of the American Board of Family Medicine*, 28(3), 351-359.

Grose, J. et al. (2012). Facilitating Sustainable Waste Management Behaviors Within the Health Sector: A Case Study of the National Health Service (NHS) in Southwest England, UK. *Sustainability*, 4, 630-642.

Guarneri, R., & Andreoni, G. (2014). Active prevention by motivating and engaging teenagers in adopting healthier lifestyles: PEGASO strategy in designing future healthcare pillars. *Lecture Notes in Computer Science*, 8529 LNCS, 351-360.

Guenther, R., & Vittori, G. (2013). Sustainable Healthcare Architecture, 2nd ed. Hoboken, NJ: John Wiley & Sons.

Gupta, S.P., & Pidgeon, A. (2016). An analytical approach to identifying potential use-related issues concerning a medical device under development, *Journal of Medical Engineering & Technology*, 40(3), 61-71.

HCWH (n.d.). Retrieved from https://noharm-global.org/content/global/about

Hoyos, C.M., & Scharoun, L. (2013). Design for paralympians: Exploring roles of graphic and industrial design in promoting awareness of athletes with disabilities. *International Journal of Design in Society*, 7 (2), 35-50.

Ing, W.J.Z., & Summers, R. (2015). Technological design considerations for home-based health care. *Measurement and Control (United Kingdom)*, 48(6), 183-188.

Islam, R., Weir, C.R., Jones, M., Del Fiol, G., & Samore, M.H. (2015). Understanding complex clinical reasoning in infectious diseases for improving clinical decision support design. *BMC Medical Informatics and Decision Making*, 15 (1), art. no. 101.

Jones, P.H. (2013). *Design for Care: Innovating Healthcare Experience*. Brooklyn, NY: Rosenfeld Media.

Jones, P.H. (2014). Design Research Methods in Systemic Design. In: *Proceedings of RSD3, Third Symposium of Relating Systems Thinking to Design*. Oslo, Norway: Oslo School of Architecture and Design, October 15-17.

Källander, K. et al. (2013). Mobile health (mhealth) approaches and lessons for increased performance and retention of community health workers in lowand middle-income countries: A review. *Journal of Medical Internet Research*, 15(1), e17.

Kanstrup, A.M., Christiansen, M.B., & Nøhr, C. (2011). Four principles for user interface design of computerised clinical decision support systems. *Studies in health technology and informatics*, 166, 65-73.

Kaplan, S., Sadler, B., Little, K., Franz, C., & Orris, P. (2012). Can Sustainable Hospitals Help Bend the Health Care Cost Curve?. Commonwealth Fund, 1641 (29), 1-13.

Kashfi, H. (2010). Applying a user centered design methodology in a clinical context. *Studies in Health Technology and Informatics*, 160 (part 1), 927-931.

Kaufman-Rivi, D., Collins-Mitchell, J.,& Jetley, R. (2010). Design considerations for medical devices in the home environment. *Biomedical instrumentation & technology / Association for the Advancement of Medical Instrumentation*, Suppl Home Healthcare, 21-26.

Kellert, S.R. (2008) Dimensions, elements, and attributes of biophilic design. In S. R. Kellert, J. H. Heerwagen, & M. L. Mador (Eds.), Biophilic design: The theory, science, and practice of bringing buildings to life, (pp. 3-19). Hoboken, NJ: John Wiley & Sons.

Kumar, S., Nilsen, W., Pavel, M., Srivastava, M. (2013). Mobile health: Revolutionizing healthcare through transdisciplinary research. *Computer*, 46 (1), 28-35.

Lang, A.R., Martin, J.L., Sharples, S., & Crowe, J.A. (2014). Medical device design for adolescent adherence and developmental goals: a case study of a cystic fibrosis physiotherapy device. *Patient Preference and Adherence*, 8,301-309

Lang, A.R., Martin, J.L., Sharples, S., Crowe, J.A., & Murphy, E. (2014). Not a minor problem: Involving adolescents in medical device design research. *Theoretical Issues in Ergonomics Science*, 15 (2), 181-192.

Langabeer, J.R. et al. (2016). Telehealth-enabled emergency medical services program reduces ambulance transport to urban emergency departments. *Western Journal of Emergency Medicine*, 17(6), 713-720.

Lemke, M.R., &Mendonca, R.J. (2013). A question of accessibility: Understanding lay users of medical devices. *Biomedical Instrumentation and Technology*, 47(SPRING), 20-25.

Li, Y. et al. (2013). A design to empower patients in long term wellbeing monitoring and chronic disease management in mHealth. *Studies in Health Technology and Informatics*, 194, 82-87.

Liang, S.-F.M., Rau, P.-L.P., Zhou, J., & Huang, E. (2013). A qualitative design approach for exploring the use of medication and health care devices among elderly persons. *Human Factors and Ergonomics In Manufacturing*, 23(3), 186-197.

Lin, L., Vicente, K.J., Doyle, D.J. (2001). Patient safety, potential adverse drug events, and medical device design: A human factors engineering approach. *Journal of Biomedical Informatics*, 34 (4), pp. 274-284.

MacAllister, L., Zimring, C., & Ryherd, E., (2017). Environmental variables that influence patient satisfaction. A review of the literature. *Health Environments Research & Design Journal*, 10 (1), 155-169.

Madhu, C.R. et al. (2009). Challenges to effective crisis management: Using information and communication technologies to coordinate emergency medical services and emergency department teams. *International Journal of Medical Informatics*, 78(4), 259-269.

Martin, J.L., Murphy, E., Crowe, J.A., & Norris, B.J. (2006). Capturing user requirements in medical device development: The role of ergonomics. *Physiological Measurement*, 27 (8), R49-R62.

McCurdie, T. et al. (2012). mHealth consumer apps: the case for user-centered design. *Biomedical instrumentation & technology*, suppl, 49-56.

McDonagh, D., & Thomas, J. (2013). Innovating alongside designers. *Australasian Medical Journal*, 6 (1), 29-35.

McDonough, W., & Braungart, M. (2002). *Cradle to Cradle: Remaking the Way We Make Things*. New York, NY: North Point Press.

McGee, B., & Marshall-Baker, A. (2015). Loving nature from the inside out: A biophilia matrix identification strategy for designers. *Health*

Environments Research and Design Journal, 8 (4), 115-130

McGuire, H., & Weigl, B.H. (2014). Medical Devices and Diagnostics for Cardiovascular Diseases in Low-Resource Settings. *Journal of Cardiovascular Translational Research*, 7(8), 737-748.

Middleton, B. et al. (2013). Enhancing patient safety and quality of care by improving the usability of electronic health record systems: Recommendations from AMIA. *Journal of the American Medical Informatics Association*, 20(E1), e2-e8.

Money, A.G., Barnett, J., Kuljis, J., Craven, M.P., Martin, J.L., & Young, T. (2011). The role of the user within the medical device design and development process: Medical device manufacturers' perspectives. *BMC Medical Informatics and Decision Making*, 11 (1), art. no. 15.

Nichols, A., & Mukonoweshuro, R. (2016). Understanding and knowledge of sustainable waste management within the neonatal unit: A qualitative investigation. *Journal of Neonatal Nursing*, (in press).

Ng, T.S.K., Yau, R.M.H., Lam, T.N.T., & Cheng, V.S.Y. (2016). Design and commission a zero-carbon building for hot and humid climate. *International Journal of Low-Carbon Technologies*, 11 (2), 222-234

Oh, H.J., & Lee, B. (2012). The effect of computer-mediated social support in online communities on patient empowerment and doctor-patient communication. Health Communication, 27(1), 30-41.

Pang, Z., Zheng, L., Tian, J., Kao-Walter, S., Dubrova, E., & Chen, Q. (2015). Design of a terminal solution for integration of in-home health care devices and services towards the Internet-of-Things. *Enterprise Information Systems*, 9(1), 86-116.

Pati, D., Harvey, T.E., Pati, S. (2014). Physical design correlates of efficiency and safety in emergency departments: A qualitative examination. *Critical Care Nursing Quarterly*, 37 (3), 299-316.

Payne, S.R., Mackrill, J., Cain, R., Strelitz, J., Gate, L. (2015). Developing interior design briefs for health-care and well-being centres through public participation. *Architectural Engineering and Design Management*, 11 (4), 264-279.

Pourdehnad, J., Wexler, E.R., & Wilson, D.V. (2011). Systems & Design Thinking: a conceptual framework for their integration. *Organizational Dynamics Working Papers*. Art. No. 10.

Powell, J. A., Darvell, M., & Gray, J. A. M. (2003). The doctor, the patient and the world-wide web: how the internet is changing healthcare. *Journal of the Royal Society of Medicine*, *96*(2), 74–76.

Privitera, M.B., Evans, M., Southee, D. (2017). Human factors in the design of medical devices – Approaches to meeting international standards in the European Union and USA. *Applied Ergonomics*, 59, 251-263.

Rajkomar, A., Farrington, K., Mayer, A., Walker, D., & Blandford, A. (2014). Patients' and carers' experiences of interacting with home haemodialysis technology: Implications for quality and safety. *BMC Nephrology*, 15(1), art. no. 195.

Rajkomar, A., Mayer, A., & Blandford, A. (2015). Understanding safety-critical interactions with a home medical device through Distributed Cognition. *Journal of Biomedical Informatics*, 56, 179-194.

Reiling, J. (2006). Safe design of healthcare facilities. *Quality & Safety in Health Care*, 15(Suppl 1), i34–i40.

Richardson, J. et al. (2014). The use of evidence-informed sustainability scenarios in the nursing curriculum: Development and evaluation of teaching methods. *Nurse Education Today*, 34(4), 490-493.

Richardson, J., Grose, J., Doman, M., & Kelsey, J. (2014). The use of evidence-informed sustainability scenarios in the nursing curriculum: Development and evaluation of teaching methods. *Nurse Education Today*, 34 (4), 490-493.

Roberts, J.P., Fisher, T.R., Trowbridge, M.J., & Bent, C. (2016). A design thinking framework for healthcare management and innovation. *Healthcare*, 4(1), 11-14.

Robichaud, L.B., & Anantatmula, V.S. (2010). Greening project management practices for sustainable construction. *Journal of Management in Engineering*, 27 (1), 48–57.

Ryan-Fogarty, Y., O'Regan, B., & Moles, R. (2016). Greening healthcare: Systematic implementation of environmental programmes in a university teaching hospital. *Journal of Cleaner Production*, in press.

Santos, L., Olumese, O., Vaughn-Cooke, M. (2014-January). Glucometer design for patients with vision and mobility impairments. *Proceedings of the Human Factors and Ergonomics Society* (pp. 669-673).

Schwartz, J.G., Kumar, U.N., Azagury, D. E., Brinton, T.J., & Yock, P.G. (2016). Needs-Based Innovation in Cardiovascular Medicine: The Stanford Biodesign Process. *JACC: Basic to Translational Science*, 1(6), 541-547.

Steinhubl, S.R., Muse, E.D., & Topol, E.J. (2015). The emerging field of mobile health. *Science Translational Medicine*, 7 (283), art. no. 283rv3.

Stichler, J. (2017). State of the Science in Healthcare Design. *Health Environments Research & Design Journal*, 10(2), 6-12.

Stramler, J.H. (1993). *The Dictionary for Human Factors/Ergnomics*. Boca Raton, LA: CRC Press.

Stroupe, J.M. (2014). Design for safety in the critical care environment: An evidence-based approach: Considering the caregiver-patient-family experiences. *Critical Care Nursing Quarterly*, 37(1), 103-114.

"Systemic Design" (n.d.). Retrieved April 3, 2017 from Wikipedia: https://en.wikipedia.org/wiki/Systemic_design

Tan, S. S.-L., & Goonawardene, N. (2017). Internet Health Information Seeking and the Patient-Physician Relationship: A Systematic Review. *Journal of Medical Internet Research*, *19*(1), e9.

Thies, A. (2015). On the value of design thinking for innovation in complex contexts: A case from healthcare. *Interaction Design and Architecture(s)*, 27 (1), 159-171.

Ticehurst, A., Ward, J., & Clarkson, J. (2010). Barriers to Design in Healthcare, AMJ, 3(9), 570-579.

Tomlinson, M., Rotheram-Borus, M.J., Swartz, L., & Tsai, A.C. (2013). Scaling Up mHealth: Where Is the Evidence? *PLoS Medicine*, 10 (2), e1001382.

Tosi, F., Rinaldi, A., & Ricci, D.B. (2016). Ergonomics and inclusive design: Innovative medical devices for home care. *Advances in Intelligent Systems and Computing*, pp. 401-412.

Ulrich, R.S. (1991*)*. Effects of interior design on wellness: theory and recent scientific research. *Journal of health care interior design*, 3, 97-109.

Van Den Berg, M.H., Schoones, J.W., & Vlieland, T.P.M.V. (2007). Internet-based physical activity interventions: a systematic review of the literature. *Journal of Medical Internet Research*, 9(3), e26.

Van der Eijk, M., Faber, M. J., Aarts, J. W., Kremer, J. A., Munneke, M., & Bloem, B. R. (2013). Using Online Health Communities to Deliver Patient-Centered Care to People With Chronic Conditions. *Journal of Medical Internet Research*, *15*(6), e115.

Vincent, C.J., & Blandford, A. (2014). The challenges of delivering validated personas for medical equipment design. *Applied Ergonomics*, 45, 1097-1105.

Vincent, C.J., Blandford, A. (2017). How do health service professionals consider human factors when purchasing interactive medical devices? A qualitative interview study. Applied Ergonomics, 59, 114-122.

Vincent, C.J., Li, Y., Blandford, A. (2014). Integration

of human factors and ergonomics during medical device design and development: It's all about communication. *Applied Ergonomy*, 45: 413-419

Vogt, J., & Nunes, K.R.A. (2014). Recycling behaviour in healthcare: waste handling at work. *Ergonomics*, 57(4), 525-535

Walker, H. and Brammer, S. (2009). Sustainable procurement in the United Kingdom public sector. *Supply Chain Management*, 14(2), 128-137.

Wärnestal, P., Svedberg, P., & Nygren, J. (2014, April). Co-constructing child personas for health-promoting services with vulnerable children. In M. Jones & P. Palanque (Eds.), *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Paper presented at the ACM CHI Conference on Human Factors in Computing Systems (CHI 2014), Toronto, Canada (pp. 3767-3776).

Watkins, C., Loudon, G., Gill, S., Hall, J. (2017). Improving aid through good design: A case study in rural Zambia. *Smart Innovation, Systems and Technologies*, 65, 881-892.

Weiskopf, N.G., & Weng, C. (2013). Methods and dimensions of electronic health record data quality assessment: Enabling reuse for clinical research. *Journal of the American Medical Informatics Association*, 20(1), 144-151.

Weiss et al. (2016). Environmentalism in surgical practice. *Current Problems in Surgery*, 53(4), 165-205.

West, J., Davey, G., Norris, B., Myerson, J., Anderson, O., & Brodie, A. (2014). Designing out Medical Error: An Interdisciplinary Approach to the Design of Healthcare Equipment. *The Design Journal*, 17(2):238–266

Wherton, J., Sugarhood, P., Procter, R., Hinder, S., & Greenhalgh, T. (2015). Co-production in practice: How people with assisted living needs can help design and evolve technologies and services. *Implementation Science*, 10 (1), art. no. 75.

Wilson, E.O. (1984). *Biophilia*. Cambridge, MA: Harvard University Press.

Wilson, E.D., & Garcia, A.C. (2011). Environmentally friendly health care food services: A survey of beliefs, behaviours, and attitudes. *Canadian Journal of Dietetic Practice and Research*, 72(3), 117-122.

WHO (2014). Global status report on noncommunicable diseases 2014. WHO Library

WHO (2005). Resolution WHA58.33. Sustainable health financing, universal coverage and social health insurance. In *Fifty-eighth World Health Assembly, Geneva, 16–25 May 2005. Resolutions and decisions annex*. Geneva, Swiss: World Health Organization.

Yang, J., Kang, U., Lee, Y. (2016). Clinical decision support system in medical knowledge literature review. *Information Technology and Management,* 17(1), 5-14.

Zhou, J., Wiggermann, N. (2017) Ergonomic evaluation of brake pedal and push handle locations on hospital beds. Applied Ergonomics, 60, pp. 305-312.

Zuo, J., & Zhao, Z.-Y. (2014). Green building research-current status and future agenda: A review. *Renewable and Sustainable Energy Reviews*, 30, 271-281.

CHAPTER 2 - RESEARCH METHODOLOGY

Ackoff, R.L. (2004, May 19). *Transforming the Systems Movement*. Retrieved from https://www.acasa.upenn.edu/RLAConfPaper.pdf

Alves R., & Jardim Nunes N. (2013). Towards a Taxonomy of Service Design Methods and Tools. In: J. Falcão e Cunha, M. Snene, & H. Nóvoa (Eds) *Exploring Services Science*. IESS 2013. Lecture Notes in Business Information Processing, vol 143. Berlin, DE: Springer.

Barbero, S. (2012). *Systemic Energy Networks: the theory of Systemic Design applied to energy sector*, (Vol. 1). Raleigh, NC: Lulu Enterprises, Inc.

Barbero, S. (2016). Opportunities and challenges in

teaching Systemic Design. Paper presented at *6th International Forum of Design as a Process Systems & Design: Beyond Processes and Thinking*, Valencia, Spain.

Barbero, S., Pereno, A., & Tamborrini, P. (2011). Qualitative/quantitative cross analysis to design eco-pack. Paper presented at the *3rd International Symposium on Sustainable Design* (pp. 105-115). Recife, Brazil: UFPE.

Bistagnino, L. (2011). *Systemic Design: designing the productive and environmental sustainability*. Bra, Italy: Slow Food Editore.

Bistagnino, L., Marino, G.P., & Virano, A. (2008). *The outside shell seen from the inside*. Milan, Italy: CEA.

Bogue, R. (2007). Design for disassembly: A critical twenty-first century discipline. *Assembly Automation*, 27(4), 285-289.

Boyd, H., McKernon, S., Mullin, B., Old, A. (2012) Improving healthcare through the use of co-design. *New Zealand Medical Journal*, 125 (1357).

Buchanan, R. (1992). Wicked Problems in Design Thinking. *Design Issues*, 8(2), 5-21.

Burnier, M., & Martin P.Y. (2013). Nephrology between economy and ecology. *Revue Medicale Suisse*, 9(375), 443-444.

Cabrera, D., Colosi, L., & Lobdell, C. (2008). Systems thinking. *Evaluation and Program Planning*, 31(3), 299-310.

Capra, F. (1997). *The Web of Life: A New Synthesis of Mind and Matter*. London, UK: Flamingo.

Connor, A., Mortimer, F., &Tomson, C. (2010). Clinical Transformation: The Key to Green Nephrology. *Nephron Clinical Practice*, 116, c200–c206.

Curry, J., McGregor, C., & Tracy, S. (2006). A communication tool to improve the patient journey modeling process. Paper presented at Annual International Conference of the IEEE Engineering in Medicine and Biology - Proceedings (pp. 4726-4730), art. no. 4029171.

European Renal Care Providers Association (2013). Facts & Figures. Retrieved from http://ercpa.eu/facts-figures/

Germak, C. (Ed.) (2008). *Man at the Centre of the Project: Design for a New Humanism*. Torino, Italy: Allemandi.

Glanville, R. (1997). *Researching Design And Designing Research*. Proceedings of the "No Guru-No Method?" conference. Helsinki. http://home.snafu.de/jonasw/PARADOXGlanvilleE.html

Global Green and Healthy Hospitals. Retrieved from http://www.greenhospitals.net/

Health Care Without Harm. Retrieved from https://noharm.org/

Hensel, M.U. (2012). Sustainability from a Performance-Oriented Architecture perspective – Alternative approaches to questions regarding the sustainability of the built environment. *Sustainable Development*, 20, 146-154.

Heylighen, F. (2000). Foundations and Methodology for an Evolutionary World View: A Review of the Principia Cybernetica Project. *Foundations of Science*, 5(4), 457-490.

Jones, P. (2014a). Design research methods for systemic design: Perspectives from design education and practice. Paper presented at *Proceedings of the 58th Annual Meeting of the ISSS*, July 28 - August 1, Washington, DC.

Jones, P.H. (2014b). Systemic Design Principles for Complex Social Systems. In G. Metcalf (Ed.), *Social Systems and Design* (pp. 91-128). New York, NY: Springer.

Laurenti, F. et al. (2014). Group Model-Building to identify potential sources of environmental impacts outside the scope of LCA studies. *Journal of Cleaner Production*, 72, 96-109.

Li, M. (2002). Fostering design culture through

cultivating the user-designers' design thinking and systems thinking. *Systemic Practice and Action Research*, 15(5), 385-410.

Lomas, D. (2015). India's Design Guru: M.P. Ranjan. *She Ji: The Journal of Design, Economics, and Innovation*, 1(2), 157-173

Marzilli Ericson, G. (2009) Great Expectations: The Healthcare Journey. *Touchpoint Journal of Service Design*, 1(2), 88-91.

McCarthy, S., et al. (2016). An integrated patient journey mapping tool for embedding quality in healthcare service reform. *Journal of Decision Systems*, 25, 354-368.

Nahar, P. (2013). Teaching systems thinking in design at National Institute of Design (NID) India. In B. Sevaldson & P.H. Jones (Eds.), *Relating Systems Thinking and Design 2013 Symposium Proceedings*. Paper presented at The Second Symposium of Relating Systems Thinking and Design, Oslo. Oslo: The Oslo School of Architecture and Design.

Özbekhan, H. (1970). *The Predicament of Mankind*. Report to the Club of Rome.

Pourdehnad, J, Wexler, E.R., & Wilson, D.V. (2011). *Systems & Design thinking: a conceptual framework for their integration*. Paper presented at the 55th Annual Meeting of the International Society for the Systems Sciences, Hull, UK, (pp. 807-821).

Ranjan, M.P. (2013a). *Design Thinking Models: A Primer*. Retrieved from: https://www.dropbox.com/s/nlac0w28p1sk5r3/Design%20Thinking%20Models_Primer_Landscape_LR.pdf

Ranjan, M.P. (2013b). *Design Thinking: Workshop for designers and craftspeople of Earth based building systems* (Vol. 5). Ahmedabad, India: CEPT University.

Ranjan, M.P., & Singh, M. (Eds.) (2004). Bamboo Initiatives: design strategies from NID-BCDI. Ahmedabad: NID Centre for Bamboo Initiatives.

Rith,C., & Dubberly, H. (2007). Why Horst W.J. Rittel matters. *Design Issues*, 23(1), 72-91.

Rittel, H.W.J., & Webber, M.M. (1973). Dilemmas in a General Theory of Planning. *Policy Sciences*, 4(2), 155-169.

Rosenbaum, M.S., Otalora, M.L., & Ramírez, G.C. (2017). How to create a realistic customer journey map. *Business Horizons*, 60 (1), 143-150.

Ryan, A.J. (2013). A Theory of Systemic Design. In B. Sevaldson and P.H. Jones (Eds.), *RSD2: Emerging Contexts for Systemic Design: Relating Systems Thinking and Design 2013 Symposium Proceedings*, AHO, Oslo.

Samson, S., Granath, K., & Alger, A. (2017). Journey mapping the user experience. *College and Research Libraries*, 78(4), 459-471.

Sevaldson, B. (2009). *Systems Oriented Design*. Retrieved from http://www.systemsorienteddesign.net/index.php/sod/about-sod

Sevaldson, B. (2010). Discussions and Movements in Design Research: A systems approach to practice research in design. *FORMakademisk*, 3(1), 8-35.

Sevaldson, B. (2011). GIGA-Mapping: Visualisation for complexity and systems thinking in design. Paper presented at *NORDES 2011*.

Sevaldson, B., Hensel, M., & Frostell, B. (2010). Systems-oriented Design and Sustainability. In F. Ceschin, C. Vezzoli, & J. Zhang (Eds.), *Sustainability in Design: Now! Challenges and Opportunities for Design Research, Education and Practices in the XXI Century*. Paper presented at LeNS Conference, Bangalore, India (pp. 465–474). Sheffield, UK: Greenleaf Publishing Limited.

Vezzoli, C., & Manzini, E. (2007). *Design per la sostenibilità ambientale*. Bologna, Italy: Zanichelli.

CHAPTER 3 - ANALYSIS OF THE SYSTEM

Agar, J.W.M. (2012). Personal viewpoint: Hemodialysis—Water, power, and waste disposal: Rethinking our environmental responsibilities. *Hemodialysis International* 2012; 16:6–10

Agar, J.W. (2013). It is time for "green dialysis". *Hemodialysis International*, 17 (4), 474-478.

Barbero, S., Pereno, A., & Tamborrini, P. (2011). Qualitative/quantitative cross analysis to design eco-pack. Paper presented at the *3rd International Symposium on Sustainable Design* (pp. 105-115). Recife, Brazil: UFPE.

Bistagnino, L., Marino, G.P., & Virano, A. (2008). *The outside shell seen from the inside*. Milan: CEA.

Bogue, R. (2007). Design for disassembly: A critical twenty-first century discipline. *Assembly Automation*, 27(4), 285-289.

