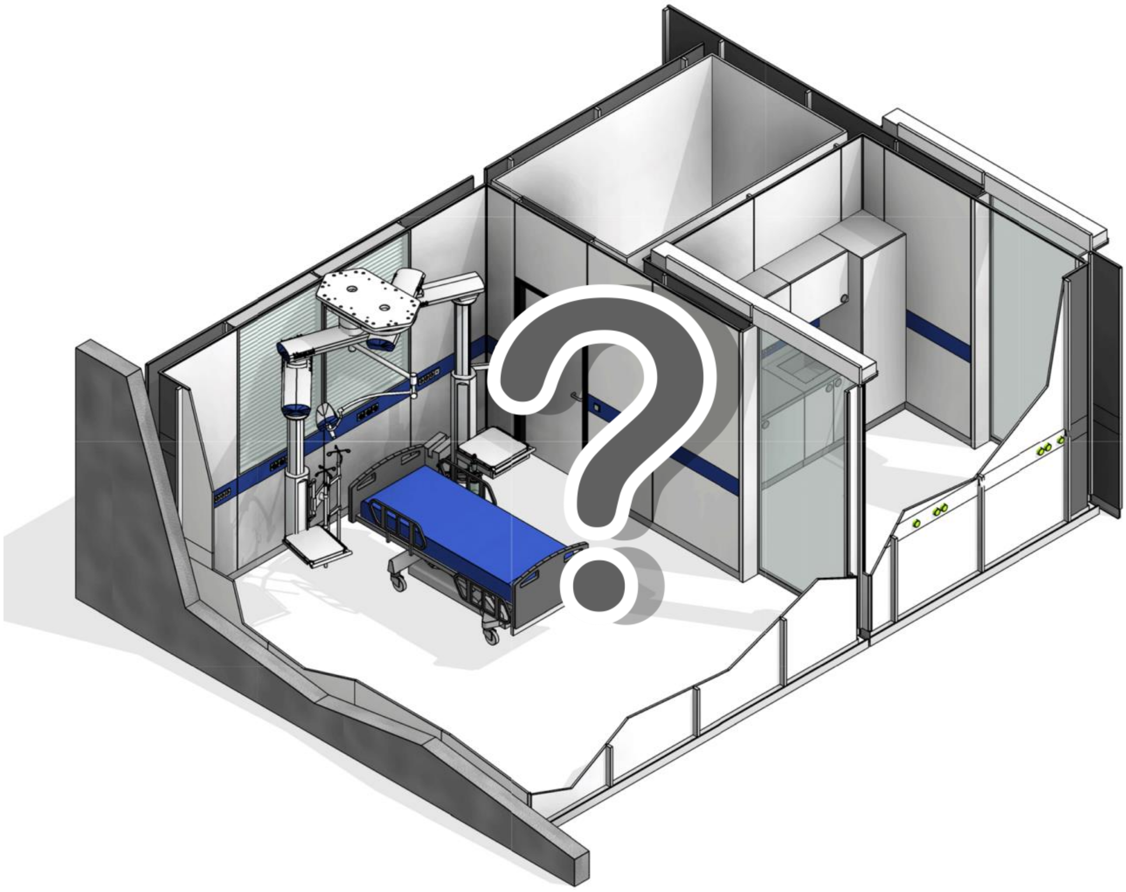
Identifying the process-based design system of isolation rooms

And providing a method for shared design decision-making by transforming complex dependencies into a structured set of feasible design solutions



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Bachelor Thesis

Department of Civil Engineering

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Prologue

The bachelor Civil Engineering from the University of Twente will be rounded off with a research report. This research report is commissioned by Royal HaskoningDHV. I would like to thank the people that supported me during my research.

Firstly, a special thanks to Xander van Ruissen. Xander, your guidance has been highly appreciated and your enthusiasm about the subject helped me during my research. Besides that, your view of life and strength inspired me on a personal level. I wish you the best.

Secondly, I would like to thank Robin de Graaf for his sharp feedback and his fresh view on the subject. Robin, thank you for helping me in being critical about my own work.

Finally, I would like to thank Erik Snip. Erik, you were the reason I was interested in this research in the first place. Also, thank you for keeping in contact and providing support during the research.

Tom Behage - Enschede, June 2018

Definitions

-	System	=	a set of connected items that operate together to fulfil one purpose.
-	Process	=	a series of actions that are needed in order to fulfil the purpose of a system.
-	Function	=	a specific action or task that a system is able to perform. A function is always formed by a verb and a noun. For example: *disinfecting hands* or *transporting patient*.
-	Function- carrier	=	an object or collection of objects fulfilling the action or task of a function.
-	Business-case	=	an explanation or set of reasons describing improvements in a business, regarding costs and profits and attractive investments.
-	Tool	=	(in this report) a (software) program or feature of a (software) program that helps you with particular activities.
-	Patient	=	(in this report) customers of hospitals who are treated in their facility.
-	Client	=	(in this report) the real estate department of a hospital, requesting a design of an isolation room.
-	User	=	(in this report) the employees of a hospital that during their work have to deal with patients in isolation rooms.

Abstract

Royal HaskoningDHV has difficulties in identifying the isolation rooms' processes, functions and their relations and dependencies. This sometimes leads to the feeling from the client of not being understood. Besides that, it has the potential to lead to a mismatch between isolation room design and the client and user needs. Royal HaskoningDHV wants to solve this problem with a collaborative design-decision making tool, enhancing collaboration with the client in creating a spatial design of an isolation room. As a basis for creating this tool, the isolation rooms' processes, functions and their dependencies need to be identified and a method for implementing this knowledge in a tool, improving collaboration in design decision-making, needs to be provided.