Burnier, M., & Martin, PY. (2013). Nephrology between economy and ecology. *Revue Médicale Suisse*, 9, 443–444

Carvalho, M.T. (2012) Challenges in the Separation of Plastics from Packaging Waste. In: Gente, V. & La Marca, F. (eds). Separating Pro-Environment Technologies for Waste Treatment, Soil and Sediments Remediation. Sharjah, Bentham Science Publishers.

Christin, E. (2012). *Apparecchiature Elettromedicali: sicurezza e valutazione*. Retrieved December 16, 2016, from http://www.ante.it/images/stories/itinerAnte_novara/7%20Christin%20ANTE0212.pdf

Connor A, Milne S, & Owen A. (2010). Toward greener dialysis: a case study to illustrate and encourage the salvage of reject water. *Journal of Renal Care*, 36, 68-72

Curry, J., McGregor, C., & Tracy, S. (2006). A communication tool to improve the patient journey modeling process. Paper presented at *Annual International Conference of the IEEE Engineering in Medicine and Biology - Proceedings* (pp. 4726-4730), art. no. 4029171.

Fargen K.M. et al. (2013). The FDA Approval Process for Medical Devices An Inherently Flawed System or a Valuable Pathway for Innovation? *Journal of Neuro Interventional Surgery*, *5*(4), 269- 275.

Fiore, E. et al. (2016). Assessment tools for disposable and long durability products. In M. Mokrys, & S. Badura (Eds.), *Proceedings of the 4th International Virtual Conference on Advanced Scientific Results* (pp. 228-233) Zilina: EDIS.

Garrick, R., Kliger, A., & Stefanchik, B. (2012). Patient and Facility Safety in Hemodialysis: Opportunities and Strategies to Develop a Culture of Safety. *Clinical Journal of the American Society of Nephrology*, 7(4), 680–688.

Holley, J.L. (2006). A descriptive report of errors and adverse events in chronic hemodialysis units. *Nephrology News & Issues*, 20(12), 57-8, 60-1.

Kliger, A.S. (2015). Maintaining Safety in the Dialysis Facility. *Clinical Journal of the American Society of Nephrology* , 10(4), 688–695.

Rosenbaum, M.S., Otalora, M.L., & Ramírez, G.C. (2017). How to create a realistic customer journey map. *Business Horizons*, 60 (1), 143-150.

Sadat-Shojai, M. And Bakhshandeh, G.-R. (2011). Recycling of PVC wastes. *Polymer Degradation and Stability*, 96, 404-415.

CHAPTER 4 - ECO-GUIDELINES FOR HAEMODIALYSIS
CHAPTER 5 - DESIGN STRATEGIES FOR SUSTAINABLE HEALTHCARE

Bakker, C.A., Wever, R., Teoh, C., de Clercq, S. (2010) Designing cradle-to-cradle products: A reality check. *International Journal of Sustainable Engineering*, 3 (1), 2-8.

Braungart, M., McDonough, W., & Bollinger, A. (2008). Cradle-to-cradle design: creating healthy emissions – a strategy for eco-effective product and system design, Journal of Cleaner Production, 15(13), 1337-1348.

Harjula, T., Rapoza, B., Knight, W.A., & Boothroyd, G. (1996). Design for Disassembly and the Environment. *Manufacturing Technology*, 45(1), 109-114.

Maeda, J. (2006). *The Laws of Simplicity*. Cambridge, USA: The MIT Press.

Money, A.G., Barnett, J., Kuljis, J., Craven, M.P., Martin, J.L., & Young, T. (2011). The role of the user within the medical device design and development process: Medical device manufacturers' perspectives. *BMC Medical Informatics and Decision Making*, 11 (1), art. no. 15

Muenchinger, K. (2011). The green product design network: Focusing on the role of materials in product design. *Design Principles and Practices*, 5 (5), 215-221.

Palani Rajan, P.K., Van Wie, M., Campbell, M., Otto, K., & Wood, K. (2003). Design for Flexibility – Measures and guidelines. Paper presented at International Conference On Engineering Design ICED03, Stockholm, Sweden.

Rashid, S.H.A., Evans, S., & Longhurst, P. (2008). A comparison of four sustainable manufacturing strategies. *International Journal of Sustainable Engineering*, 1 (3), 214-229.

Schroeder, K., Thompson, T., Frith, K., & Pencheon, D. (2012). *Sustainable Healthcare*. Chichester, UK: John Wiley & Sons.

Scudieri, P., & Gill, C. (2008). Giving the product a voice: Users and information in sustainable systems. Paper presented at *DS 46: Proceedings of E and PDE 2008, the 10th International Conference on Engineering and Product Design Education* (pp. 6P).

Shedroff, N. (2009). Design Is the Problem: The Future of Design Must be Sustainable. Brooklyn, USA: Rosenfeld Media.

Thackaara, J. (2005). *In the Bubble: Designing in a Complex World*. Cambridge, USA: MIT Press.

Van Nes, N., Cramer, J. (2005). Influencing product lifetime through product design. *Business Strategy and the Environment,* 14(5), 286-299

Vezzoli, C., & Manzini, E. (2007). *Design per la sostenibilità ambientale*. Bologna, Italy: Zanichelli.

annexes

Annex I

Analyses of the system items

A.1 PRODUCT ANALYSIS

A.1.1 Qualitative analysis of products

The method used to assess the haemodialysis products is based on the qualitative-quantitative methodology that has been developed at the Politecnico di Torino, within the Observatory of Eco-Pack (see par. 3.1.1).

The **qualitative analysis** was performed to compare the quantitative features of packaging and disposables (weight, materials, volume) and the qualitative ones. The analysis is based on the disassembly of the product, that is represented by an exploded view; volumes and technical features are shown through orthographic projections while a table summarizes the weight and materials of all the components. A qualitative table reports the observations about the design issues concerning functionality, sustainability, and communication
In particular, the qualitative table summarizes the whole analysis according to special criteria that relate to:

1. **Functionality**:
- *Storage optimization*
- *Preservation and protection*
- *Usability*

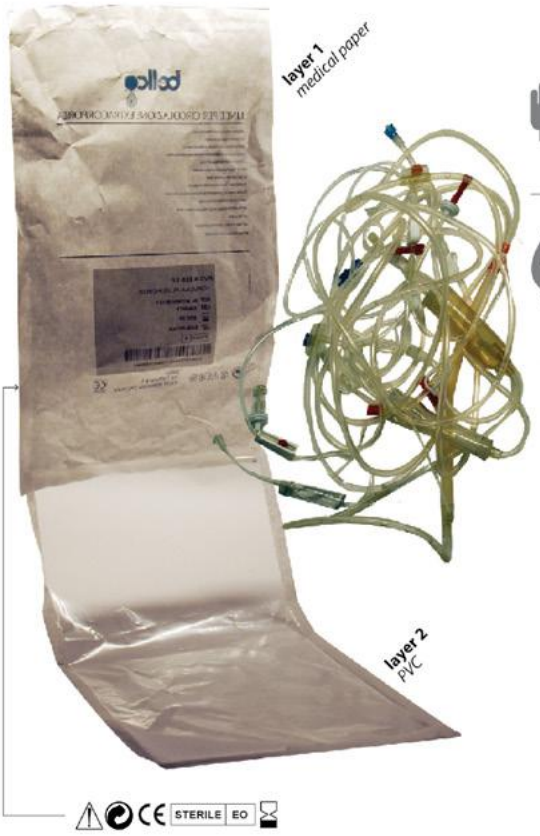
2. **Environmental sustainability**:
- *Over-use of materials*
- *Easiness of disassembly*
- *Volume optimization*

3. **Communication**:
- *Operating information*
- *Waste sorting information*
- *Use of standard labels*
-

The qualitative analysis has been applied to **all the type of products** used in different dialysis methods and all the three case studies. Most of the qualitative criteria consider **the packaging and the packed product** in close relationship (e.g. storage optimization, usability, volume optimization, waste sorting information).

Consequently, disposables and biomedical devices have been analysed together with their packaging (packaging for distribution) while packaging for treatment has been considered alone since they already include the product (usually liquids or powders).

BLOODLINES



Flexible pack facilitates the storage

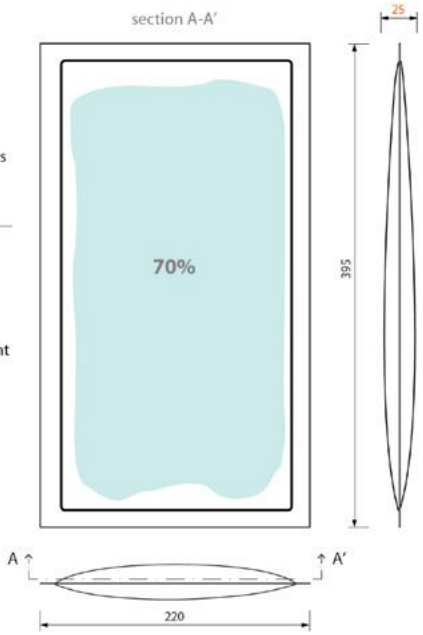
The pack provides good preservation of product from dust and contaminants

The pack is easy to open and allows to see and identificate the product

No overpackaging

Different materials are disassembled to open the packaging

The packaging is lightweight but slightly oversized



COMPONENT	MATERIAL	WEIGHT
Layer 1	Medical paper	6 g
Layer 2	Polyvinyl chloride	4.8 g
	Total	10.8 g

DIALYZER/1

Flexible pack facilitates the storage

The pack provides good preservation of product from dust and contaminants

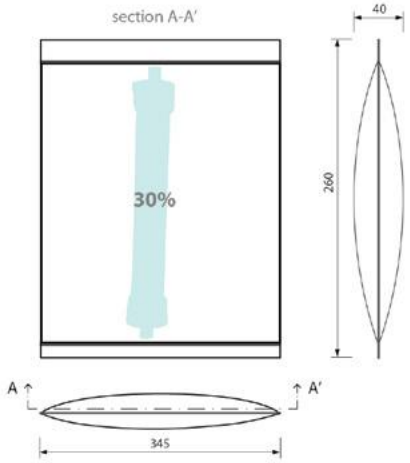
The pack is easy to open and allows to see and identificate the product

No overpackaging

Single-material packaging

The packaging is quite lightweight but highly oversized regarding the product

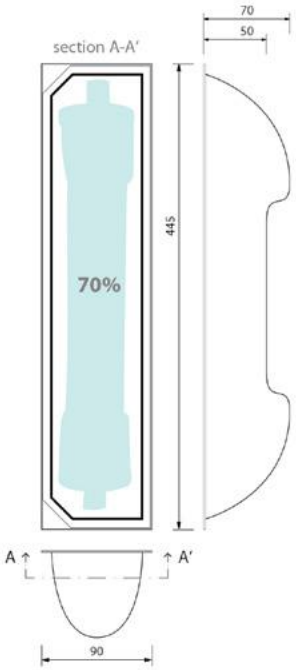
COMPONENT	MATERIAL	WEIGHT
Bag	polypropylene	10.6 g
	Total	10.6 g



DIALYZER/2

- Flexible pack facilitates the storage
- The pack provides good preservation of product from dust and contaminants
- The pack is easy to open and allows to see and identificate the product
- No overpackaging
- Easy to disassembly
- The packaging is lightweight but slight oversized

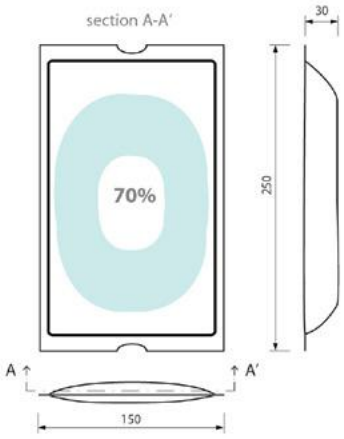
COMPONENT	MATERIAL	WEIGHT
Layer 1	High-density polyethylene	4.5 g
Layer 2	Medical paper	3.8 g
	Total	**8.3 g**



INFUSION TUBE

- Flexible pack facilitates the storage
- The pack provides good preservation of product from dust and contaminants
- The pack is easy to open and allows to see and identificate the product
- No overpackaging
- Different materials are easy to disassembly but no communication promotes this action
- The packaging is lightweight but oversized regarding the product

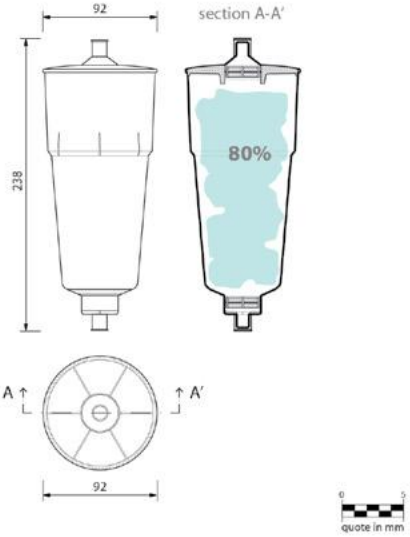
COMPONENT	MATERIAL	WEIGHT
Layer 1	Medical paper	2.1 g
Layer 2	Polyvinyl chloride	4.7 g
	Total	**6.8 g**



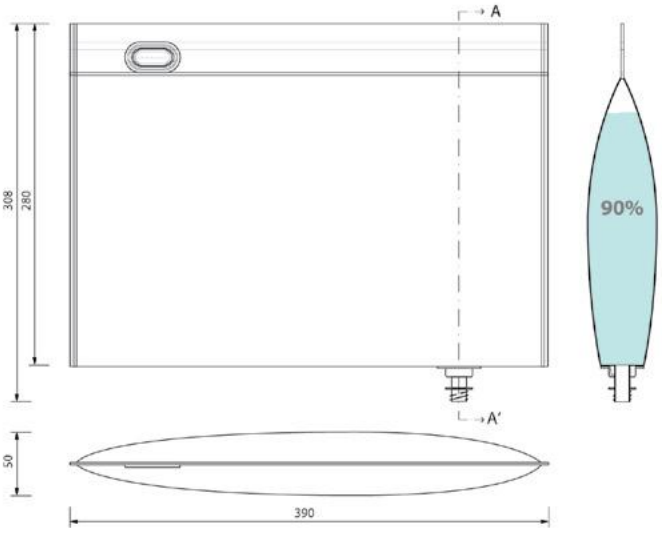
BICARBONATE

- Irregular shape does not optimize space but it is functional to the use phase
- The pack provides good preservation of product
- The pack is easy to connect but cannot be emptied after use
- No overpackaging
- Monomateric, phthalates are recyclable but can be toxic
- The packaging is proportionate to the content and the usage requirements

COMPONENT	MATERIAL	WEIGHT
Cartridge	Polypropylene (with phthalate DEHP)	550 g
Upper cap	Polypropylene	<1 g
Lower cap	Polypropylene	<1 g
	Total	**550 g**



ACIDE CONCENTRATE/1



Flexibility optimizes space within the secondary pack.

The pack provides good preservation of product

Easy to connect but it can't be emptied by residual materials

No overpackaging

Monomateric, phthalates are recyclable but can be toxic

The packaging is proportionate to the content and the usage requirements

COMPONENT	MATERIAL	WEIGHT
Cartridge	Polypropylene (with phthalate DEHP)	550 g
Upper cap	Polypropylene	<1 g
Lower cap	Polypropylene	<1 g
	Total	550 g

160

ACIDE CONCENTRATE/2

The irregular shape does not optimize storage

The pack provides good preservation of product from any contaminants

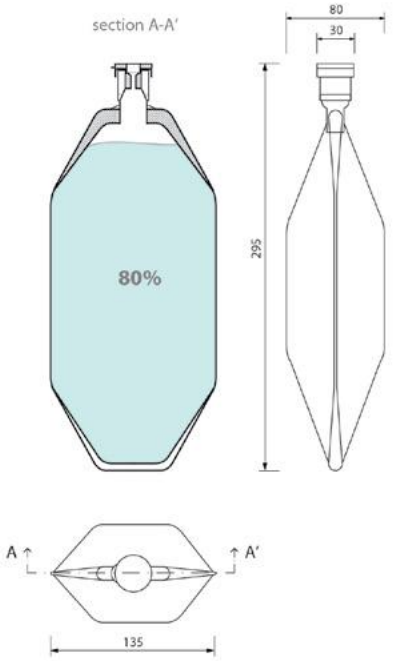
The pack is easy to open, handle and connect to the equipment

No overpackaging

Mono-material packaging

The packaging is a heavy but proportionate

COMPONENT	MATERIAL	WEIGHT
Bag	Polypropylene	40.2
Cap	Other plastics	10.5
	Total	50.7 g

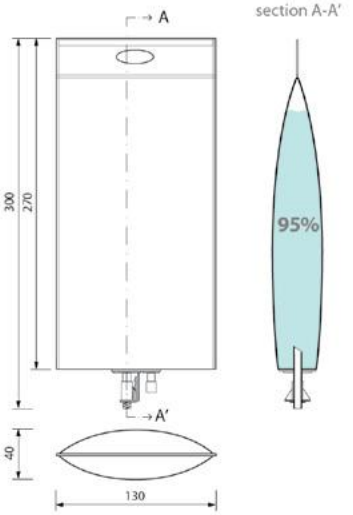


quote in mm

SALINE SOLUTION 1000 ML

- Flexible bags optimize space within the secondary pack
- The pack provides good preservation of product
- The pack is easy to connect but cannot be emptied after use
- No overpackaging
- Bag made from three layers of different polyolefins; components non-separable
- The packaging is lightweight and proportionate to the content

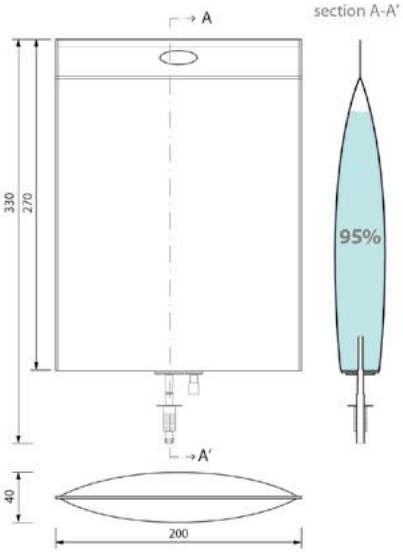
COMPONENT	MATERIAL	WEIGHT
Bag	Clear-Flex (polyethylene; nylon; polypropylene)	19 g
Luer lock connector	Plastic	3.5 g
	Total	22.5g



WASH SOLUTION 2000 ML

- Flexible bags optimize space within the secondary pack
- The pack provides good preservation of product
- The pack is easy to connect but cannot be emptied after use
- No overpackaging
- Bag made from three layers of different polyolefins; components non-separable
- The packaging is lightweight and proportionate to the content

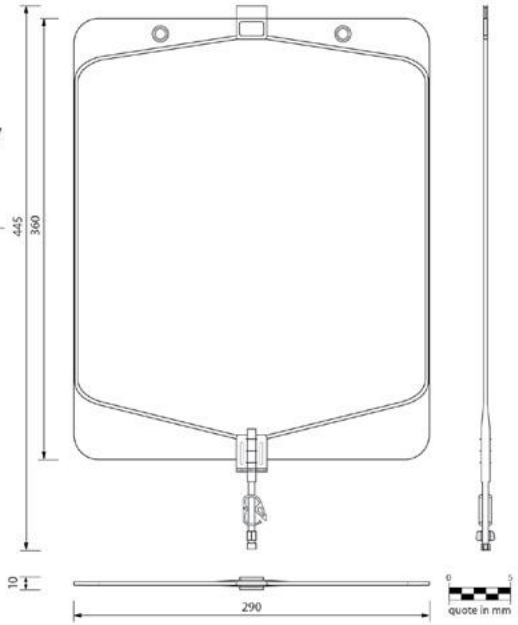
COMPONENT	MATERIAL	WEIGHT
Bag	Clear-Flex (polyethylene; nylon; polypropylene)	30.1 g
Connecting element	Polymer	1.5 g
Luer lock connector	Polymer	3.5 g
	Total	35.1 g



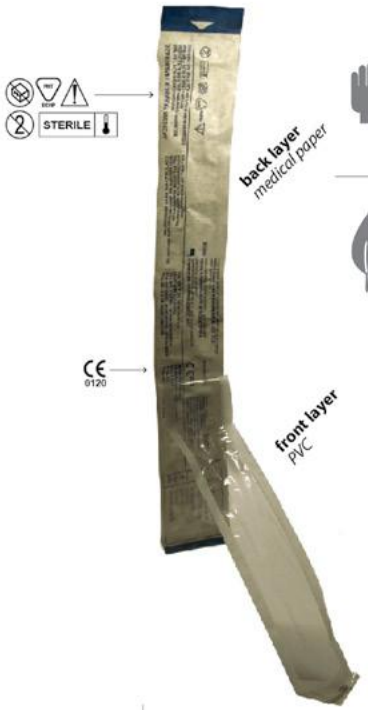
COLLECTION BAG OF WASH SOLUTION

- The bag is storaged emptied. The flexibility optimizes spaces
- The pack ensures impermeability and effective sealing
- It is easy to open/seal thanks to the screw cap and the clamp
- No overpackaging
- Different polymer can't be separated
- The packaging is lightweight, product quantity can vary

COMPONENT	MATERIAL	WEIGHT
bag	composite polymer	32 g
pinch clamp	polypropylene	2 g
	Total	34 g



FISTULA NEEDLES



Irregular shape does not optimize space but it is functional to the use phase

The pack provides good preservation of product

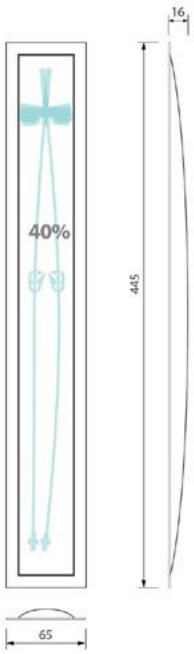
The pack is easy to open thanks to a small area not bonded

No overpackaging

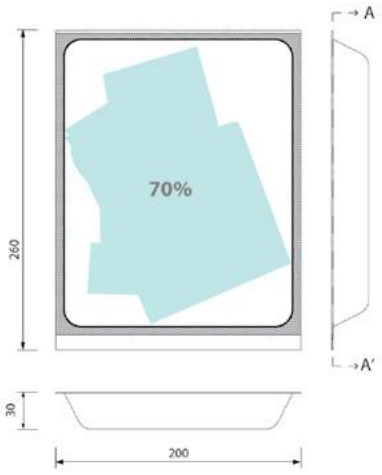
Different materials are separated during opening. Phthalates are recyclable but can be toxic

The packaging is lightweight but not proportionate to the product

COMPONENT	MATERIAL	WEIGHT
back layer	medical paper	3.4 g
front layer	polyvinyl chloride (with phthalate DEHP)	4.2 g
	Total	7.6 g



CONNECTION KIT



The flexibility optimizes spaces

The pack is properly sealed

It is easy to open but once opened, all disposables are no more sterile

Many components have a further packaging

Disassemblying is easy but not encouraged

Packaging is lightweight but oversized

COMPONENT	MATERIAL	WEIGHT
Layer 1	polypropylene	4.5 g
Layer 2	medical paper	3 g
	Total	7.5 g

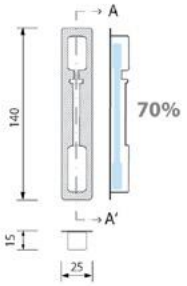
quote in mm

ANTI-COAGULANT SYRINGE /1

- The irregular shape does not optimize storage
- The pack provides good impact protection and preservation of sterility
- The pack is not easy to open and product is difficult to take

- No overpackaging
- Different materials are difficult to separate because of the sealing system
- The packaging is lightweight but slight oversized

COMPONENT	MATERIAL	WEIGHT
Layer 1	polyethylene	1 g
Layer 2	medical paper	0.4 g
	Total	**1.4 g**

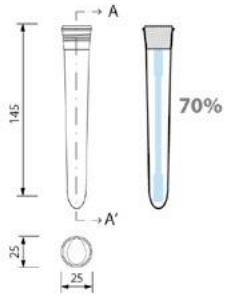


ANTI-COAGULANT SYRINGE /2

- The shape does not facilitate storage
- The pack provides good impact protection and preservation of sterility
- The pack is easy to open and handle, re-close is possible but not necessary

- No overpackaging
- Mono-material
- The packaging is heavy in relation to the content and slight oversized

COMPONENT	MATERIAL	WEIGHT
cap	plastic	1.5 g
case	plastic	4 g
	Total	**5.5 g**

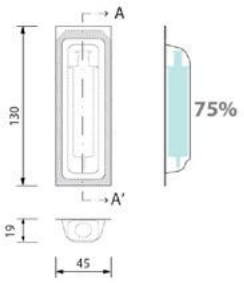


SYRINGE

- Flexible pack facilitates the storage
- The pack provides good preservation of product from any contaminant
- The pack is easy to open and allows to see and identificate the product

- No overpackaging
- Different materials are easy to disassembly but no communication promotes this action
- The packaging is lightweight and adequate to the product

COMPONENT	MATERIAL	WEIGHT
Layer 1	polypropylene	1.8 g
Layer 2	medical paper	1.2 g
	Total	**3 g**



quote in mm

A.1.2 Quantitative analysis of different treatment methods

The quantitative analysis has mainly concerned weights and materials since they are huge issues both for environmental and economic impacts.
The assessment of waste production considered two different practices of waste sorting that could deeply affect the cost of disposal:

- *Careless practice* (no waste emptied)
- *Careful practice* (all waste emptied; materials properly sorted)

All waste produced during the whole treatment was collected and weighed using an electronic weighing scale. Then, waste production was compared according to:

- *Weights (careful and careless)*
- *Materials*
- *Product type*
- *Contamination*
- *Treatment stage*

BICARBONATE DIALYSIS

Bicarbonate dialysis (HD) is the standard treatment of haemodialysis, which uses the dialytic technique of purification from which all others derive. This method has replaced the use of acetate as the buffer base in haemodialysis fluid, becoming the most common method of haemodialysis. The treatment process of HD has been described in par. 2.1.1.

BICARBONATE DIALYSIS (HD)

NIKKISO DBB-06

PRODUCT	WEIGHT careful (gr)	WEIGHT careless (gr)	MATERIAL	PRODUCT TYPE	C/NC	TREAT. STAGE
Venous bloodline	1000	1050	misto	Biomed. Device	C	End
Arterious bloodline						
Dialyzer						
Infusion line						
Pack of bloodlines Stoppers (x4)	12,9	12,9	paper + PVC PP	Pack for distrib.	NC	Set up
Dialyzer pack	10,8	10,8	PP	Pack for distrib.	NC	Set up
Pack of Infusion tube Stopper	7,1	7,1	paper + PVC PP	Pack for distrib.	NC	Set up
Bicarbonate Cartridge	600	800	PE+PVC+PP	Pack for treat.	NC	End

Pack of Bicarbonate Cartridge	1,7	1,7	nylon	Pack for distrib.	NC	Set up
Saline Solution 1000 ml	22,5	900	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	End
Pack of Saline Solution 1000 ml Stopper	9,8	9,8	PP PP	Pack for distrib.	NC	Set up
Fistula Needles (x2)	20	20	Silicon + metal	Disposable	C	End
Pack of fistula needles (x2) Stoppers of fistula needles (x2)	8,2	8,2	paper + PVC PP	Pack for distrib.	NC	Start
Wash Solution 2000 ml	30,1	30,1	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	Start
Pack for wash solution 2000 ml	18,6	18,6	PP	Pack for distrib.	NC	Set up
Collection bag of wash solution	34	1800	PP+PE+PVC	Pack for treat.	C	Start
Acid concentrate bag 5000 ml	43	3300	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	End
AVF CONNECTION KIT						
Absorption crosspiece 60x40cm	30	30	cellulose	Disposable	C	Start
Pack of AVF connection kit	7,5	7,5	paper+plastic	Pack for distrib.	NC	Start
Pre-cut patches 10x4 cm (x6)	1,2	1,2	paper	Disposable	NC	Start
Gauze pads	2,5	2,5	cotton	Disposable	C	Start
Pack of gauze pads	2,8	2,8	paper+plastic	Pack for distrib.	NC	Start
AVF DISCONNECTION KIT						
Absorption crosspiece 60x40cm	30	30	cellulose	Disposable	C	End
Pre-cut patches for fistula 15x5 cm (x2)	1,7	1,7	paper+patch	Disposable	C	End
Pack of Pre-cut patches for fistula 15x5 cm (x2)	6	6	paper+PVC	Pack for distrib.	NC	End
Gauze pads	2,5	2,5	cotton	Disposable	C	End
Pack of gauze pads (x2)	2,8	2,8	paper+plastic	Pack for distrib.	NC	End
Syringes (x2)	30	30	PP	Disposable	C	Start
Pack of syringes (x2)	3	3	paper+PVC	Pack for distrib.	NC	Start
Heparin injection	15	15	PP	Disposable	C	?
Pack of heparin injection	1,4	1,4	paper+plastic	Pack for distrib.	NC	?
TOTAL	**1955,10**	**8105,60**				
TOT. Pack for Treatment	729,6	6830,1				
TOT. Pack for Distribution	92,6	92,6				
TOT. Disposables	132,9	132,9				
TOT. Biomedical Device	1000	1050				
CONTAMINATED	1165,7	2981,7				
NON CONTAMINATED	789,40	5123,90				

HEMOFILTRATION

Hemofiltration (HF) is a renal replacement therapy similar to bicarbonate dialysis, which uses ultrafiltration (removed by convection) and simultaneous reinfusion of sterile replacement solution. Compared to HD, the HF can achieves higher filtration of large- and medium-sized molecules, but it takes considerably more time. HF is mainly used to treat acute renal failure, or for patients suffering from certain pathologies, such as multiple organ dysfunction syndrome.

HEMOFILTRATION (HF)

BELLCO LYNDA

PRODUCT	WEIGHT careful (gr)	WEIGHT careless (gr)	MATERIAL	PRODUCT TYPE	C/NC	TREAT. STAGE
Pre-assembled pack (bloodline + filter)	1200	1200	Mix	Biomed. Device	C	End
Infusion tube						
Heater kit						
Pack of pre-assembled kit	63,8	63,8	paper + PVC	Pack for distrib.	NC	Set up
Pack of the additional component of the pre-assembled	200	200	n.c.	Pack for distrib.	NC	Set up
Pack of the infusion tube	7,04	7,04	paper + PVC, PP	Pack for distrib.	NC	Set up
Pack of heater kit	51	51	PP	Pack for distrib.	NC	Set up
Saline solution 2000 ml (x2)	100	100	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	End
Pack saline solution (x2)	18,5	18,5	PP	Pack for distrib.	NC	End
UF bag (x8)	90	720	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	End
Pack of acid concentrate (x8)	573,6	573,6	PP	Pack for treat.	NC	Set up
Saline solution 1000 ml	22,5	500	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	End
Pack of saline solution	9,7	9,7	PP	Pack for distrib.	NC	End
Fistula needles	20	20	Silicone + metal	Disposable	C	Start
Pack of fistula needles	3,75	3,75	paper + PVC, PP	Pack for distrib.	NC	End
CVC CONNECTION KIT						
Absorption crosspiece	30	30	cellulose	Disposable	C	Start
Pack of CVC connection kit	7,5	7,5	paper + PVC	Pack for distrib.	NC	Start
Pre-cut patches for fistula (6)	10,2	10,2		Disposable	C	Start
Pack of pre-cut patches	1,02	1,02	paper	Pack for distrib.	NC	Start
Gauze pads	8	8	TNT	Disposable	C	Start
Pack of gauze pads	2,2	2,2	paper + plastic	Pack for distrib.	NC	Start

CVC DISCONNECTION KIT						
Absorption crosspiece	30	30	cellulose	Disposable	C	End
Pack Kit attacco CVC	7,5	7,5	paper + PVC	Pack for distrib.	NC	End
Pre-cut patches for fistula (6)	10,2	10,2		Disposable	C	End
Pack of pre-cut patches	2,5	2,5	paper	Pack for distrib.	NC	End
Gauze pads	8	8	TNT	Disposable	C	End
Pack of gauze pads	2,2	2,2	paper + plastic	Pack for distrib.	NC	End
Syringes (x2)	15	15	PP	Disposable	C	Start
Pack of syringes (x2)	1,4	1,4	paper + plastic	Pack for distrib.	NC	Start
Medical drape	30	30	TNT+PE	Disposable	C	Start
Mask and cap	10	10	TNT	Disposable	C	Start
Gloves	12	12	Nitrile	Disposable	C	Start
Syringe 20 cc (x2)	15	15	PP	Disposable	C	Start
Syringe 2,5 cc (x2)	12	12	PP	Disposable	C	Start
TOTAL	**2574,61**	**3682,11**				
TOT. Pack for Treatment	786,1	1320				
TOT. Pack for Distribution	378,11	951,71				
TOT. Disposables	180,4	180,4				
TOT. Biomedical Device	1200	1200				
CONTAMINATED	1410,4	1410,4				
NON CONTAMINATED	1164,21	2271,71				

HEMODIAFILTRATION

Hemodiafiltration (HFR) simultaneously combines haemodialysis and hemofiltration. HFR uses two different filters to combine diffusive and convective solute transport: the diffusion allows to filtrate smaller molecules, while the convective transport removes the larger ones. This method is spreading rapidly since it is reported to improve the dialysis tolerance of patients.

HEMODIAFILTRATION (HFR)

BELLCO FORMULA

PRODUCT	WEIGHT careful (gr)	WEIGHT careless (gr)	MATERIAL	PRODUCT TYPE	C/NC	TREAT. STAGE
Venous bloodline	1750	1850	mix	Biomed. Device	C	End
Arterial bloodline						
Dialyzer						
Infusion line						
Pack of bloodlines Stoppers (x4)	23,6	23,6	paper + PVC PP	Pack for distrib.	NC	Set up
Dialyzer pack	13,6	13,6	PP	Pack for distrib.	NC	Set up
Pack of Infusion tube Stopper	7,3	7,3	paper + PVC PP	Pack for distrib.	NC	Set up
Bicarbonate Cartridge	550	1000	PE+PVC+PP	Pack for treat.	NC	End
Pack of Bicarbonate Cartridge	1,7	1,7	nylon	Pack for distrib.	NC	Set up
Saline Solution 1000 ml	22,5	650	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	End
Pack of Saline Solution 1000 ml Stopper	9,8	9,8	PP PP	Pack for distrib.	NC	Set up
Fistula Needles (x2)	20	20	Silicon + metal	Disposable	C	End
Pack of fistula needles (x2) Stoppers of fistula needles (x2)	8,2	8,2	paper + PVC PP	Pack for distrib.	NC	Start
Wash Solution 2000 ml	30,1	30,1	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	Start
Pack for wash solution 2000 ml	18,6	18,6	PP	Pack for distrib.	NC	Set up
Collection bag of wash solution	34	1800	PP+PE+PVC	Pack for treat.	C	Start
Acid concentrate bag 3800 ml	42,9	2100	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	End
AVF CONNECTION KIT						
Absorption crosspiece 60x40cm	30	30	cellulose	Disposable	C	Start
Pack of AVF connection kit	7,5	7,5	paper+plastic	Pack for distrib.	NC	Start
Pre-cut patches 10x4 cm (x6)	1,2	1,2	paper	Disposable	NC	Start
Gauze pads	2,5	2,5	cotton	Disposable	C	Start
Pack of gauze pads	2,8	2,8	paper+plastic	Pack for distrib.	NC	Start

AVF DISCONNECTION KIT						
Absorption crosspiece 60x40cm	30	30	cellulose	Disposable	C	End
Pre-cut patches for fistula 15x5 cm (x2)	1,7	1,7	paper+patch	Disposable	C	End
Pack of Pre-cut patches for fistula 15x5 cm (x2)	6	6	paper+PVC	Pack for distrib.	NC	End
Gauze pads	2,5	2,5	cotton	Disposable	C	End
Pack of gauze pads	2,8	2,8	paper+plastic	Pack for distrib.	NC	End
Syringes (x2)	30	30	PP	Disposable	C	Start
Pack of syringes (x2)	3	3	paper+PVC	Pack for distrib.	NC	Start
Heparin injection	15	15	PP	Disposable	C	?
Pack of heparin injection	1,4	1,4	paper+plastic	Pack for distrib.	NC	?
Pack of adsorbing dialyzer Stoppers (x2)	10,5	10,5	PP PP	Pack for distrib.	NC	Set up
Pack of bloodline for adsorbing dialyzer	11,4	11,4	paper+PVC	Pack for distrib.	NC	Set up
TOTAL	**2690,60**	**7691,20**				
TOT. Pack for Treatment	679,5	5580,1				
TOT. Pack for Distribution	128,2	128,2				
TOT. Disposables	132,9	132,9				
TOT. Biomedical Device	1750	1850				
CONTAMINATED	1915,7	3781,7				
NON CONTAMINATED	774,90	3909,50				

A.1.3 Quantitative analysis of different case studies

The second step of the quantitative analysis has focused on the same treatment (bicarbonate haemodialysis), performed in three dialysis units, located in different European Countries:

1. **SS Nephrology, San Luigi Gonzaga University Hospital** - Orbassano, Italy (performed with Bellco Forumla Therapy)
2. **Dialysmottagning 42:AN, Skånes Universitetssjukhus (SUS)** - Malmö, Sweden (performed with Gambro ARTIS™)
3. **Haemodialyse 1, Frederiksberg Hospital** - Frederiksberg, Denmark (performed with Gambro AK 200™ ULTRA S)

The analysis has been carried out as for the quantitative analysis of different treatment methods. The assessed criteria are the same, so as to make the results obtained for each analysis comparable: waste sorting practice, materials, product type, contamination or non-contamination of waste, and treatment stage.

SS NEPHROLOGY, SAN LUIGI GONZAGA HOSPITAL

In the previous analysis the bicarbonate dialysis has been performed with a Nikkiso DBB-06 machine, so as to perform each type of treatment with different equipment. In this case, the analysis focus is not on the treatment method neither on the equipment, but on the impact of local practices on waste disposal and product management. Therefore, it was necessary to achieve adequate comparability between the type of machine used to perform the treatment: in all the three case studies, a "full system" machine (able to perform different types of treatment) has been chosen. So, in San Luigi Gonzaga Hospital, the HD treatment has been assessed using a Bellco Formula Therapy machine

The waste production, considering careful sorting, is 1968.40 g, but the overall weight considerably increases if all waste is not properly emptied, reaching 6568.9 g that is more than three times the dry weight.

As regards materials, most products are made of plastics, accounting for the 97% of non-contaminated waste. Composite polymers represent the 90% of plastic waste, while PP is at 6% of the total and PVC at 3%. The remaining 3% is made of medical paper.

SAN LUIGI GONZAGA HOSPITAL

BELLCO FORMULA (HD)

PRODUCT	WEIGHT careful (gr)	WEIGHT careless (gr)	MATERIAL	PRODUCT TYPE	C/NC	TREAT. STAGE
Pack of bloodlines (x2) Stoppers (x4)	23,6	23,6	paper + PVC PP	Pack for distrib.	NC	Set up
Dialyzer pack	10,6	10,6	PP	Pack for distrib.	NC	Set up
Pack of Infusion tube Stopper	7,1	7,1	paper + PVC PP	Pack for distrib.	NC	Set up
Pack of Bicarbonate Cartridge	1,7	1,7	nylon	Pack for distrib.	NC	Set up
Pack of Saline Solution 1000 ml Stopper	9,8	9,8	PP PP	Pack for distrib.	NC	Set up
Pack for wash solution 2000 ml	18,6	18,6	PP	Pack for distrib.	NC	Set up
AVF CONNECTION KIT						
Absorption crosspiece 60x40cm	30	30	cellulose	Disposable	C	Start
Pack of AVF connection kit	7,5	7,5	paper+ plas-tic	Pack for distrib.	NC	Start
Pre-cut patches 10x4 cm (x6)	1,2	1,2	paper	Disposable	NC	Start
Gauze pads	2,5	2,5	cotton	Disposable	C	Start
Pack of gauze pads	2,8	2,8	paper+ plas-tic	Pack for distrib.	NC	Start
Pack of fistula needles (x2) Stoppers of fistula needles (x2)	8,2	8,2	paper + PVC PP	Pack for distrib.	NC	Start
Wash Solution 2000 ml	30,1	30,1	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	Start
Collection bag of wash solution	34	1800	PP+PE+PVC	Pack for treat.	C	Start
Syringes (x2)	30	30	PP	Disposable	C	Start
Pack of syringes (x2)	3	3	paper+ PVC	Pack for distrib.	NC	Start
Heparin injection	15	15	PP	Disposable	C	?
Pack of heparin injection	1,4	1,4	paper+ plas-tic	Pack for distrib.	NC	?
Bicarbonate Cartridge	550	800	PE+PVC+PP	Pack for treat.	NC	End
Saline Solution 1000 ml	22,5	900	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	End
Fistula Needles (x2)	20	20	Silicon + metal	Disposable	C	End
Acid concentrate bag	43	1700	nylon, PP,PE, Latex, PVC	Pack for treat.	NC	End
Venous bloodline	1050	1100	mix	Biomed. Device	C	End
Arterious bloodline						
Dialyzer						
Infusion line						
AVF DISCONNECTION KIT						
Absorption crosspiece 60x40cm	30	30	cellulose	Disposable	C	End
Pre-cut patches for fistula 15x5 cm (x2)	1,7	1,7	paper+patch	Disposable	C	End
Pack of Pre-cut patches for fistu-la 15x5 cm (x2)	6	6	paper+ PVC	Pack for distrib.	NC	End

Gauze pads	2,5	2,5	cotton	Disposable	C	End
Pack of gauze pads (x2)	5,6	5,6	paper+ plas-tic	Pack for distrib.	NC	End
TOTAL	**1968,40**	**6568,90**				
TOT. Pack for Treatment	643,7	2550,7				
TOT. Pack for Distribution	152	2795,5				
TOT. Disposables	122,7	122,7				
TOT. Biomedical Device	1050	1100				
CONTAMINATED	1191,5	1241,5				
NON CONTAMINATED	776,90	5327,40				

DIALYSMOTTAGNING 42:AN, SUS MALMÖ

The waste production at Dialysmottagning 42:AN may vary from 1441.80 g (careful sorting) to 1829.90 g (careless sorting), with a percentage variation of 27%. Like the other case studies, plastics constitutes the major part of the non-contaminated waste, in particular, polypropylene (82%) and polyethylene (10%). Despite its low weight, the medical paper is present in many products, and cardboard is used for the pack for transportation that holds the cartridge set together (it can thus be included in the analysis of a single session).

SUS MALMO

GAMBRO ARTIS (HD)

PRODUCT	WEIGHT careful (gr)	WEIGHT careless (gr)	MATERIAL	PRODUCT TYPE	C/NC	TREAT. STAGE
Pack of Bicarbonate and Sodium Chloride Cartridges	42,3	42,3	Cardboard	Pack for transp.	NC	Set-up
Pack of bloodlines Stoppers (x2)	17,6	17,6	Medical Pa-per+Plastic	Pack for distrib.	NC	Set-up
Bands for bloodlines (x5)	0,5	0,5	Paper	Pack for distrib.	NC	Set-up
Pack of on line Prime Line	16,8	16,8	Medical Pa-per+Plastic	Pack for distrib.	NC	Set-up
Dialyzer pack	8,3	8,3	Medical Pa-per+HDPE	Pack for distrib.	NC	Set-up
AVF CONNECTION KIT						Start
Pack of AVF connection kit	4,8	4,8	Medical Pa-per+Plastic	Pack for distrib.	NC	Start
Wrapping field 40x50cm	6,8	6,8	Cellulose	Disposable	NC	
Swabs 7,5x7,5 cm (x2)	1,2	1,2	Nonwoven	Disposable	C	
Swabs 5x5 cm (x2)	0,2	0,2	Nonwoven	Disposable	C	
Tape 10x5cm (x2)	1,4	1,4	paper+patch	Disposable	C	
Tape 10x2,5 cm (x6)	2,4	2,4	paper+patch	Disposable	C	

Balls Ø 50mm (x6)	12	12	Nonwoven	Disposable	C	Start
Forcep	5,4	5,4	Plastic	Disposable	C	
Plastic tray 16,5x9,5x3cm	9,8	9,8	Plastic	Disposable	NC	
Folded field (crosspiece) 42x50cm	6,8	6,8	Cellulose	Disposable	C	
Syringes (20 ml x1)	13,3	13,3	Polypropylene + Polyisoprene	Disposable	C	Start
Pack of syringes (x2)	1,8	1,8	Medical Paper+Plastic	Pack for distrib.	NC	Start
Apron	15	15	Plastic	Disposable	C	Start
Examination gloves (x2)	7,2	7,2	Nitrile rubber	Disposable	C	Start
Pack of fistula needles (x2) Stoppers of fistula needles (x2)	8,4	8,4	Medical Paper+Plastic	Pack for distrib.	NC	Start
Pack of sodium chloride	4,3	4,3	PP	Pack for treat.	NC	Start
Pack of Tinzaparin Sodium injection (x2)	5,5	5,5	Hard plastic	Pack for distrib.	NC	Start
Syringe Tinzaparin Sodium injection (x2)	4,7	4,7	Mix (glass+ plastic+ metal)	Disposable	C	Start
Apron	15	15	Plastic	Disposable	C	End
Examination gloves (x2)	7,2	7,2	Nitrile rubber	Disposable	C	End
Venous bloodline	305,9	900	mix (containing PVC phtalate-free)	Biomedical device	C	End
Arterious bloodline						
Dialyzer	328,3					
On line prime line	54,8					
Bicarbonate Cartridge	306	334,7	PP	Pack for treat.	NC	End
Sodium Chloride Cartridge	131,8	229,3	PP	Pack for treat.	NC	End
Fistula Needles (x2)	24,4	24,4	PVC	Disposable	C	End
Acid concentrate bag	50,8	101,7	LDPE	Pack for treat.	NC	End
AVF DISCONNECTION KIT						End
Pack of disconnection kit	2,7	2,7	Medical Paper+Plastic	Pack for distrib.	NC	End
Wrapping field 40x50cm	6,8	6,8	Cellulose	Disposable	NC	
Swabs 7,5x7,5 cm (x5)	3	3	Nonwoven	Disposable	C	
Swabs 5x5 cm (x2)	0,2	0,2	Nonwoven	Disposable	C	
Tape 10x2,5cm (x4)	1,6	1,6	paper+patch	Disposable	C	
Folded field (crosspiece) 42x50cm	6,8	6,8	Cellulose	Disposable	C	
CleanCart C	16,3	16,3			NC	End
TOTAL	**1441,80**	**1829,90**				
TOT. Pack for Treatment	492,9	670				
TOT. Pack for Distribution	108,7	108,7				
TOT. Disposables	151,2	151,2				
TOT. Biomedical Device	689	900				
CONTAMINATED	816,8	1027,8				
NON CONTAMINATED	625,00	802,10				

HAEMODIALYSE 1, FREDERIKSBERG HOSPITAL

The overall amount of waste produced within the session is similar to Dialysmottagning 42:AN (1450.30 g), but the variation due to careless sorting is higher (+86%), rising to 2701.4 g. This variation is due to the absence of on-line priming systems that are, on the contrary, present at SUS Malmö.

As regards material, the plastic fraction of non-contaminated waste is slightly lower than the other case studies (84%), but the paper fraction increases (12%) and the 4% are represented by cellulose, which made up the wrapping field of the AVF kits.

FREDERIKSBERG HOSPITAL

GAMBRO ARTIS (HD)

PRODUCT	WEIGHT careful (gr)	WEIGHT careless (gr)	MATERIAL	PRODUCT TYPE	C/NC	TREAT. STAGE
Pack of Bicarbonate and Sodium Chloride Cartridges	42,3	42,3	Cardboard	Pack for distrib.	NC	Set-up
Pack of bloodlines	17,1	17,1	Medical Paper+Plastic	Pack for distrib.	NC	Set-up
Saline Solution 1000 ml	26	900	Paper	Pack for treat.	NC	Set-up
Pack of Saline Solution 1000 ml Stopper (x2)	18,6	18,6		Pack for distrib.	NC	
Pack of Dialyzer	11,2	11,2	Medical Paper+HDPE	Pack for distrib.	NC	Set-up
AVF CONNECTION KIT						Start
Pack of AVF connection kit	7,1	7,1	Medical Paper+Plastic	Pack for distrib.	NC	
Wrapping field 37x46cm (x2)	14	14	Cellulose	Disposable	NC	
Sprayer 10 ml (x2)	22	22		Disposable	C	
Gauze 7,5x7,5 cm (x10)	6	6	Nonwoven	Disposable	C	
Balls Ø 25mm (x10)	10	10	Nonwoven	Disposable	C	
connection stoppers (x2)	2,4	2,4	plastic	Disposable	C	
stoppers bloodlines (x1 blue, x1 red)	0,6	0,6	Nonwoven	Disposable	C	
Plastic tray	15	15	Plastic	Disposable	NC	
Collection bag of wash solution	42,6	42,6	Plastic	Pack for treat.		Start
Pack of syringes needle (x1)	0,3	0,3	Medical Paper+Plastic	Pack for distrib.	NC	Start
Examination gloves (x2)	7,2	7,2	Nitrile rubber	Disposable	C	Start
Pack of fistula needles (x2) Stoppers of fistula needles (x2)	9	9	Medical Paper+Plastic	Pack for distrib.	NC	Start
Pack of sodium chloride		0	PP	Pack for distrib.	NC	Start
Heparin injection		0	Medical Paper+Plastic	Disposable	C	Start

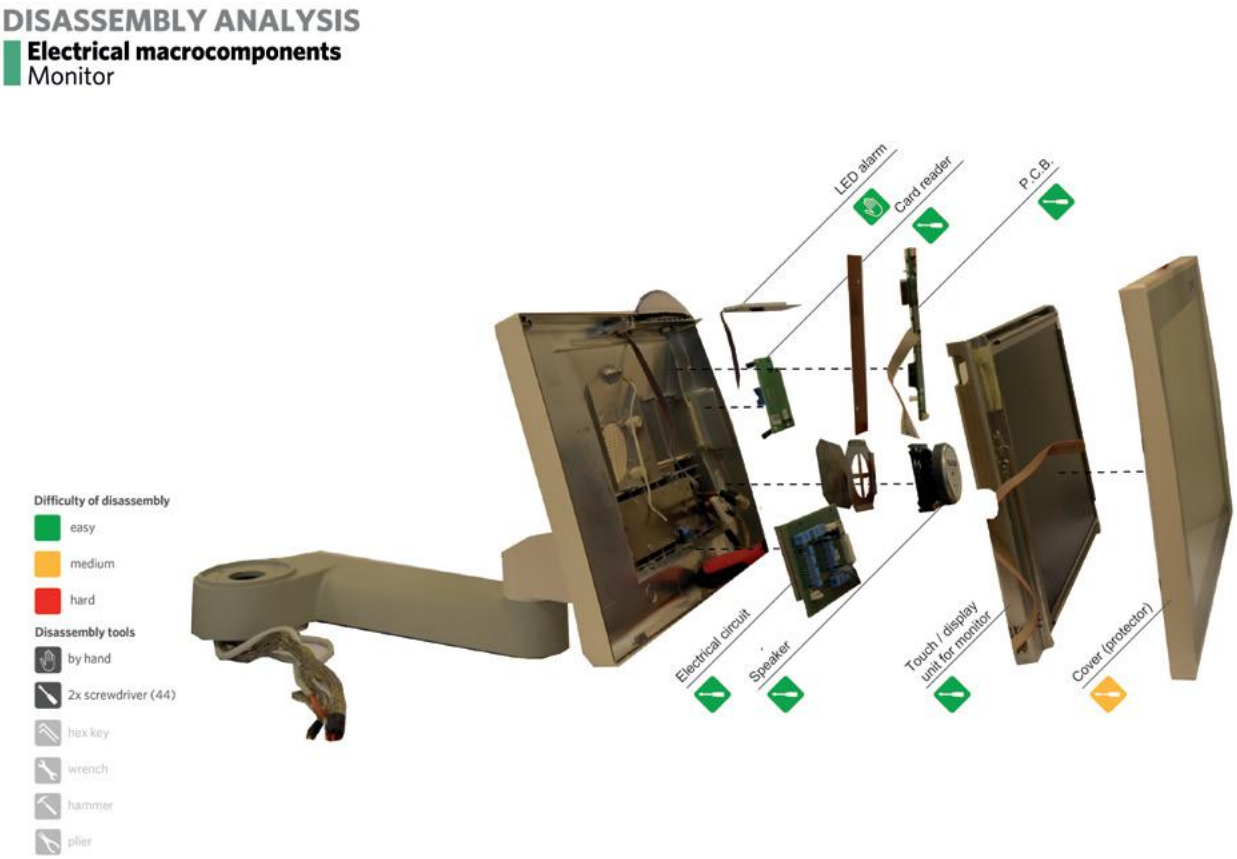
Pack of heparin injection		0		Pack for distrib.	NC	Start
Examination gloves (x2)	7,2	7,2	Nitrile rubber	Disposable	C	End
Venous bloodline	600	800	mix (containing PVC and phtalate)	Biomedical Device	C	End
Arterious bloodline						
Dialyzer Polyflux 210						
Bicarbonate Cartridge	306	334,7	PP	Pack for treat.	NC	End
Sodium Chloride Cartridge	131,8	229,3	PP	Pack for treat.	NC	End
Fistula Needles (x2)	26	26	PVC+metal	Disposable	C	End
Acid concentrate bag	50,8	101,7	LDPE	Pack for treat.	NC	End
DISCONNECTION KIT (= Connection)						End
Pack of AVF connection kit	7,1	7,1	Medical Paper+Plastic	Pack for distrib.	NC	
Wrapping field 37x46cm (x2)	14	14	Cellulose	Disposable	NC	
Sprayer 10 ml (x2)	22	22		Disposable	C	
Gauze 7,5x7,5 cm (x10)	6	6	Nonwoven	Disposable	C	
Balls Ø 25mm (x10)	10	10	Nonwoven	Disposable	C	
connection stoppers (x2)	2,4	2,4	plastic	Disposable	C	
stoppers bloodlines (x1 blue, x1 red)	0,6	0,6	Nonwoven	Disposable	C	
Plastic tray	15	15	Plastic	Disposable	NC	
CleanCart C	16,3	16,3			NC	End
TOTAL	**1450,30**	**2701,40**				
TOT. Pack for Treatment	557,2	1608,3				
TOT. Pack for Distribution	112,7	112,7				
TOT. Disposables	180,4	180,4				
TOT. Biomedical Device	600	800				
CONTAMINATED	722,4	922,4				
NON CONTAMINATED	870,20	1944,20				

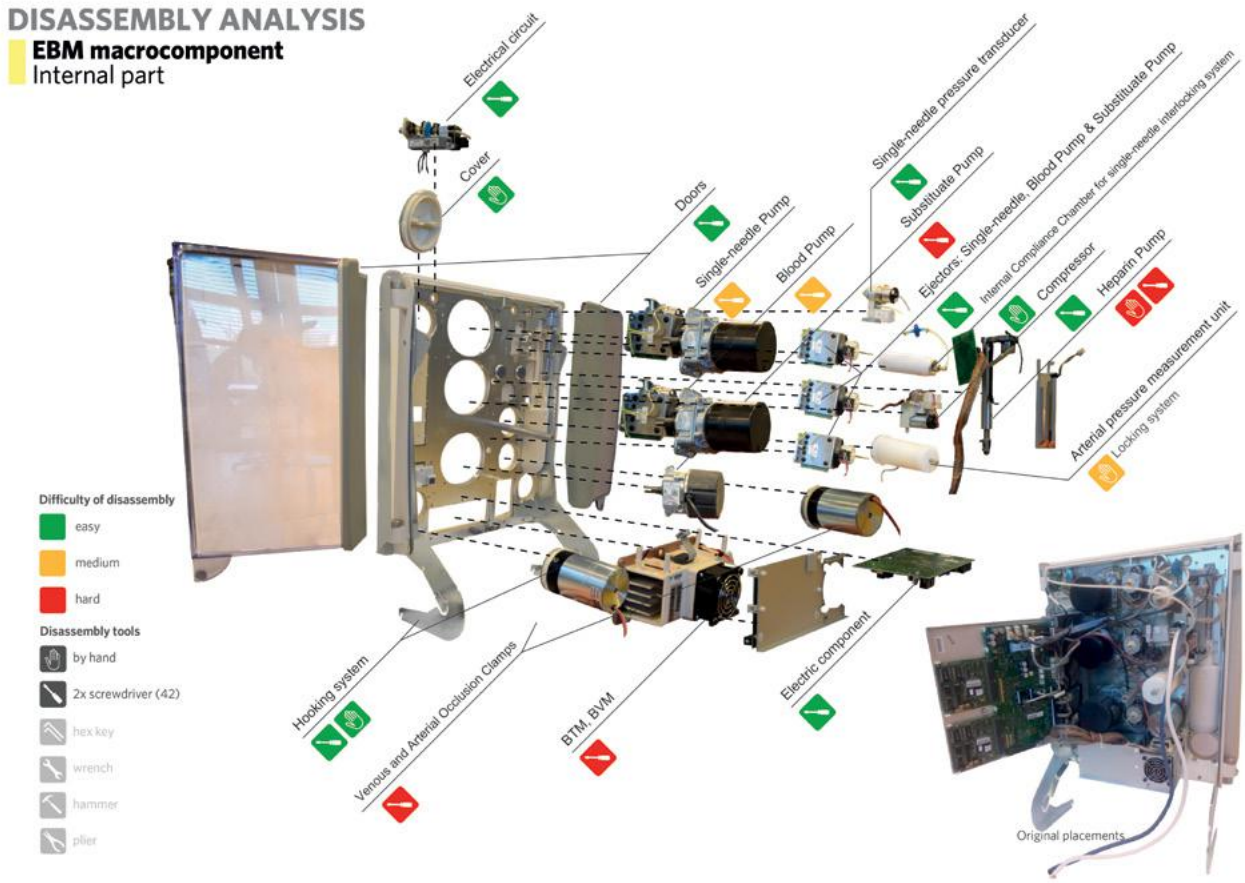
A.2 EQUIPMENT ANALYSIS

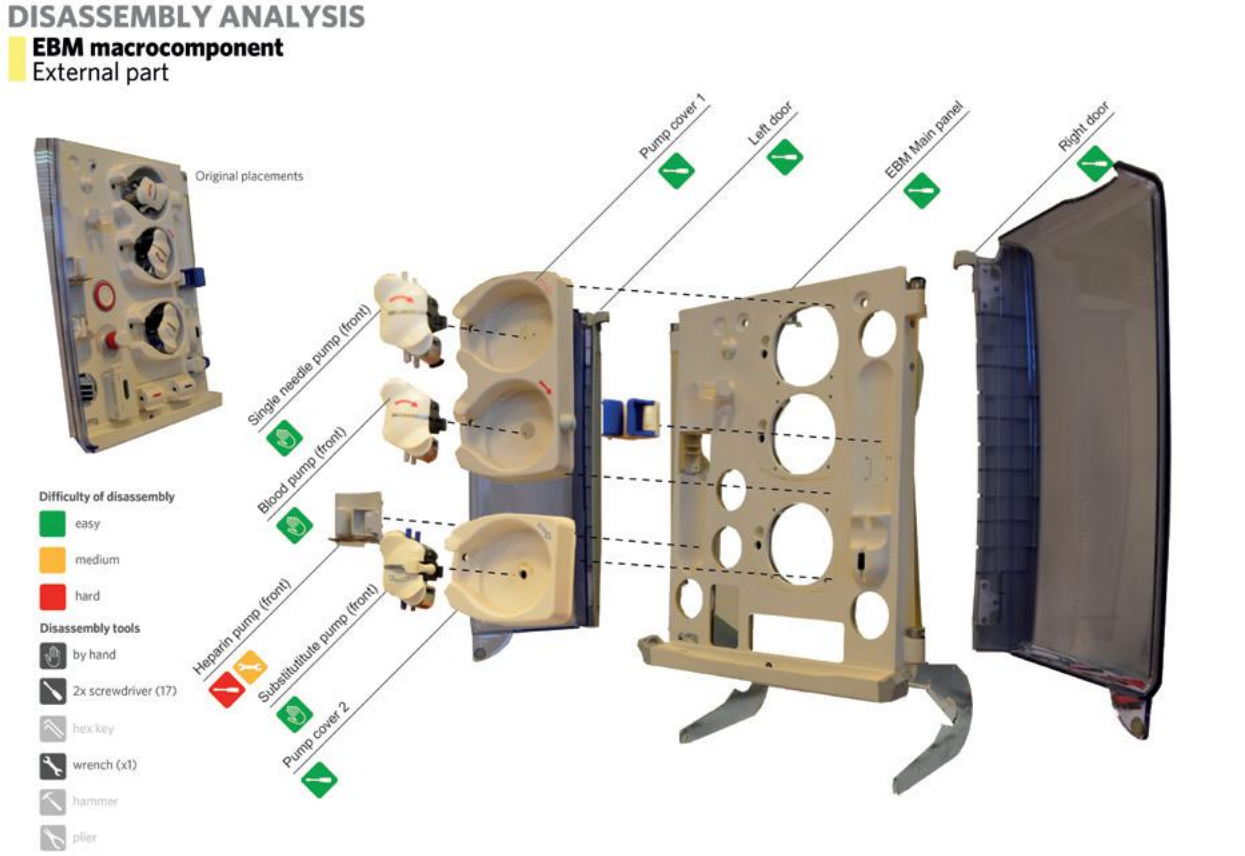
A.2.1 Disassembly analysis

The method chosen to analyse the equipment combines the approaches of Design By Components and Design for Disassembly to understand the main environmental and functional issues of a complex product (see par. 3.2.2).
In the first part of the analysis, each macro-component has been completely disassembled. Each sub-component has been identified by an identification code that designates its function and the sequential number

The Disassembly Analysis identified the most critical issues regarding environmental sustainability, considering both the maintenance of the equipment (ease of replacement, ease of separation of sub-components) and the disposal at the end of its useful lifespan (ease of disassembly different components and materials)

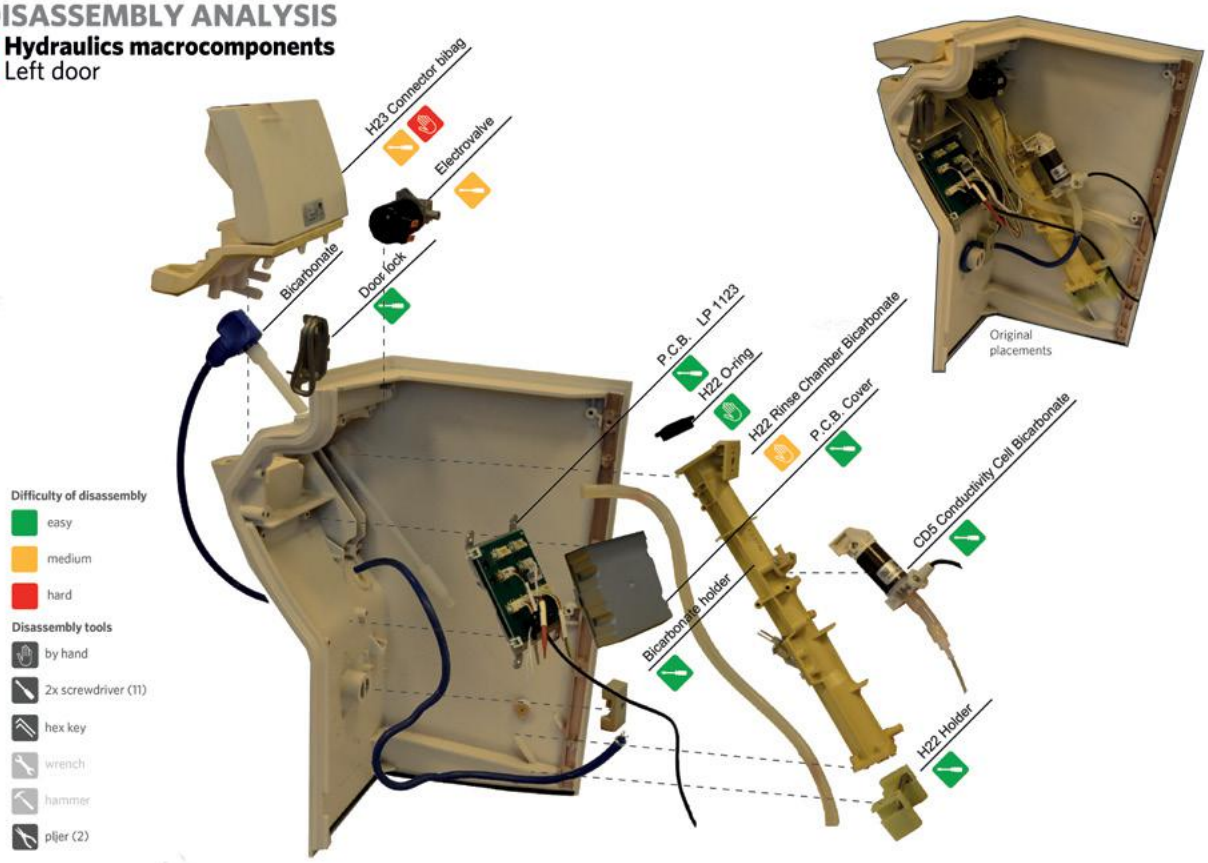



DISASSEMBLY ANALYSIS
EBM macrocomponent
Internal part
Electrical circuit
Cover
Doors
Single-needle Pump
Blood Pump
Single-needle pressure transducer
Substituate Pump
Electors: Single-needle, Blood Pump & Substituate Pump
Internal Compliance Chamber for single-needle interlocking system
Compressor
Heparin Pump
Arterial pressure measurement unit
Locking system
Hooking system
Venous and Arterial Occlusion Clamps
BTM, BVM
Electric component
Original placements
Difficulty of disassembly
easy
medium
hard
Disassembly tools
by hand
2x screwdriver (42)
hex key
wrench
hammer
plier


DISASSEMBLY ANALYSIS
EBM macrocomponent
External part
Original placements
Pump cover 1
Left door
EBM Main panel
Right door
Single needle pump (front)
Blood pump (front)
Heparin pump (front)
Substitutitute pump (front)
Pump cover 2
Difficulty of disassembly
easy
medium
hard
Disassembly tools
by hand
2x screwdriver (17)
hex key
wrench (x1)
hammer
plier

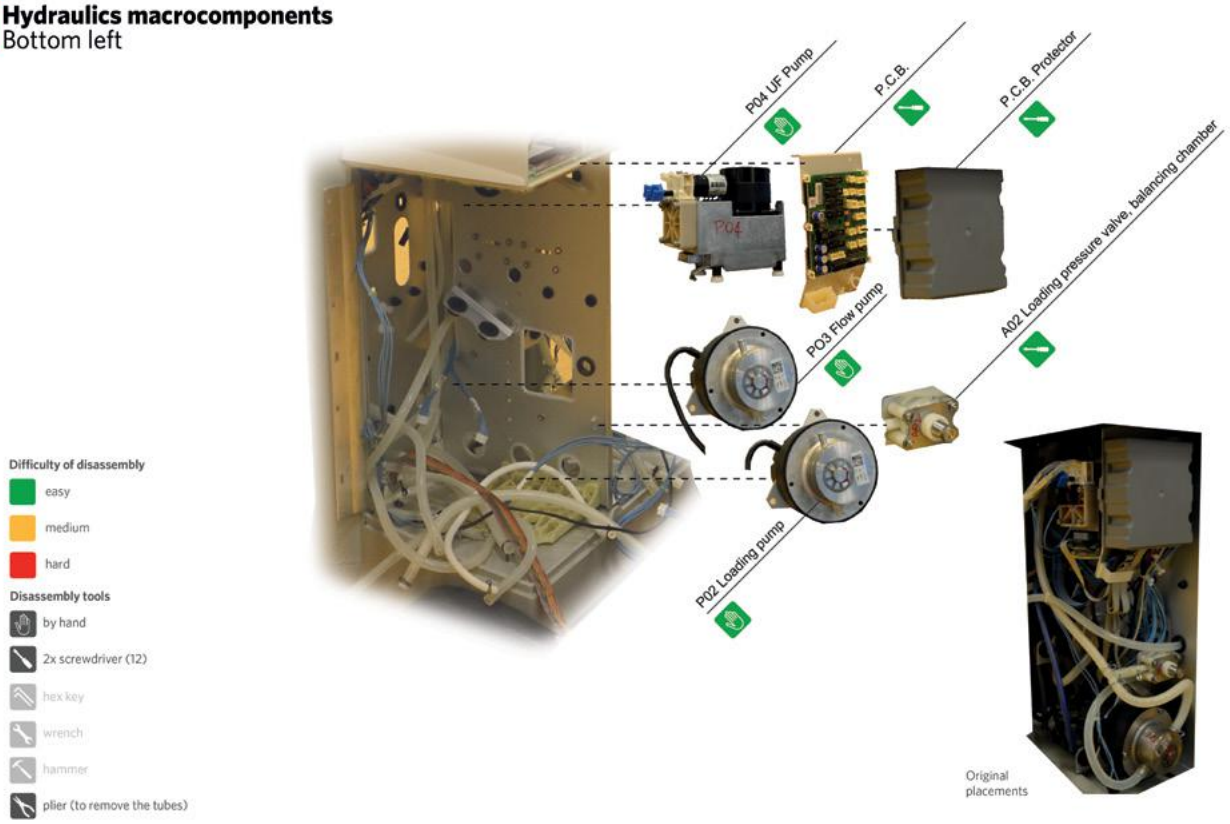
DISASSEMBLY ANALYSIS

Hydraulics macrocomponents
Left door



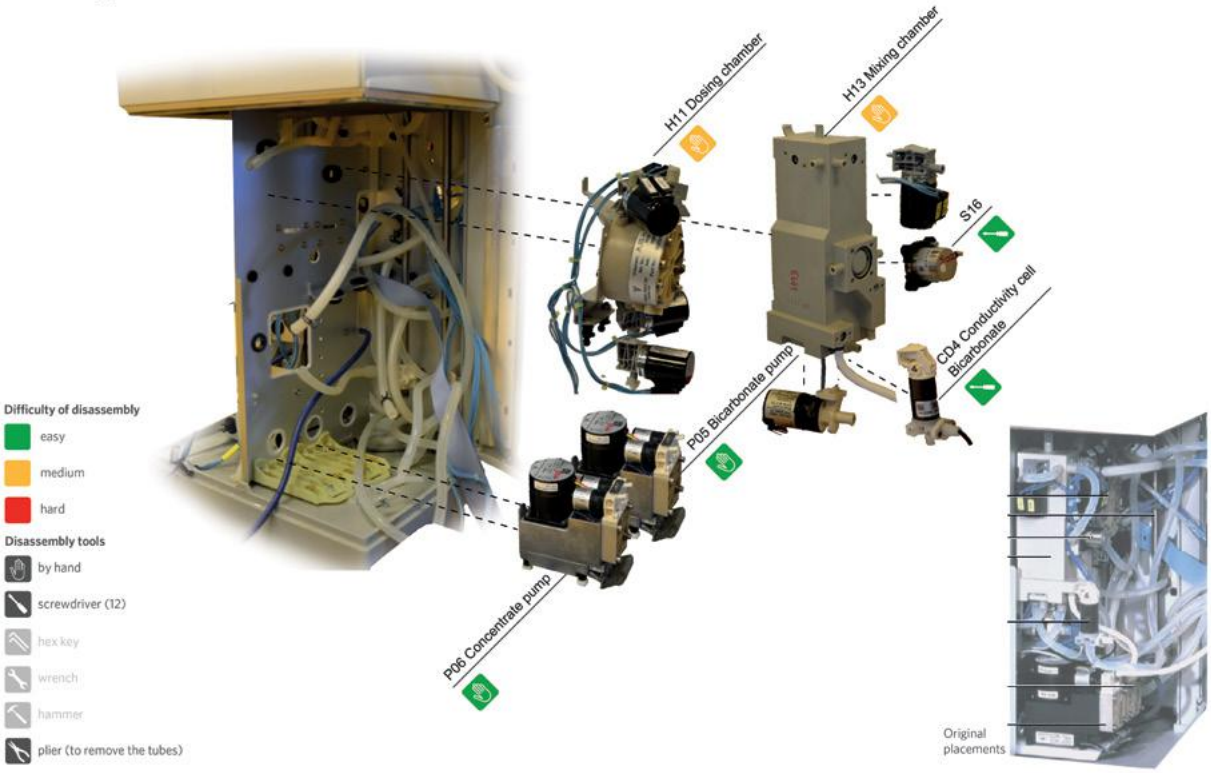
DISASSEMBLY ANALYSIS

Hydraulics macrocomponents
Bottom left



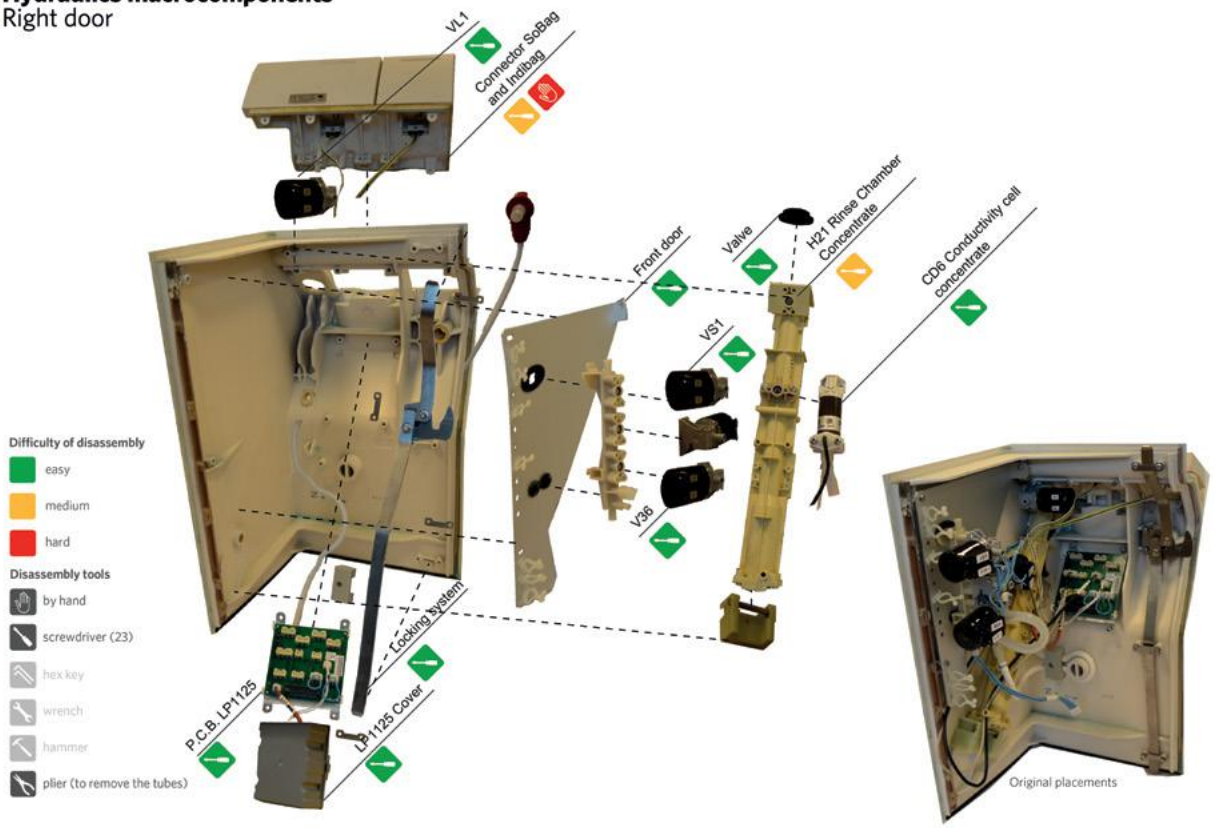
DISASSEMBLY ANALYSIS

Hydraulics macrocomponents
Bottom right



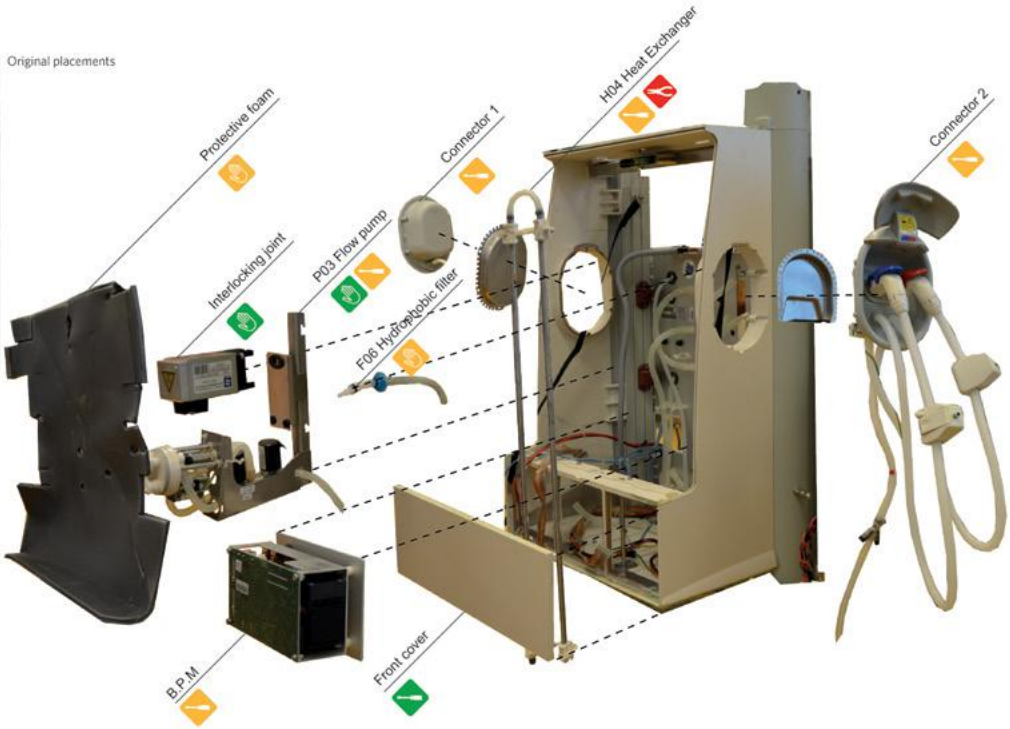
DISASSEMBLY ANALYSIS

Hydraulics macrocomponents
Right door



DISASSEMBLY ANALYSIS
Hydraulics macrocomponents
Front

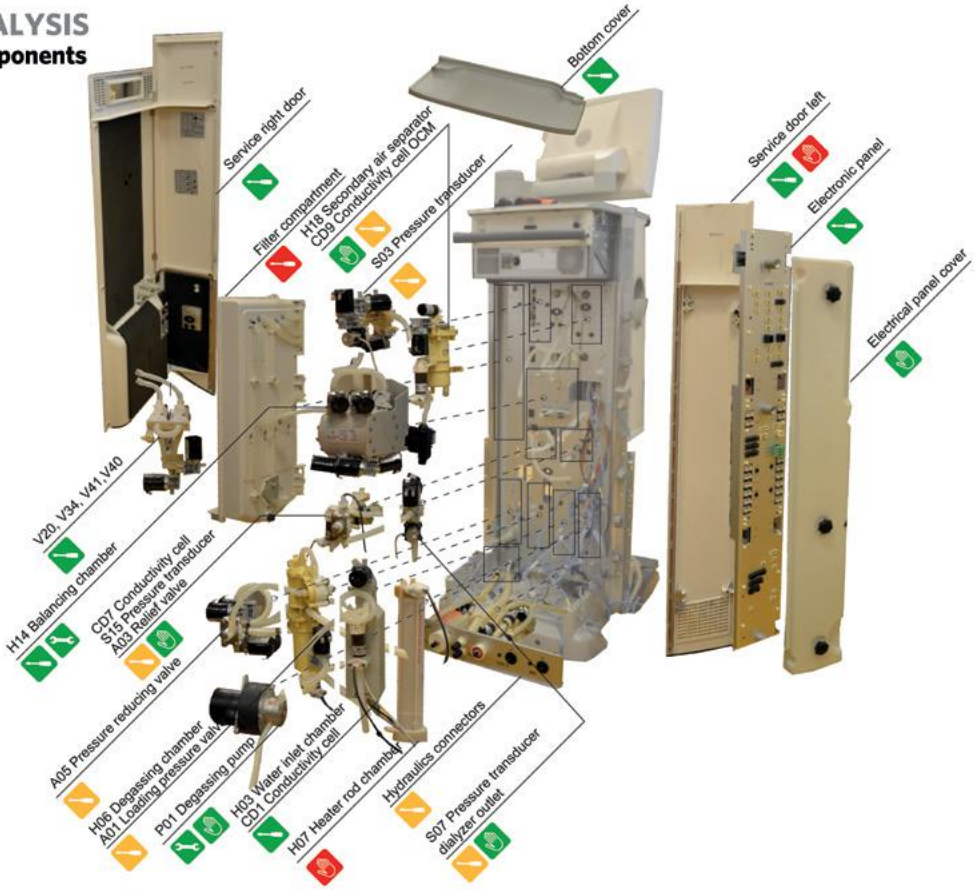
Original placements



Difficulty of disassembly
- easy
- medium
- hard

Disassembly tools
- by hand
- 2x screwdriver (26)
- hex key
- wrench (1)
- hammer
- plier (to remove the tubes)

DISASSEMBLY ANALYSIS
Hydraulics macrocomponents
Back

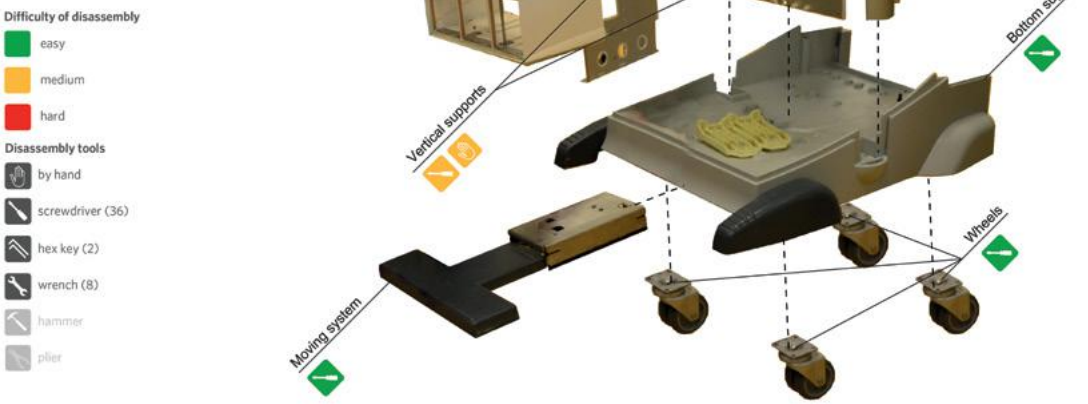


Difficulty of disassembly
- easy
- medium
- hard

Disassembly tools
- by hand
- 2x screwdriver (53)
- hex key
- wrench (2)
- hammer
- plier (to remove the tubes)

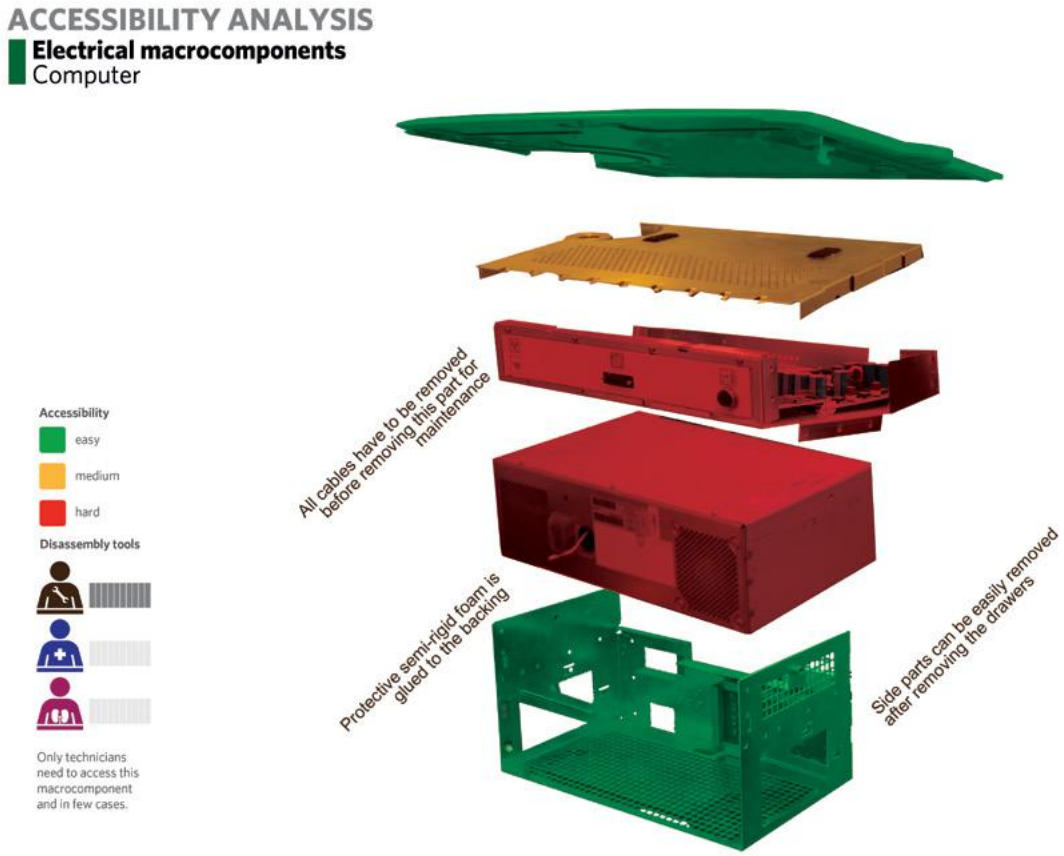
DISASSEMBLY ANALYSIS

Protective macrocomponents
Shell



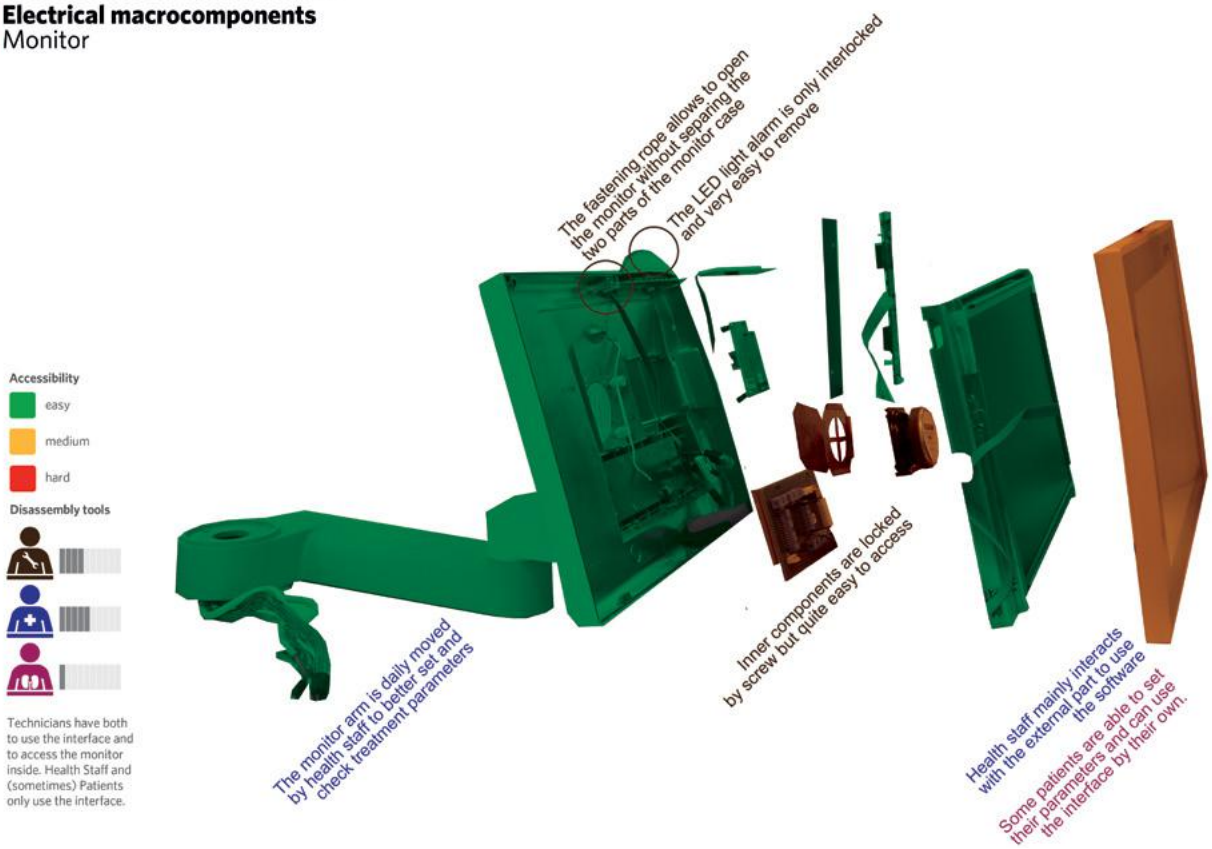
A.2.2 Analysis of Accessibility and interaction

The second part of the analysis aims at defining the ease of access to macro- and sub-components by different users (technicians, health staff, patients).
The colour coding is the same of the Disassembly Analysis. However, it does not identify one single component but groups of components according to their function.
The analysis of accessibility, carried out during disassembly, is verified by the on-the-field analysis that takes into account treatment routines (healthcare staff and patients) and routine preventive maintenance (technicians).
The comparison allows understanding the frequency and the use of different groups of components.
This analysis aims at establishing a hierarchy regarding accessibility to functional components, by comparing the component functionality with the ease of access.



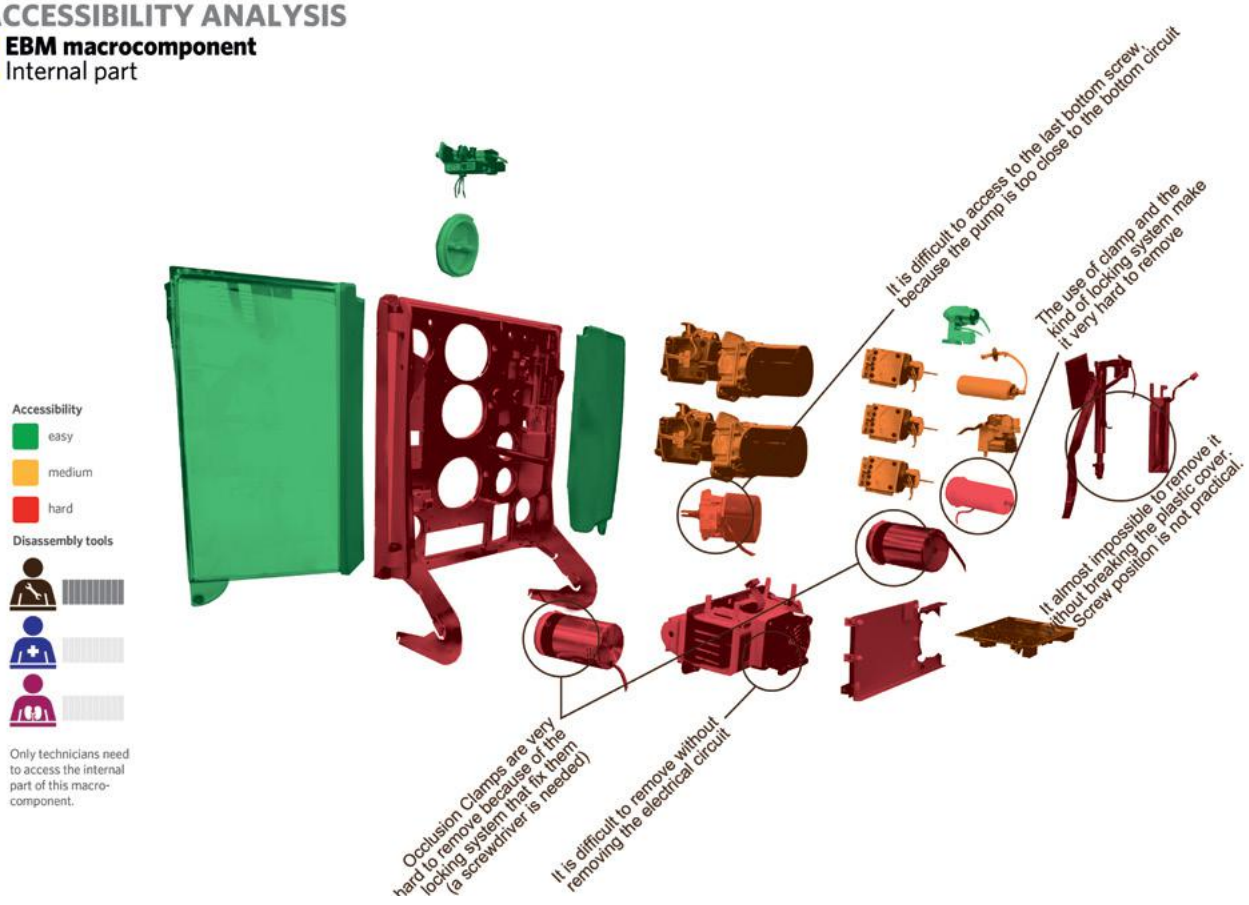
ACCESSIBILITY ANALYSIS

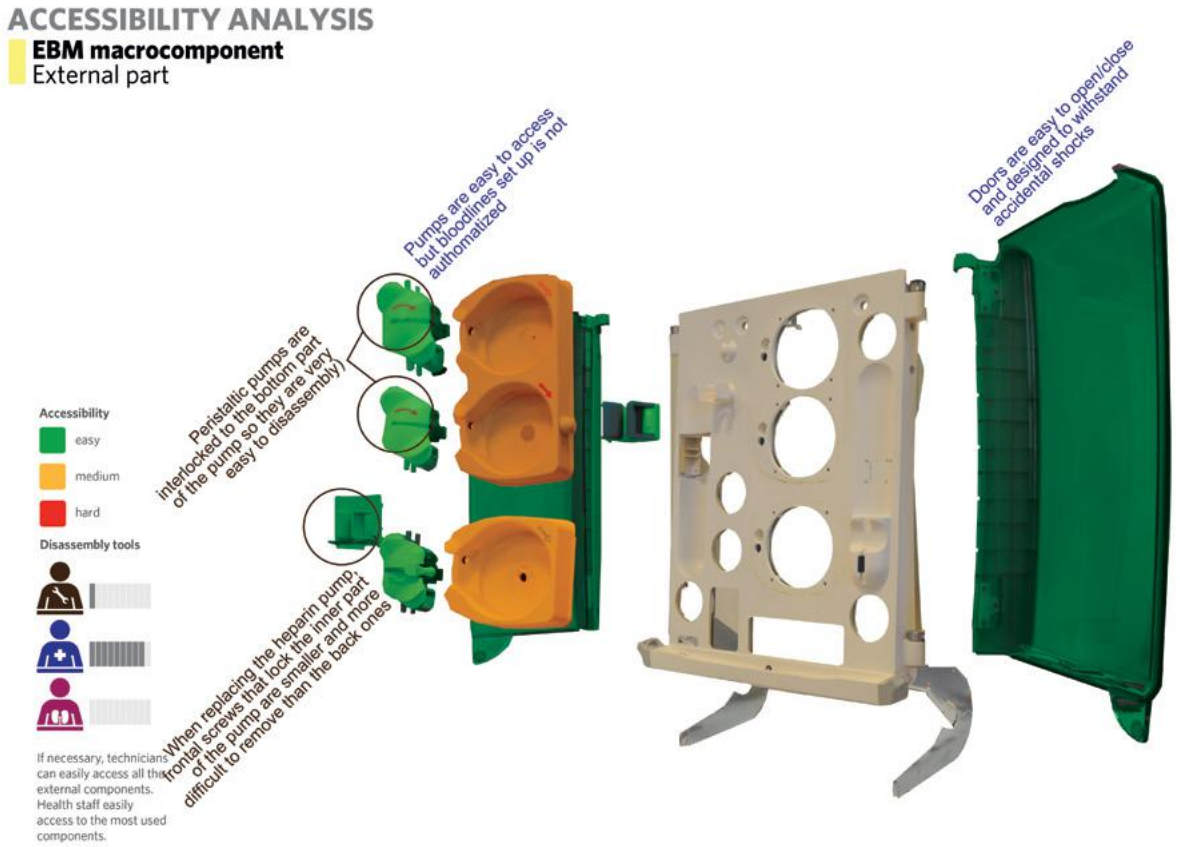
Electrical macrocomponents
Monitor



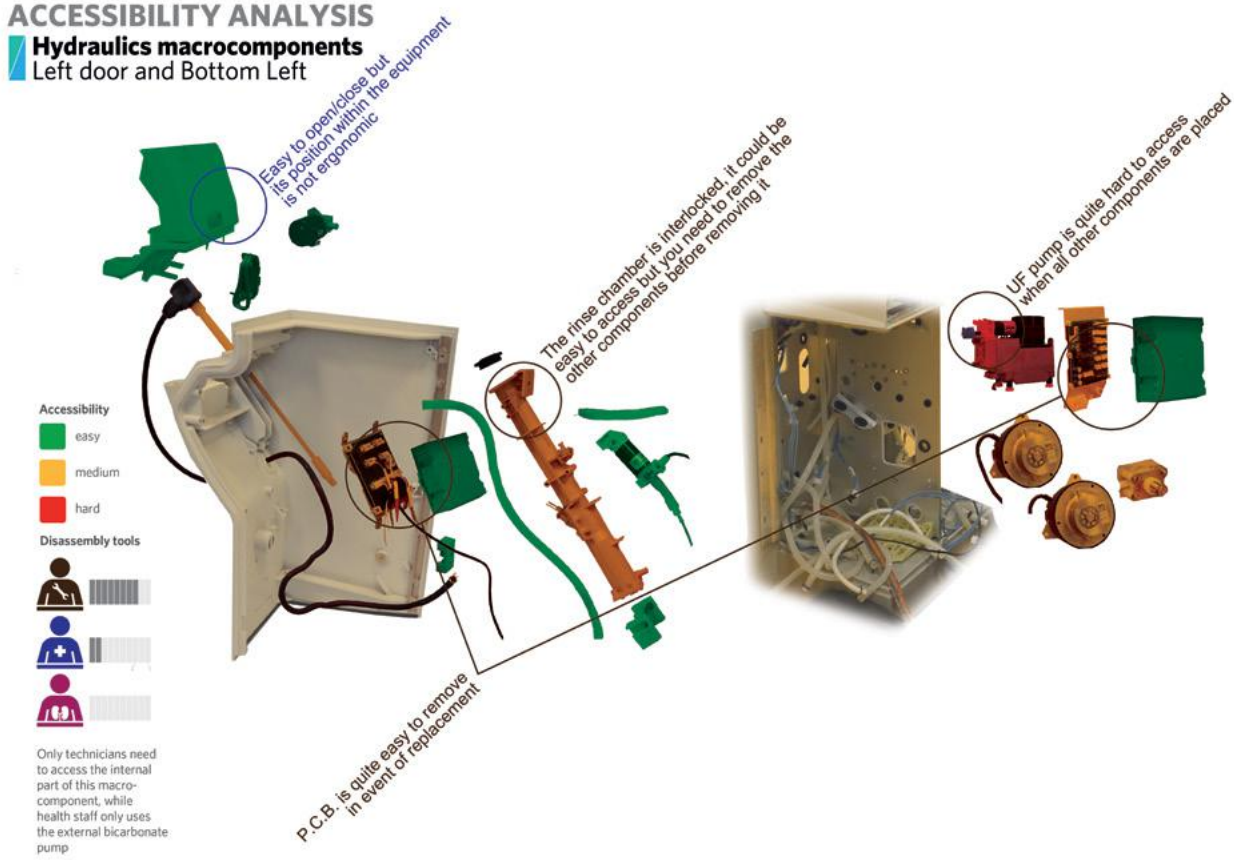
ACCESSIBILITY ANALYSIS

EBM macrocomponent
Internal part



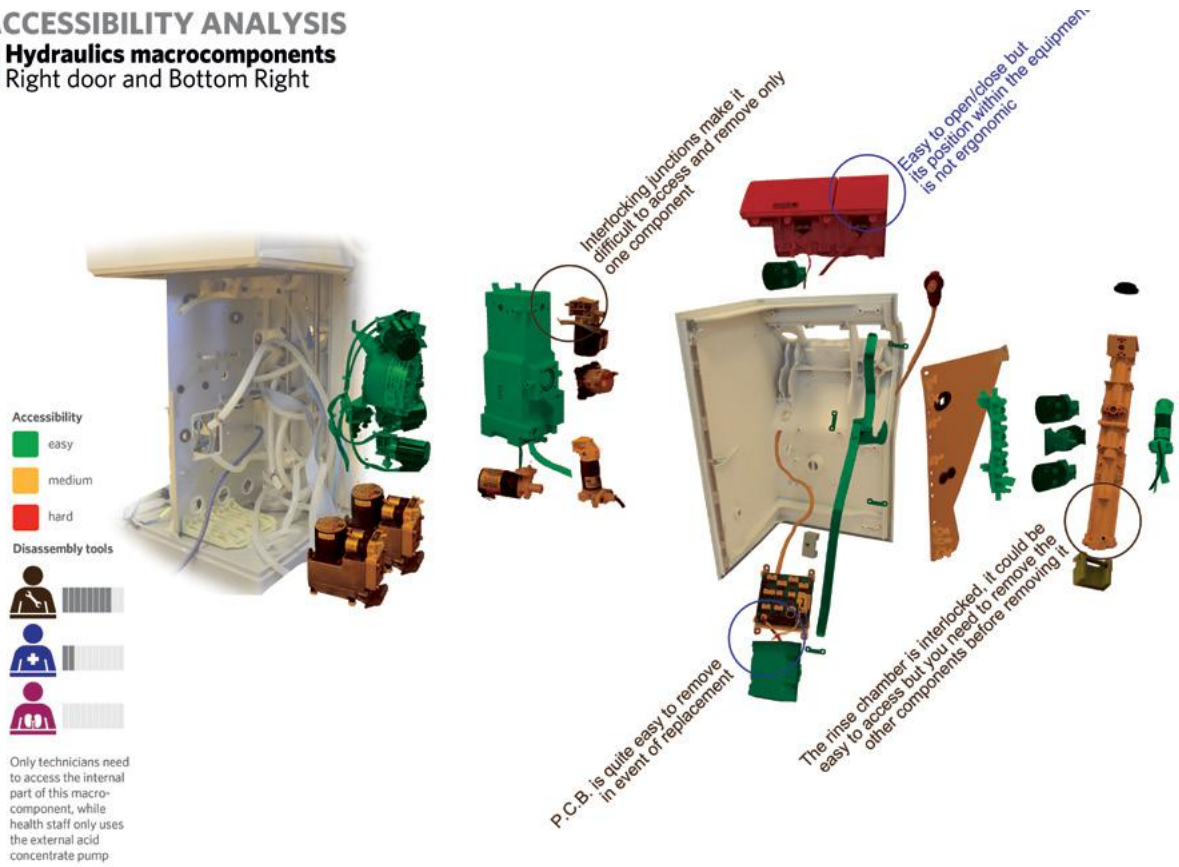

ACCESSIBILITY ANALYSIS
EBM macrocomponent
External part
Pumps are easy to access but bloodlines set up is not authomatized
Doors are easy to open/close and designed to withstand accidental shocks
Peristaltic pumps are interlocked to the bottom part of the pump so they are very easy to disassembly)
When replacing the heparin pump, frontal screws that lock the inner part of the pump are smaller and more difficult to remove than the back ones
Accessibility
easy
medium
hard
Disassembly tools
If necessary, technicians can easily access all the external components. Health staff easily access to the most used components.

184


ACCESSIBILITY ANALYSIS
Hydraulics macrocomponents
Left door and Bottom Left
Easy to open/close but its position within the equipment is not ergonomic
The rinse chamber is interlocked, it could be easy to access but you need to remove the other components before removing it
UF pump is quite hard to access when all other components are placed
P.C.B. is quite easy to remove in event of replacement
Accessibility
easy
medium
hard
Disassembly tools
Only technicians need to access the internal part of this macro-component, while health staff only uses the external bicarbonate pump

ACCESSIBILITY ANALYSIS

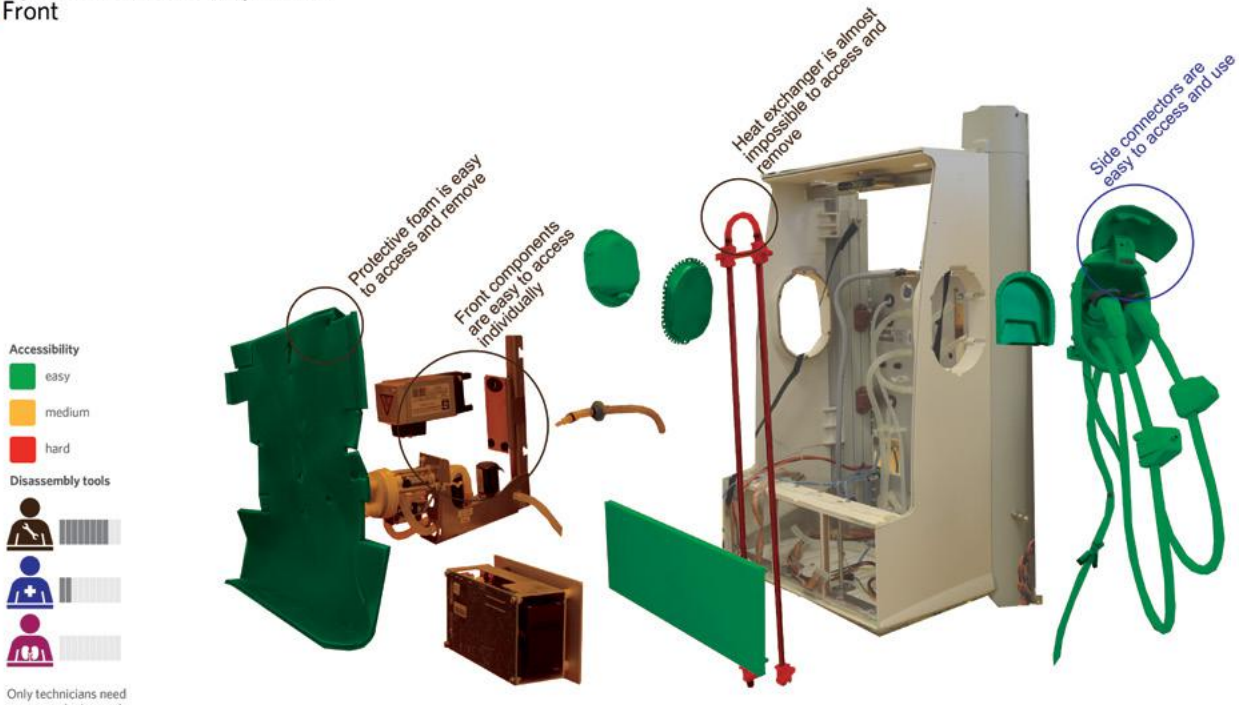
Hydraulics macrocomponents
Right door and Bottom Right



Only technicians need to access the internal part of this macro-component, while health staff only uses the external acid concentrate pump

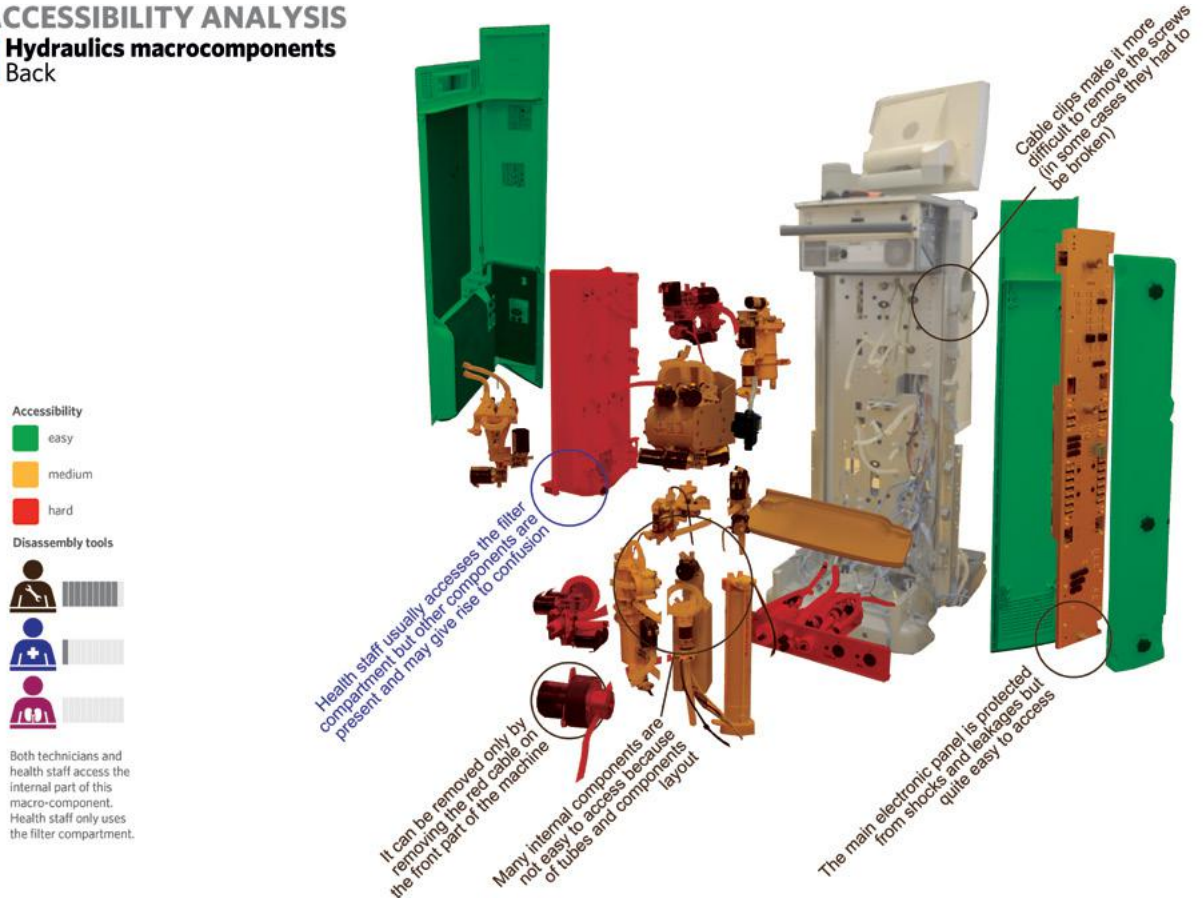
ACCESSIBILITY ANALYSIS

Hydraulics macrocomponents
Front



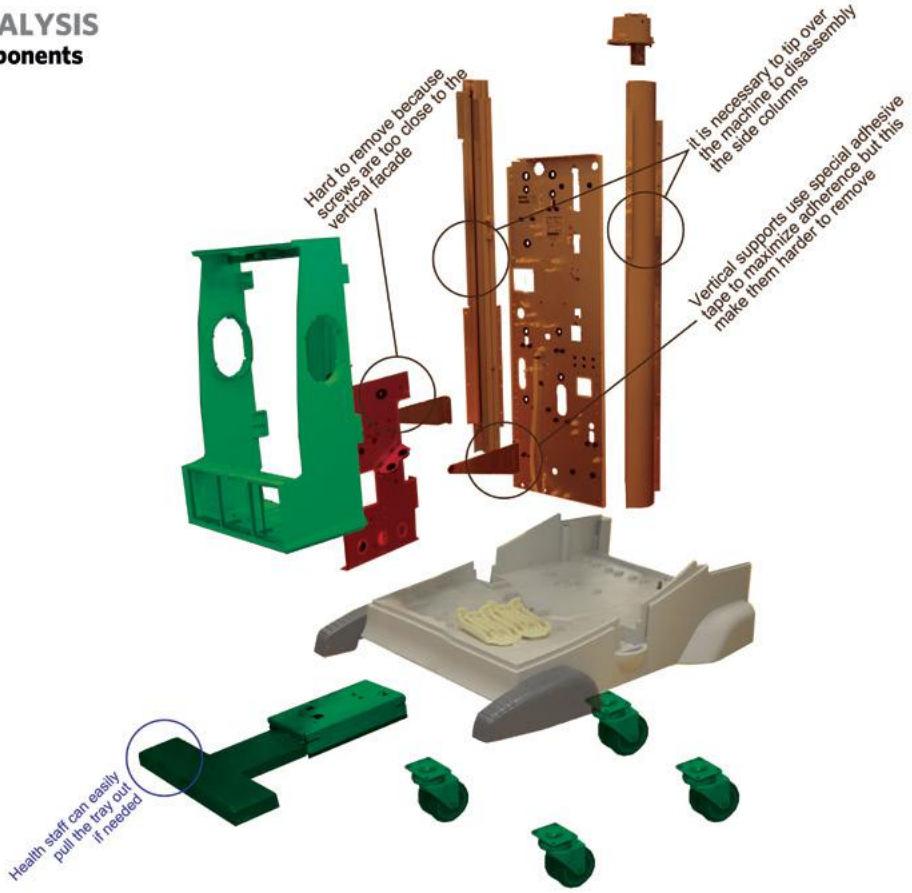
Only technicians need to access the internal part of this macro-component, while health staff only uses the side connectors.

ACCESSIBILITY ANALYSIS
Hydraulics macrocomponents
Back



Both technicians and health staff access the internal part of this macro-component. Health staff only uses the filter compartment.

ACCESSIBILITY ANALYSIS
Protective macrocomponents
Shell



Health staff daily moves and interacts the equipment shell, as well as patients. Technicians may need to remove some components.

FRESENIUS 5008 | WEIGHT ASSESSMENT

COMPONENT		WEIGHT	MATERIAL
Code	Name	gr	type
HYDRAULICS BOTTOM RIGHT DOOR		**4328**	
-	Door	1744	PUR
-	Connector SoBag	971	plastic + metal elements
LP1125	P.C.B.	108	WEEE
-	P.C.B. cover	43	PP
VI1, VS1, VB1, V36	Electrovalves (x4)	680	WEEE
-	Electrovalves support	40	PES
H21	Rinse Chamber concentrate	198	plastic + metal elements
-	H21 Holder	45	PA66 + metal
-	Locking system	264	metal
CD6	Conductivity Cell, concentrate	88	WEEE
-	Front Door	147	Al + plastic elements
HYDRAULICS BOTTOM RIGHT SIDE		**4671**	
H11	Dosing chamber (including 4 valves)	1211	WEEE
H13	Mixing chamber	598	WEEE
CD4	Conductivity Cell, bicarbonate	88	WEEE
P05	Bicarbonate pump	1342	WEEE
P06	Concentrate pump	1342	WEEE
S16	Pressure transducer, fill dry concentrate bag	90	WEEE
HYDRAULICS BOTTOM LEFT DOOR		**2838**	
-	Door	1366	PUR
H23	Connector BiBag	608	plastic + metal elements
LP1123	P.C.B.	108	WEEE
-	P.C.B. cover	43	PP
	Electrovalve	170	WEEE
H22	Rinse Chamber concentrate	198	plastic + metal elements
-	H22 Holder	45	PA66 + metal
-	O-ring	4	rubber (EPDM)
CD5	Conductivity Cell, bicarbonate	90	WEEE
	Bicarbonate ???	135	plastic mix + rubber
	Bicarbonate ??? Holder	11	plastic
	Door locker	60	metal
HYDRAULICS BOTTOM LEFT SIDE		**4909**	
P04	UF pump	1335	WEEE
P03	Flow pump	1494	WEEE
P02	Loading pump	1759	WEEE
A02	Loading pressure valve	62	WEEE
-	P.C.B.	204	WEEE
-	P.C.B. cover	55	PP
HYDRAULICS BACK		**21402**	
H07	Heater rod chamber	528	WEEE

H03+CD1	Water Inlet Chamber + Conductivity Cell, permeate	738	WEEE
H06+A01	Degassing chamber + Loading Pressure Valve	622	WEEE
P01	Degassing pump	1606	WEEE
A05	Check valve, water inlet	875	WEEE
CD7+ S15+ A03	Conductivity Cell, overall conductivity + Pressure transducer, balancing chamber switching + Relief valve	392	WEEE
S07	Pressure transducer, dialyzer outlet	709	WEEE
H14	Balancing chamber (+4 valves)	2329	WEEE
V20, V34, V40, V41	4 valves (disinfection control)	780	WEEE
S03	Pressure transducer, dialyzer inlet (+4 valves)	860	WEEE
H18+CD9	Secondary air separator + Conductivity cell, OCM (+1 valve)	502	WEEE
S08	Blood Leak detector	101	WEEE
-	Electronic Control Board	1281	WEEE
-	Electronic Control Board cover	350	ABS
-	Filter compartment	2331	PUR + metallic elements + tubes
-	Hydraulics connectors (+5 valves)	1508	WEEE
-	Bottom cover	630	PUR
-	Service Door right	3900	PUR + glued foam rubber + metallic elements
-	Service Door left	1360	PUR
HYDRAULICS FRONT		**4439**	
-	Connector 1	232	WEEE
	Connector 2	814	PP
	Interlocking joint	616	WEEE
	Flow pump	1887	WEEE
	Heat exchanger	430	PC + iron
	Front cover	460	PUR
EBM - inner		**7653**	
-	EBM Main Panel	3555	PUR + iron
-	Door 1	1237	ABS
	Door 2	1237	ABS
-	Pump cover 1	406	PC + ABS
-	Pump cover 2	208	PC + ABS
-	Front part - heparin pump	56	PC + ABS + Iron
-	Blood pump	300	WEEE
	Substitute pump	300	WEEE
	Single needle pump	300	WEEE
-	Tube holders	54	PC + ABS
EBM - outer		**8323**	
-	Ejectors (x3)	792	WEEE
-	Electronic component	88	WEEE
-	Heparin pump	132	WEEE
-	Blood pump	1040	WEEE
	Substitute pump	1245	WEEE

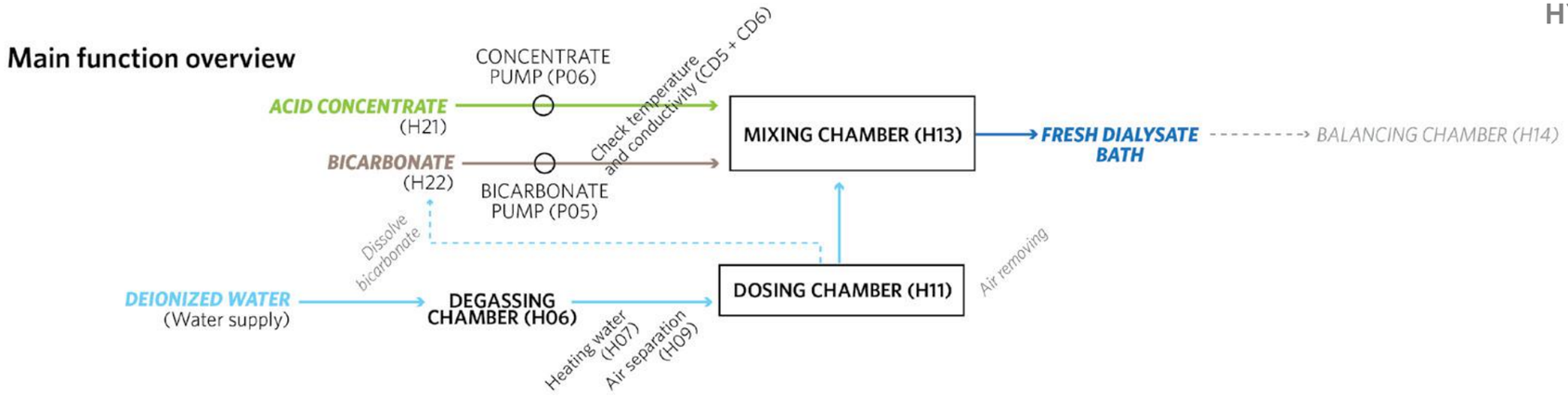
	Single needle pump	1040	WEEE
-	Internal Compliance Chamber for single- needle interlocking system	56	WEEE
	Compressor	425	WEEE
	Arterial preasure measurement unit	395	WEEE
	Venous and Arterial Occlusion Clamps	1454	WEEE
	Electrical circuit	139	WEEE
	BTW / BWM	858	WEEE
	Temperature control system	638	WEEE
	BTW/BWM Cover	21	PC + ABS
COMPUTER		**11237**	
-	Electric module	2038	WEEE
-	PC protection	694	Iron
-	PC component	4908	WEEE
-	Support	1687	Iron
	Protective foam	50	PE
	Cover	1860	PUR
MONITOR		**6764**	
-	Display unit	1666	WEEE
-	speaker	282	WEEE
-	Electrical circuit	82	WEEE
-	LED alarm	19	WEEE
-	Card reader	28	WEEE
-	Movable arm	3910	PC + ABS + Iron
-	Cover	777	WEEE
SHELL		**26201**	
-	EBM holder	3503	PUR
-	Middle panel	947	Al
-	Central panel	1640	Al
-	Bottom support	8374	PUR
-	Side column (x2)	7288	PUR + Al
	Moving system	3189	Iron
-	Wheels (x4)	1260	Al + PP + TPO
TOTAL		**102.765**	

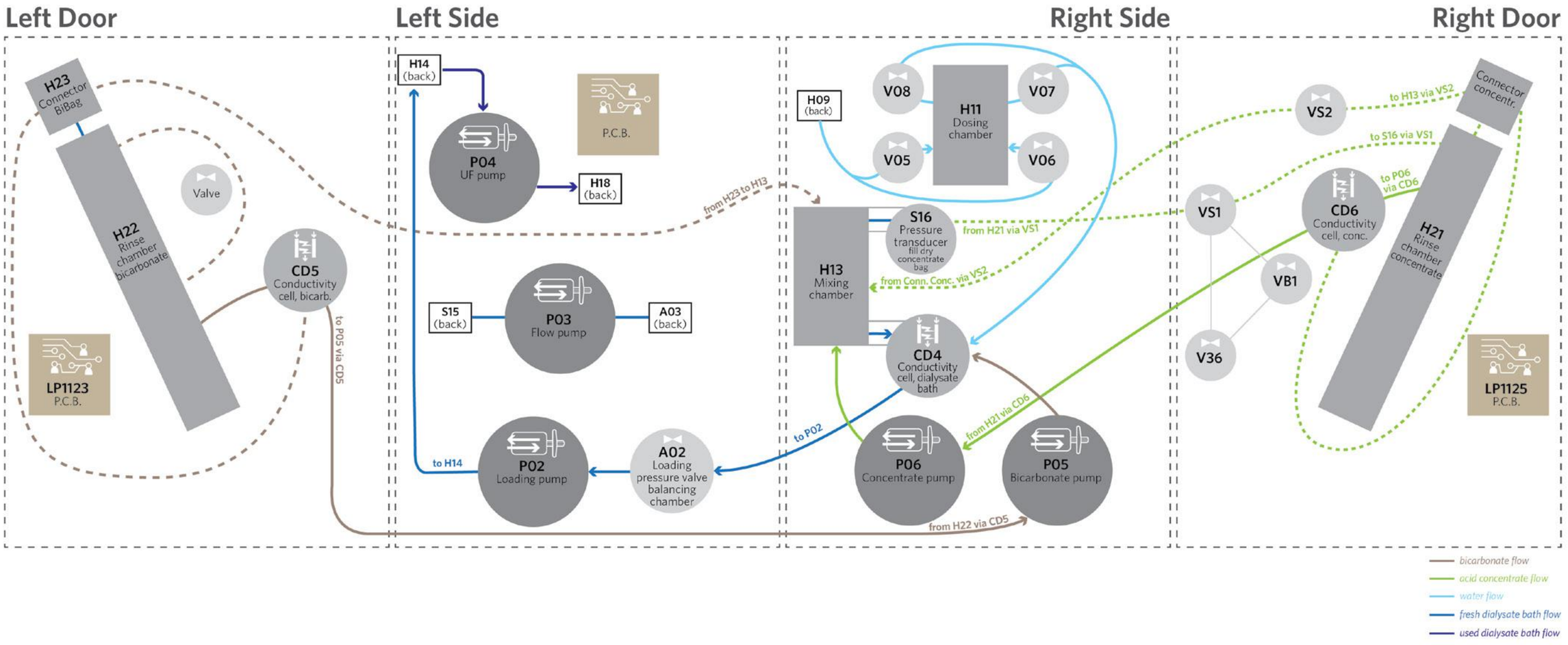
A.2.3 Analysis of input-output flows

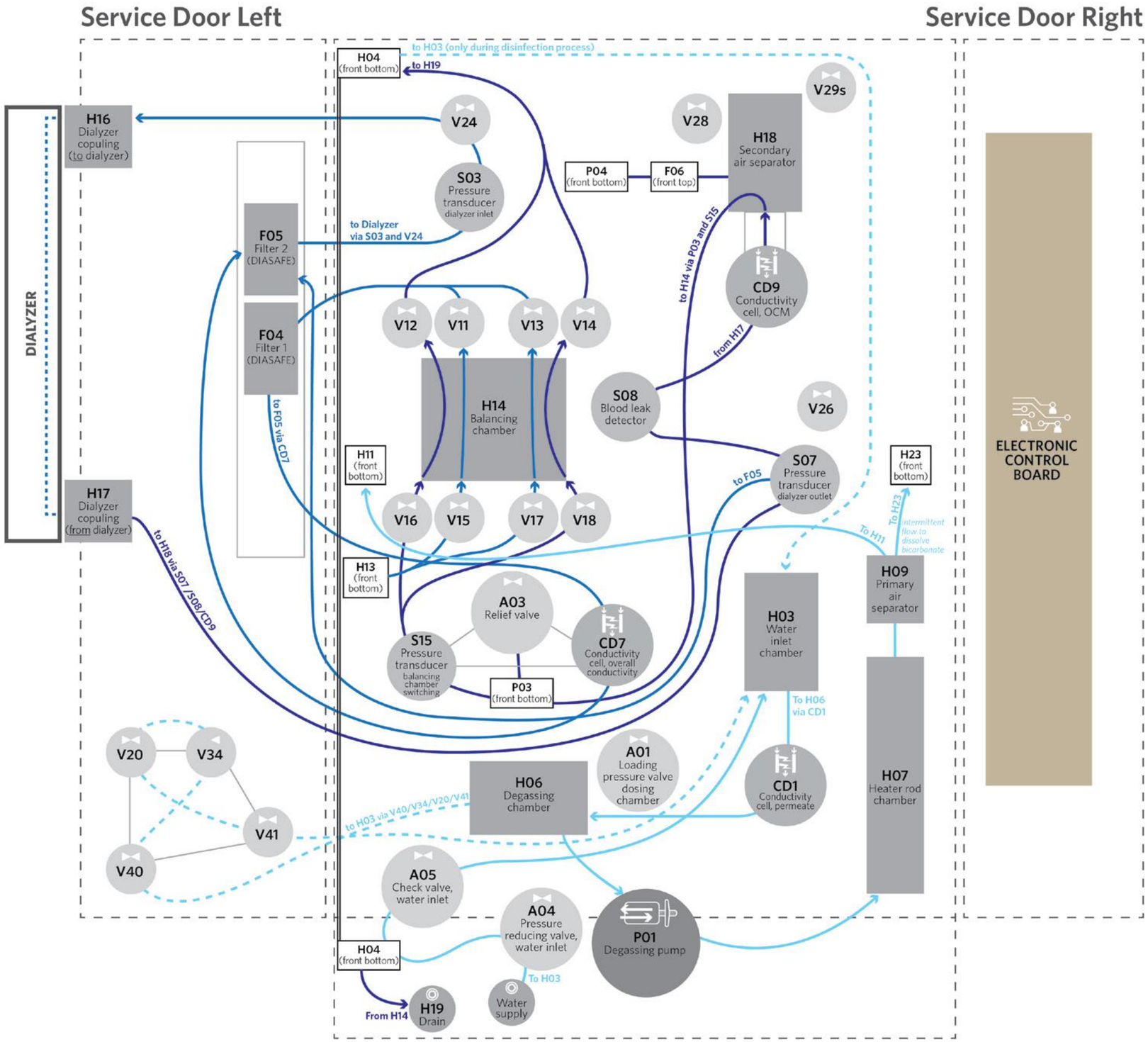
The analysis of the inputs and outputs of the process aims at highlighting critical issues and potentialities from the points of view of environmental sustainability and usability.
The analysis is usually carried out through the creation of a general scheme, which sums up flows and functions of the product. Then, an essential scheme is designed to simplify the product features, stressing the main components and flows

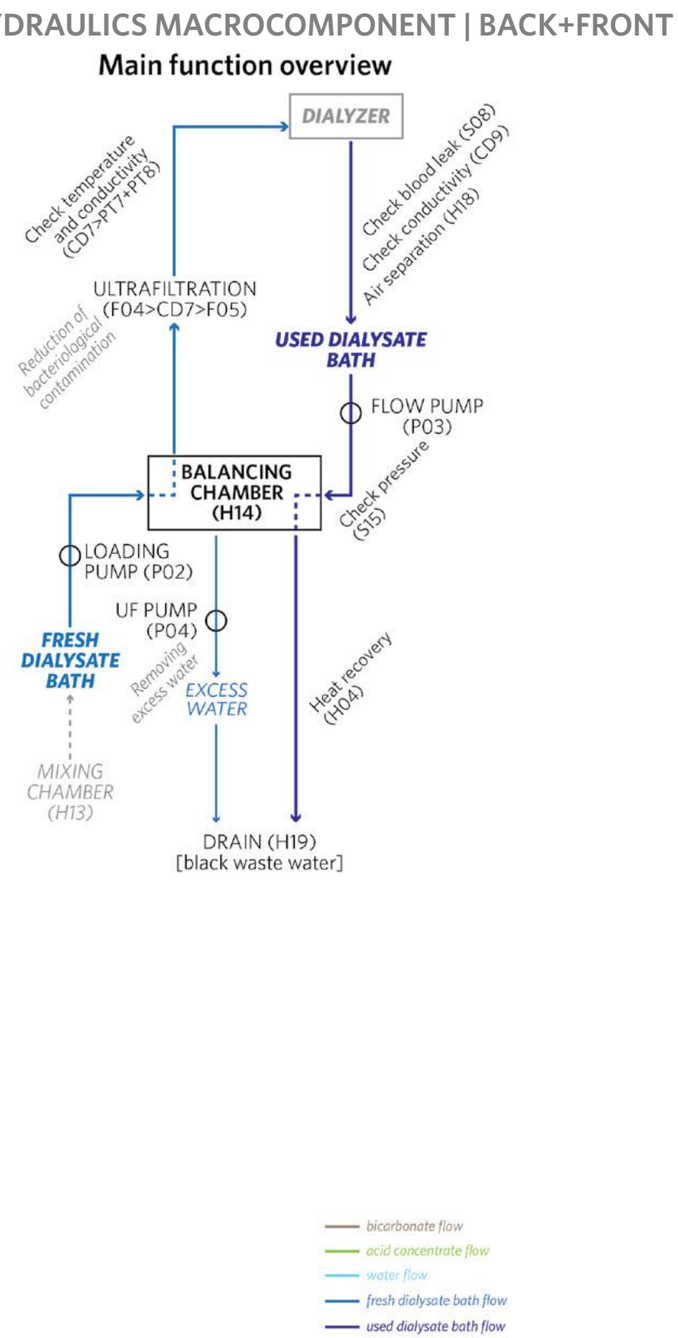
HYDRAULICS MACROCOMPONENT | BOTTOM

Main function overview

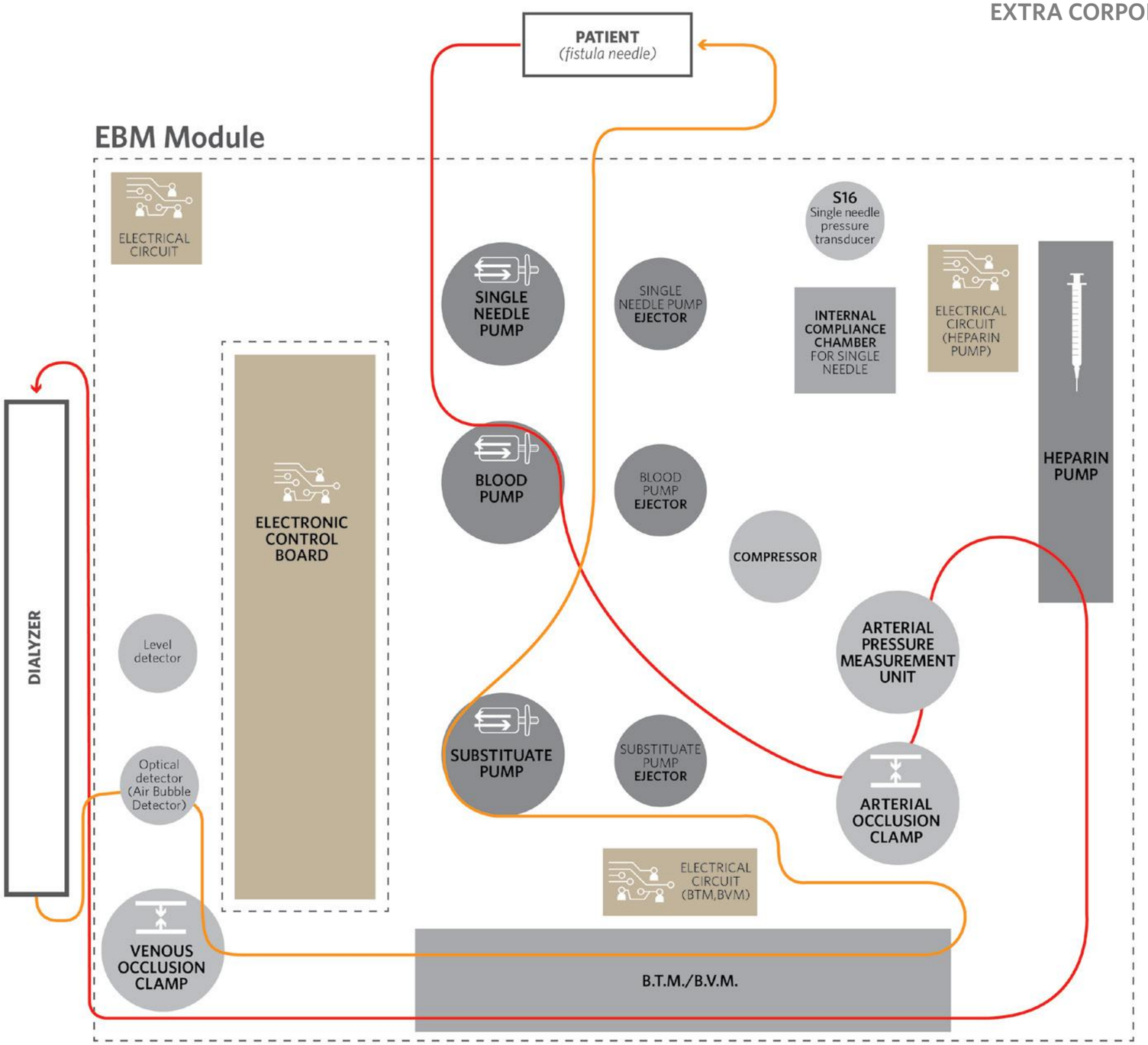




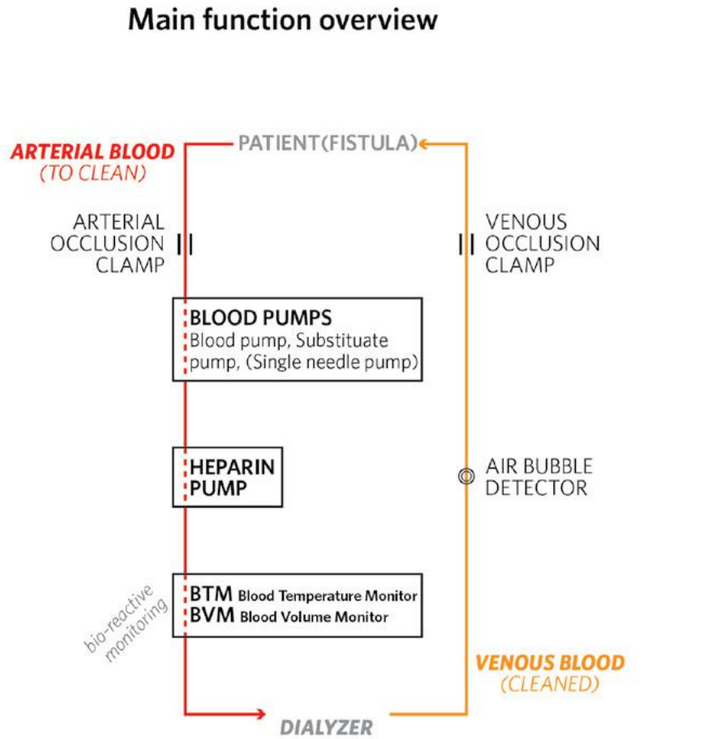

Service Door Left
Service Door Right
DIALYZER
H16 Dialyzer coupling (to dialyzer)
H17 Dialyzer coupling (from dialyzer)
to H18 via S07 / S08 / CD9
F05 Filter 2 (DIASAFE)
F04 Filter 1 (DIASAFE)
to F05 via CD7
to H03 (only during disinfection process)
H04 (front bottom)
to H19
V24
S03 Pressure transducer dialyzer inlet
to Dialyzer via S03 and V24
V28
V29s
H18 Secondary air separator
P04 (front bottom)
F06 (front top)
to H14 via P03 and S15
from H17
CD9 Conductivity cell, OCM
V12
V11
V13
V14
H14 Balancing chamber
S08 Blood leak detector
V26
S07 Pressure transducer dialyzer outlet
to F05
H23 (front bottom)
To H23
To H11
intermittent flow to dissolve bicarbonate
H11 (front bottom)
V16
V15
V17
V18
H13 (front bottom)
A03 Relief valve
S15 Pressure transducer balancing chamber switching
CD7 Conductivity cell, overall conductivity
P03 (front bottom)
H03 Water inlet chamber
H09 Primary air separator
To H06 via CD1
H07 Heater rod chamber
V20
V34
V41
V40
A01 Loading pressure valve dosing chamber
CD1 Conductivity cell, permeate
H06 Degassing chamber
to H03 via V40/V34/V20/V41
A05 Check valve, water inlet
A04 Pressure reducing valve, water inlet
P01 Degassing pump
To H03
Water supply
H04 (front bottom)
From H14
H19 Drain
ELECTRONIC CONTROL BOARD


HYDRAULICS MACROCOMPONENT | BACK+FRONT
Main function overview
DIALYZER
Check temperature and conductivity (CD7>PT7+PT8)
Check blood leak (S08)
Check conductivity (CD9)
Air separation (H18)
ULTRAFILTRATION (F04>CD7>F05)
Reduction of bacteriological contamination
USED DIALYSATE BATH
FLOW PUMP (P03)
Check pressure (S15)
BALANCING CHAMBER (H14)
LOADING PUMP (P02)
UF PUMP (P04)
Removing excess water
FRESH DIALYSATE BATH
EXCESS WATER
Heat recovery (H04)
MIXING CHAMBER (H13)
DRAIN (H19) [black waste water]
bicarbonate flow
acid concentrate flow
water flow
fresh dialysate bath flow
used dialysate bath flow

EXTRA CORPOREAL BLOOD CRICUIT MODULE (EBM) MACROCOMPONENT



Main function overview



A.3 TREATMENT ANALYSIS

A.3.1 Routine analysis

A specific method has been defined to describe and compare the haemodialysis routines of the three case studies.
The data collected during on-field observation have been visualized through a specific map that combines three levels of analysis:

- *Routine Activities* (manual actions, digital actions/checking, staff interaction, patient empowerment)
- *Users' role* (patients, nurses, and physicians
- *Strengths and weaknesses*

The comparison revealed treatment issues that design can contribute to improving.

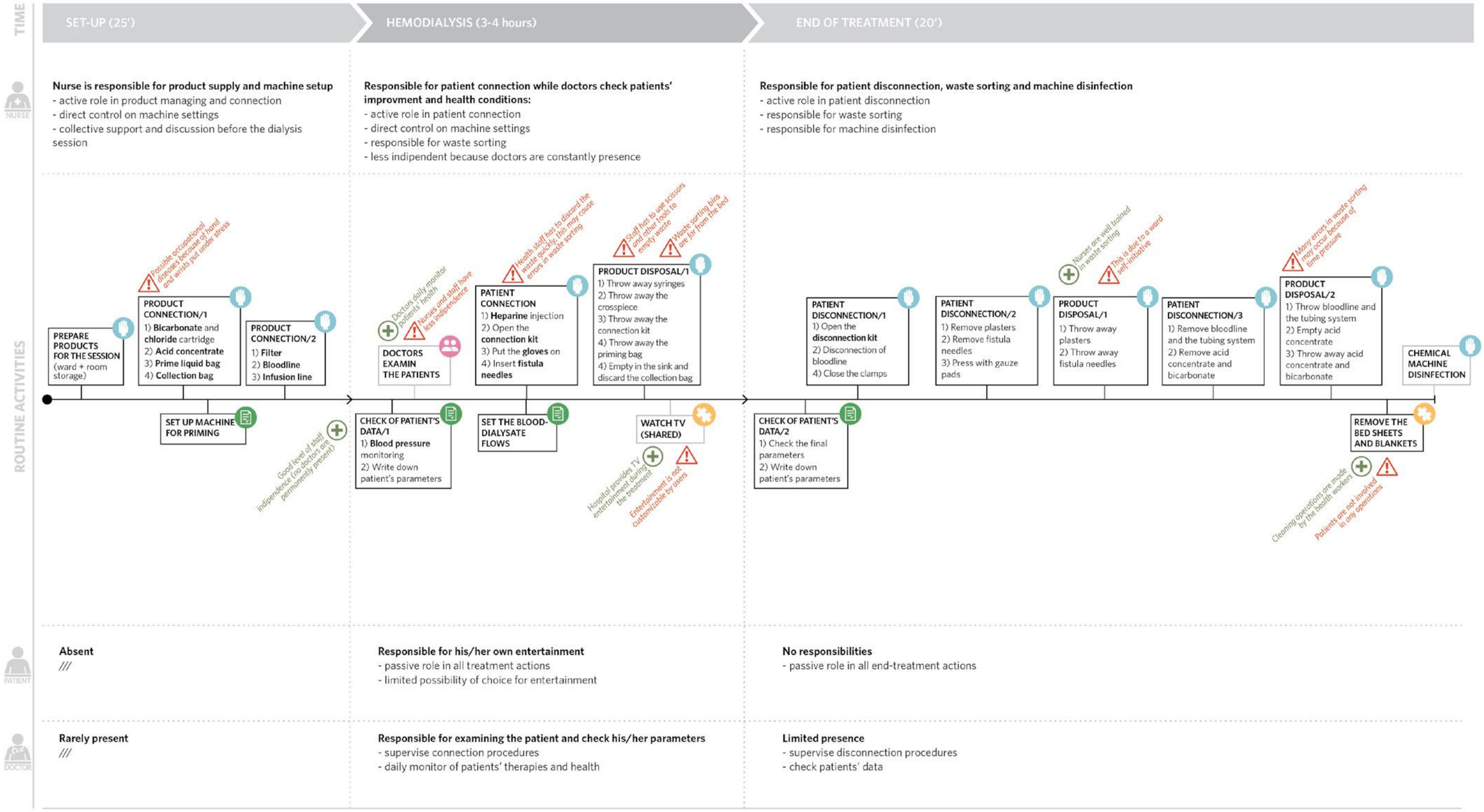
SS Nephrology
San Luigi Gonzaga Hospital

Credits: amicidipieroonlus.com

Dialysmottagning 42:An
Sus Malmö

Haemodialyse 1
Frederiksberg Hospital

ROUTINE ANALYSIS | SAN LUIGI HOSPITAL



ROUTINE ANALYSIS | SUS HOSPITAL

TIME

SET-UP (30')	HEMODIALYSIS (3-4 hours)	END OF TREATMENT (20')

NURSE

Nurse is responsible for product supply and machine setup
- active role in product managing and connection
- direct control on machine settings
- collective control mechanism for procedures (double-check)

Responsible for patient connection and monitoring during the whole treatment
- active role in patient connection
- partially control on patient parameter (doctors check patients daily)
- direct control on machine settings
- responsible for waste sorting

Responsible for patient disconnection, waste sorting and machine disinfection
- active role in patient disconnection
- direct control on patient parameter
- responsible for waste sorting
- responsible for machine and bed disinfection

ROUTINE ACTIVITIES

Priming is automatically managed by the machine avoiding waste and effort

PRODUCT CONNECTION/1
1) **Bicarbonate** and **chloride** cartridge
2) **Acid concentrate**

Possible occupational diseases because of hand and wrists put under stress

PRODUCT CONNECTION/2
1) **Filter**
2) **Bloodline**

TAKE NOTE OF CONCENTRATE AND PRODUCTION BATCH

Check and note of all the product used

Additional effort for nurses and usability problems in noting the batches

SET UP MACHINE FOR PRIMING

Patients have a passive role both in their connection to the machine and in checking their parameters

PATIENT CONNECTION/1
1) Open the **connection kit**
2) Wear a **plastic apron**
3) Put the **gloves** on

SET THE BLOOD-DIALYSATE FLOWS

Health staff has to discard the waste quickly, this may cause errors in waste sorting

PATIENT CONNECTION/2
1) Insert **fistula needles**
2) **Heparine** injection
3) Fix the bloodline with patient's **Fistula Stop**

CHECK OF PATIENT'S DATA/1
1) **Blood pressure** monitoring
2) Write down patient's parameters

PRODUCT DISPOSAL/1
1) Throw away syringes
2) Throw away the crosspiece
3) Throw away the connection kit
4) Throw away the apron

SET OF TV SYSTEM

Hospital provides TV entertainment

TV is shared with others patients (entertainment cannot be customized)

CHECK OF ALARM WITH THE PATIENT

DOUBLE CHECK BY ANOTHER NURSE

procedures to limit staff errors

Disposable aprons increase the waste production

PATIENT DISCONNECTION/1
1) Wear **apron** and **gloves**
1) Open the **disconnection kit**
3) Disconnection of bloodline
4) Lock the fistula

PATIENT DISCONNECTION/2
1) Remove plasters
2) Remove fistula needles
3) Press with Fistula Stop

CHECK OF PATIENT'S DATA/2
1) Check the final parameters
2) Write down patient's parameters

PRODUCT DISPOSAL/2
1) Throw away plasters
2) Throw away fistula needles

PATIENT DISCONNECTION/3
1) Remove bloodline and the tubing system

SET THE MACHINE FOR THE EMPTYING PROCESS

Often there is no time for the emptying process

Nurses are trained on waste sorting, and summary posters are present in the ward

Lack of waste sorting bins close to the disposal actions (most are out of the room)

PRODUCT DISPOSAL/2
1) Throw bloodline and the tubing system
2) Throw away apron
3) Remove bed sheets

Many errors in waste sorting may occur because of time pressure

ACID CITRIC MACHINE DISINFECTION

Cleaning operations are perceived as devaluing

CLEAN MACHINE, MATTRESS AND PILLOW

PREPARE PRODUCTS FOR THE NEXT SESSION (in the ward storeroom)

PATIENT

Absent
///

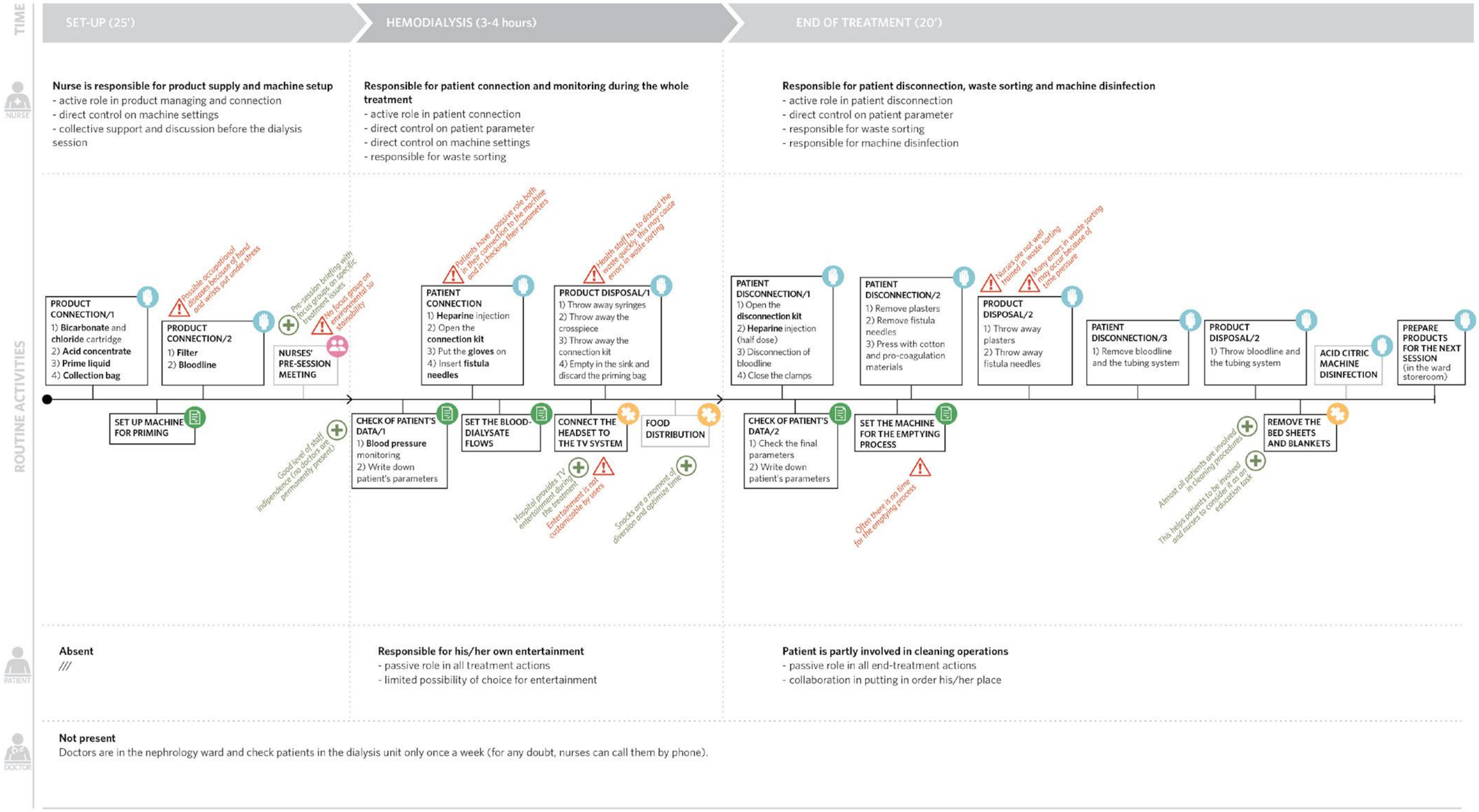
Responsible for his/her own entertainment
- passive role in all treatment actions
- limited possibility of choice for entertainment

No responsibilities
- passive role in all end-treatment actions

DOCTOR

Limited presence in the ward
Doctors are in the nephrology ward and daily check patients record but are rarely physically present during dialysis (in the dialysis unit there are 1-2 doctors)

ROUTINE ANALYSIS | FREDERIKSBERG HOSPITAL

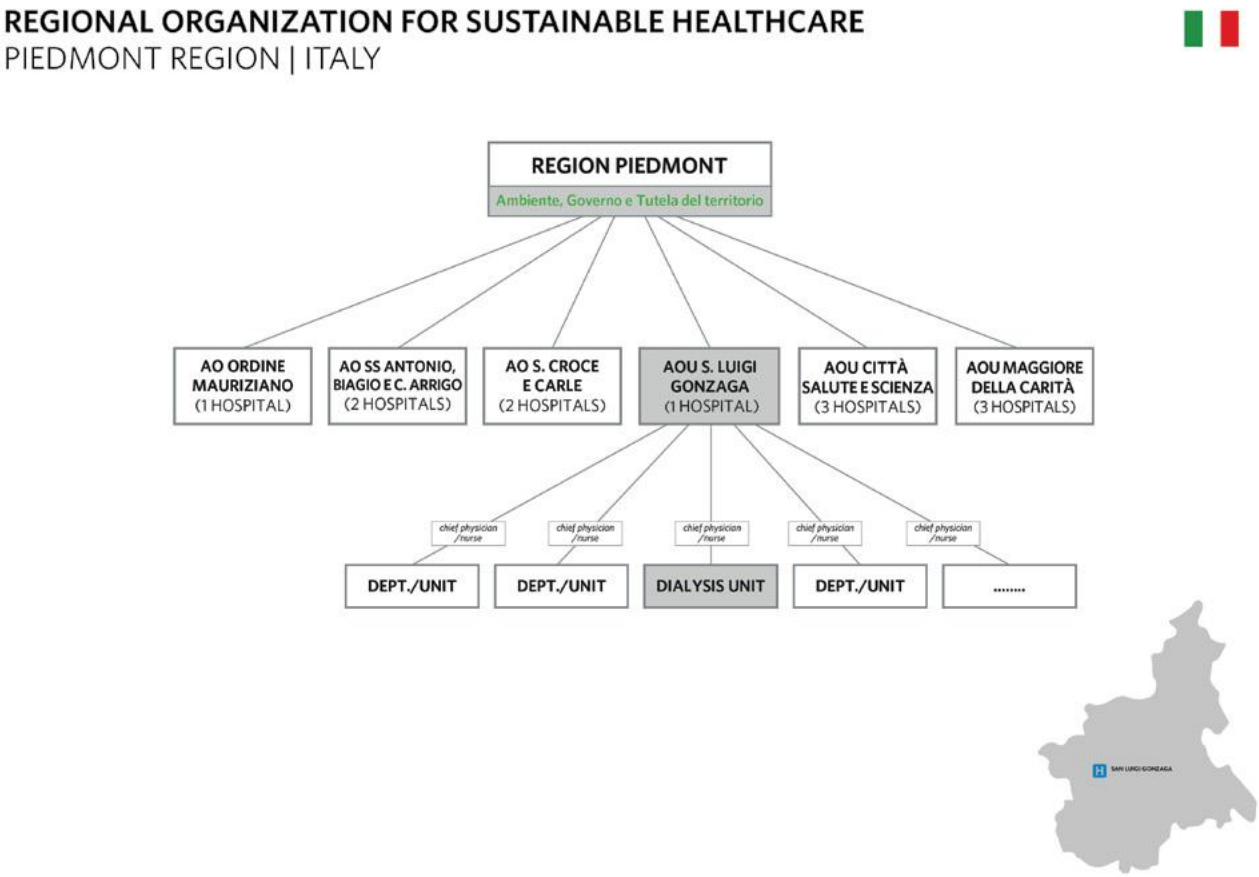


A.4 LOCAL ENVIRONMENT ANALYSIS

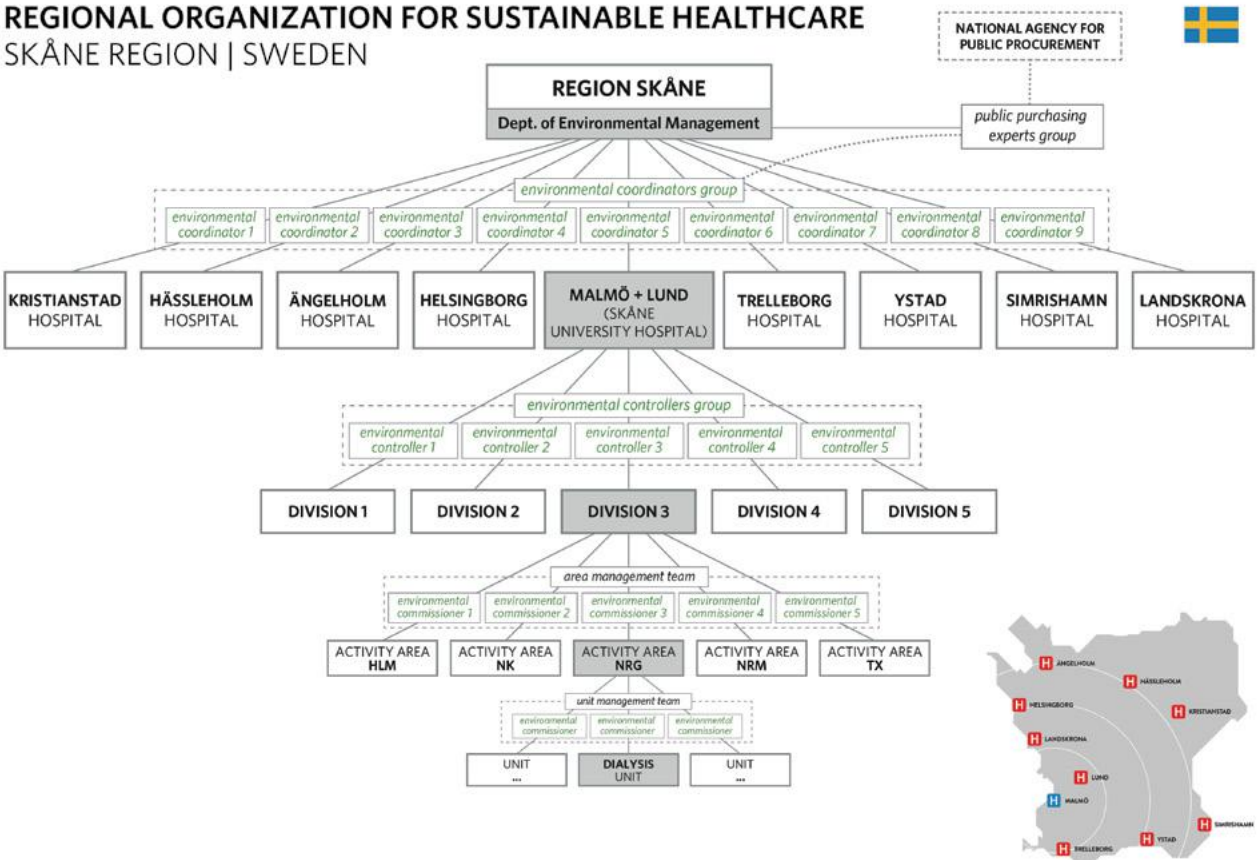
A.4.1 Regional organization for Sustainable Healthcare

The organizational analysis aims at providing an overview of different approaches to Sustainable Healthcare, analysing environmental strategies both at the macro (Region) and the micro level (hospital and dialysis wards).
Health stakeholders and their responsibilities and tasks were considered to define a methodology that could be applied to different contexts and countries. The analysis has been carried out considering two levels of the organization.

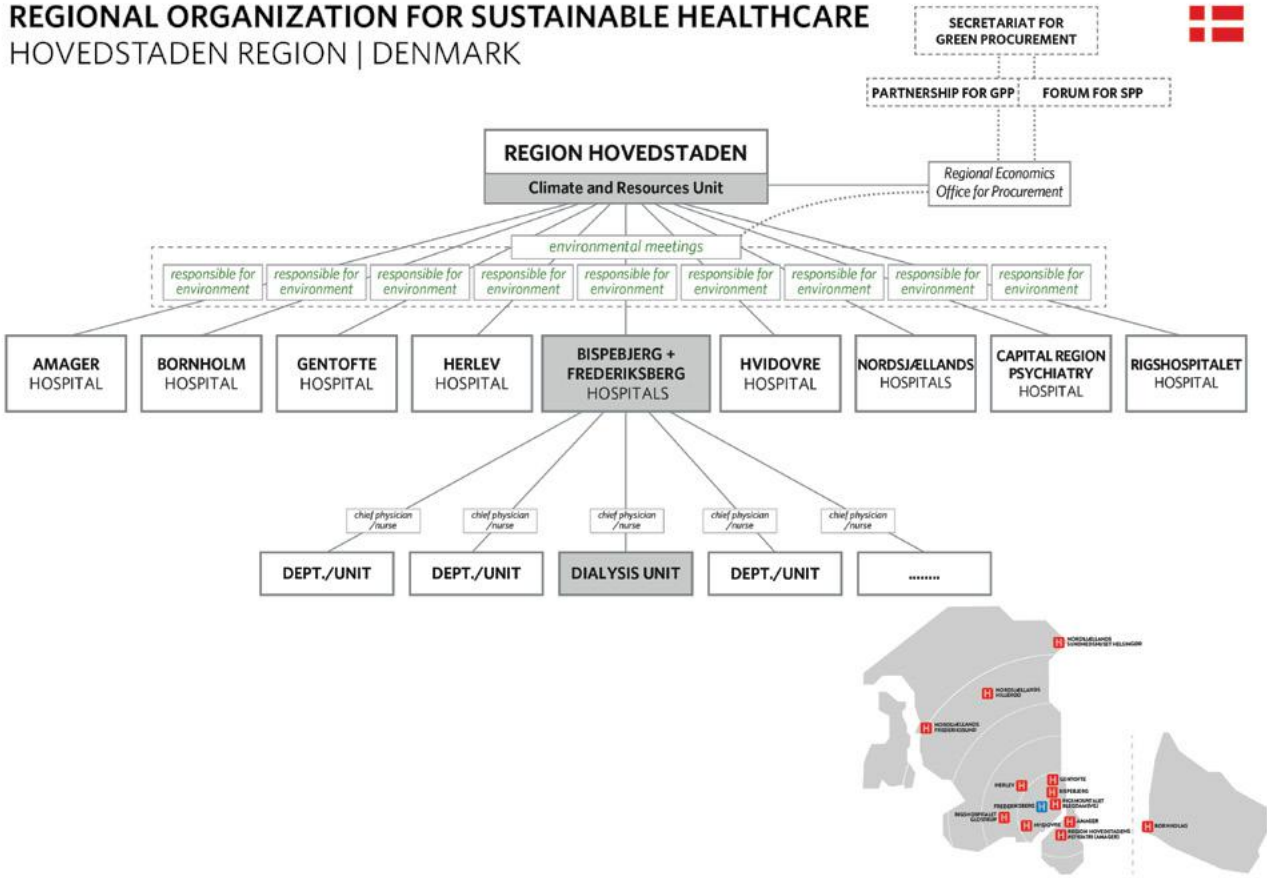
The first one concerns the analysis of national/ regional policies and regional organization. It focuses on defining the regional management organization, and the organizational figures responsible for environmental sustainability in health care.



REGIONAL ORGANIZATION FOR SUSTAINABLE HEALTHCARE
SKÅNE REGION | SWEDEN

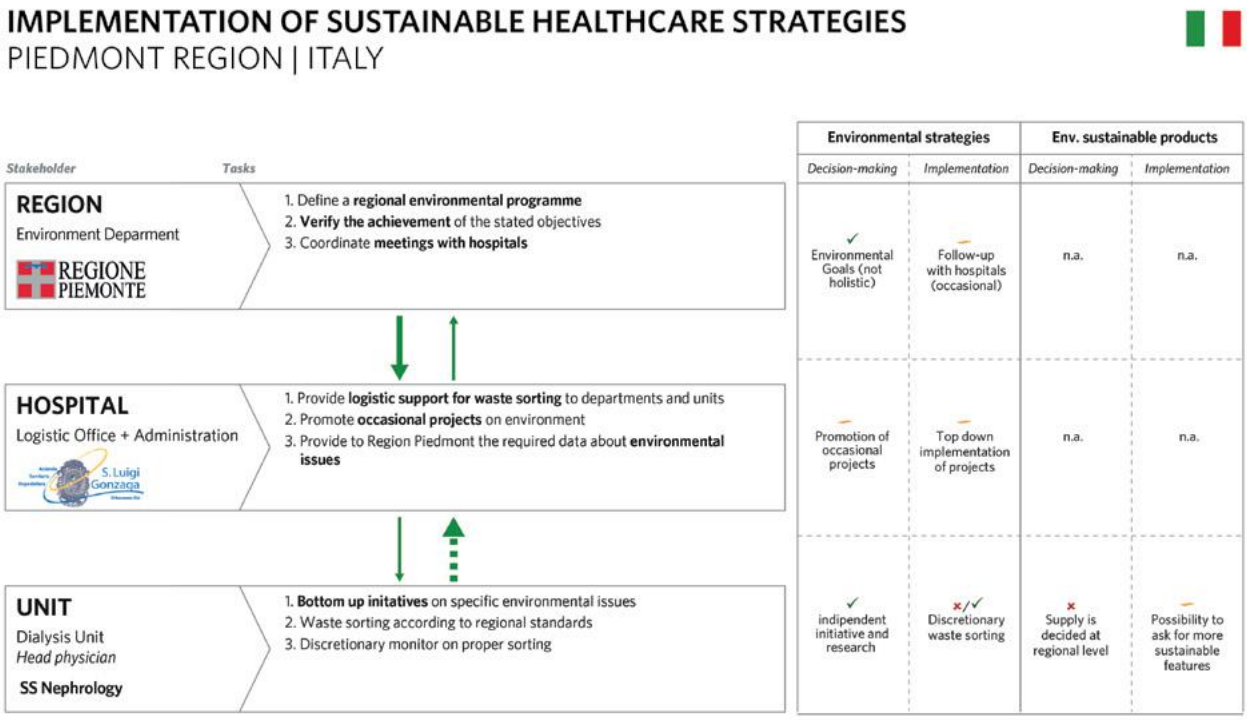


REGIONAL ORGANIZATION FOR SUSTAINABLE HEALTHCARE
HOVEDSTADEN REGION | DENMARK



A.4.2 Implementation of Sustainable Healthcare strategies

The second step of analysis concerns the practical application of macro-strategies, focusing on the responsibilities and tasks of the key stakeholders (Region, Hospital, Ward/Unit), and their role in promoting and implementing environmental strategies and sustainable procurement.



IMPLEMENTATION OF SUSTAINABLE HEALTHCARE STRATEGIES
SKÅNE REGION | SWEDEN

Stakeholder	Tasks	Environmental strategies		Env. sustainable products	
		Decision-making	*Implementation*	*Decision-making*	*Implementation*
REGION Dept of Environmental Management *Environmental manager*	1. Define a **regional environmental programme** (10 y) 2. **Verify the achievement** of the stated objectives 3. **Promote sustainability** actions (tools, incentives, etc.) 4. Coordinate a monthly group of **environmental coordinators** 5. Coordinate the expert group for **healthcare purchasing**	✓ Environmental Programme	– Follow-up with hospitals once or twice a year	✓ Purchasing group	× Only collect some feedbacks
HOSPITAL Environmental Office *Hospital environmental coordinator* **Skåne University Hospital**	1. Help staff to understand and use **environmental routines** 2. Carry out **internal audits on environmental sustainability** and support staff for external audits (ISO 14001) 3. Monitor and **promote sustainable initiatives** within SUS 4. Provide to Region Skåne a summary of level of achievement of **Environmental Programme**	✓ Environmental routines	✓ Periodical meetings with environmental commissioners	– Sometimes participate in the purchasing group	– Collect all the feedbacks from units
UNIT Dialysis Unit *Unit environmental commissioner* **Dialysmottagningen 42:n**	1. **Implement environmental strategies** into daily routines 2. Fulfill the **self-assessment report** and provide information for environmental **audits** 3. Manage the relationship with the environmental coordinator 4. Take part in the **unit management team**	× (only some minor decisions)	✓ Application of environmental routines and initiatives	× (only provide feedbacks)	✓ Use and disposal of products

IMPLEMENTATION OF SUSTAINABLE HEALTHCARE STRATEGIES
HOVEDSTADEN REGION | DENMARK

Stakeholder	Tasks	Environmental strategies		Env. sustainable products	
		Decision-making	*Implementation*	*Decision-making*	*Implementation*
REGION Climate and Resource Unit *Environmental manager* Region Hovedstaden	1. Define a **regional environmental programme** (from 2016) 2. **Verify the achievement** of the stated objectives 3. Coordinate **environmental meetings with coordinators** objectives (3-4 times per year)	– Environmental Programme (January 2016)	– Follow-up with hospitals 3-4 times a year	✓ Purchasing group	× Only collect some feedbacks
HOSPITAL Logistic Office *Hospital environmental coordinator* Frederiksberg Hospital	1. Define specific guidelines and **environmental routines** 2. Carry out **internal audits on waste management** (with the collaboration of environmental consultants) 3. Support external auditor (from other Danish Regions) 4. Provide to Region Hovedstaden a summary of level of achievement of **environmental goals**	✓ Environmental guidelines (manly for waste)	– Occasional meetings with head nurse or physician	× Provide feedback to region	– Collect any feedbacks from units
UNIT Dialysis Unit *Head nurse* **Hæmodialyse 1**	1. **Implement environmental rountines** into daily routines 2. Answer the auditors' questions	× (few minor decisions)	– Discretionary application of environmental guidelines	× Possibility to order new products to test (usually focus on quality)	✓ Use and disposal of products

annexes

Annex II

Publication list

PROCEEDINGS

Barbero, S., Pereno, A., Ferraresi, M., Piccoli, G.B. (2014). Eco-Dialysis: a bottom-up design approach for preliminary analysis towards sustainability in medical packaging. *5th International Forum of Design as a Process - Advance Design Cultures: The Shapes of the Future as the Front End of Design Driven Innovation* (pp. 418-424), Instituto Tecnológico de Monterrey, Guadalajara, Mexico. 18-20 September 2014. ISBN: 9786075151472

Pereno, A., Barbero, S., Tamborrini, P. (2015). Design for healthcare sustainability: ethical implications of eco-design research. 1*1th International European Academy of Design Conference – The Value of Design Research*. Paris Descartes University, Paris, France. 22-24 April 2015

Pereno, A., Nazha, M., Tamborrini, P. (2015). Packaging design in the healthcare field: eco-guidelines for sustainable packaging and disposables in dialysis treatments. 3rd European Conference on Design4Health, Sheffield, UK. 13-16 July 2015

Pereno, A., & Tamborrini, P. (2016). Design for Sustainable Healthcare in a European context. A comparative analysis of Sustainable Healthcare and Design strategies in three European case studies. *SCIECONF 2016 - The 4th International Virtual Conference on Advanced Scientific Results* (pp. 234-238). Zilina: EDIS.

Pereno, A. (2016). Design sistemico in campo medico sanitario: un caso studio sull'emodialisi. In R. Riccini (Ed.) Fare Ricerca in Design. Forum nazionale dei dottorati di ricerca in design. *2° Forum nazionale dei dottorati di ricerca in design*, Università Iuav di Venezia (pp.149-156). Padova, Italy: Il Poligrafo.

Barbero, S., Pereno, A., & Tamborrini, P. (2017 - in press). Systemic innovation in sustainable design of medical devices. *12th European Academy of Design Conference - Design for Next*, Sapienza University of Rome, Italy.

POSTERS

Ferraresi, M., Pereno, A., Nazha, M., Barbero, S., Piccoli, G.B. (2014). Ecodialysis: is it possible an eco-friendly system? Poster presented at *51st ERA-EDTA Congress*, Amsterdam, Netherlands. May 31-June 3, 2014. DOI: 10.3252/pso.eu.51era.2014

JOURNAL ARTICLES

Ferraresi, M., Pereno, A., Nazha, M., Barbero, S., Piccoli, G.B. (2014). Ecodialysis: is it possible to design an eco-friendly system? N*ephrology Dialysis Transplantation*, 29, 210. DOI: 10.1093/ndt/gfu153

Ferraresi, M., Nazha, M., Vigotti, F.N., Pereno, A., Di Giorgio, G., Gatti, R., Bevilacqua, M.L., Cagnazzo, M., Cassetta, B., Denti, G., Grimaldi, G., Monterossi, M., Barbero, S., Piccoli, G.B. (2014). Ecodialisi: primi consigli per limitare i danni e ridurre i costi. *Giornale Italiano di Nefrologia*, 31 (5)

Piccoli, G.B., Nazha, M., Ferraresi, M., Vigotti, F.N., Pereno, A., Barbero, S. (2015) Eco-dialysis: the financial and ecological costs of dialysis waste products: is a 'cradle-to-cradle' model feasible for planet-friendly haemodialysis waste management? *Nephrology Dialysis Transplantation*, 30 (6), 1018-1027. DOI: 10.1093/ndt/gfv031

Health systems are facing significant societal and organizational challenges that require enhancing their resilience and sustainability. The transition toward more sustainable health systems is both delicate and complex, and it needs radical changes of perspective as regards the holistic and multi-disciplinary approach to health care. Over the past years, interest in what is called Sustainable Healthcare has grown globally: there is no common definition, but all the approaches to this emerging domain focus on making health care environmentally, economically and socially viable. The present work aims at investigating the role of design towards Sustainable Healthcare, to propose, through case study experience, a systemic vision of the topic. The research methodology is deeply rooted in the framework of Systemic Design, aiming at defining how design strategies can improve the environmental sustainability of medical products, services, and systems, considering its close relationship with the social and economic aspects. Specifically, the research addressed the case study of chronic haemodialysis. The thesis focuses on the definition and the analysis of the items which make up the dialysis system, by combining different approaches, borrowed from sustainable design and human-centred design. In order to establish a general frame, three different dialysis units and hospitals based in different European countries (Italy, Sweden, Denmark) were compared. This comprehensive analysis allowed to set specific guidelines for dialysis products, equipment, and treatment. The comparison of three international case studies highlighted how design should work on product and equipment to improve environmental sustainability on a global scale while addressing local systems to improve sustainability on a territorial level. The outcome of the research is a set of design strategies for the healthcare sector that take into account the technical, operational, social and environmental requirements of chronic treatments.

Politecnico di Torino
2017