For this research, a generic isolation room is used. In this report, the first steps of the design process of an isolation room will be researched using various methods. Knowledge from theory and practice will be combined in analyses. Validation will be done by the work field.

To review the processes and functions of an isolation room, a FAST diagram is made. For reviewing the dependencies, a Functional Performance Specification is done on which an AIDA analysis is applied. As a result of this, the specific feasible solutions for an isolation room design and their main characteristics are presented.

After that, a research is conducted to review the implementation of this knowledge in a tool that improves collaboration in design decision-making. This resulted in a list of generic conditions and requirements for the wanted tool. Besides that, recommendations for further research about this implementation are given.

Overall, this research provides the basis needed for a collaborative design decision-making tool and gives recommendations about the needed extended research for realising this tool.

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1. Preface

1.1. Introduction

Last year, the Norovirus broke out in the AZ Turnhout hospital due to malfunctioning of isolation measures. Several departments in the hospital needed to go on lockdown for 48 hours. All planned medical interventions and patient admissions to the hospital were postponed (Belga News Agency, 2017). Closure of hospital departments results in a negative cash flow, influencing the hospitals business-case. Besides that, due to negative publicity, the image of the hospital was damaged.

This example illustrates the need for good functioning containment measures. One of these measures is a facility like an isolation room. Well-functioning isolation rooms are crucial to the hospital business-case. When considering the hospital business-case from the perspective of the client in selecting a new isolation room design, the design should contribute to better health benefits and efficient health care. A hospital can be seen as a system which is striving for an optimal price-performance ratio (Sing & Lillrank, 2017).

1.2. Problem statement

Even though the importance of isolation rooms is known, achieving a functional design of an isolation room, fulfilling the needs of the client, is still a challenge. This is caused by three main issues. Firstly, the dependencies between the clients business-case and isolation room design are not all fully understood. The actual design needs are difficult to identify, because the isolation room design is mainly based on demands from the real-estate department of a hospital, and not from the users of the room. Secondly, regulations in spatial design of isolation rooms are limited and sometimes even outdated. This makes the design highly dependent on experience and interpretations of the engineer/consultant. Thirdly, due to the preferences, spatial- and functional factors of a single hospital, a large amount of different spatial alternatives for an isolation room design exist.
The complexity of these three issues sometimes leads to the feeling from the client of not being understood. Besides that, it has the potential to lead to a mismatch between isolation room design and the client and user needs.

Royal HaskoningDHV wants to solve this problem with a collaborative design-decision making tool, enhancing collaboration with the client in creating a spatial design of an isolation room. This tool should give freedom of choice on essential criteria and provide an insight into the consequences of design decisions at an early stage. This makes it possible for clients to co-create their own spatial design and give feedback easily and quickly. However, implementing the design process of an isolation room in such a tool is still a challenge.

Problem statement

Royal HaskoningDHV has difficulties in identifying the isolation rooms' processes, functions and their relations and dependencies, and how to implement these design elements in a collaborative design decision-making tool.

1.3. Research objective

To cope with this problem, research is needed about the design system of an isolation room. Because this design system is not fully understood, identification of the processes, functions and their dependencies within the room should be done. This is the first step in creating the wanted collaborative design decision-making tool. After that, an assessment is needed about transforming this design system into a structured set of feasible design solutions. Finally, the question on how to implement the findings in a collaborative design decision-making tool needs to be researched.

Overall, this research should improve the relation between Royal HaskoningDHV and the client, which results in a better business-case for Royal HaskoningDHV.

Research objective
Identifying the isolation rooms' processes, functions and their dependencies and providing a method for implementing this knowledge in a tool improving collaboration in design decision-making.

1.4. Reading guide
This report is structured as follows: Firstly, an extended research plan will be given in chapter 2. Next, the report will be structured by the design process of an isolation room. Every chapter will represent one step in the design process with a corresponding research question. Chapter 3 represents the identification of the process and functions inside of an isolation room. Chapter 4 describes the possible function-carriers and their characteristics. In chapter 5, the dependencies and design consequences are researched. Chapter 6 gives the conditions and requirements needed for implementation in a collaborative design decision-making tool. Afterwards, the results of the analyses are discussed in chapter 7 and a conclusion is given in chapter 8.

2. Research plan
To set up a well-structured research report, a research plan is needed. This research plan consists of the concept thoughts and research context that provides the background needed to understand the problem statement. It also includes research questions, the research scope and the research setup. The used methods are determined by a literature research.

2.1. Concept thoughts
Before conducting research, Royal HaskoningDHV has put some concept thoughts on paper about the design of isolation rooms. These thoughts are put together in a mind map. This mind map describes the variables that influence the design of an isolation room, but does not include relations between variables. The mind map can be seen in Appendix A. This appendix is in Dutch, because this is how the document was delivered.

2.2. Context problem statement
In this report, knowledge from outside and within Royal HaskoningDHV about the design decisions of an isolation room will be combined and documented. This captured knowledge will contribute to the data needed as input for a design decision-making tool. Also research will be done about what the structure of such a tool might look like, looking at its requirements and conditions.

Royal HaskoningDHV wants to improve the design process of an isolation room on four aspects; increased efficiency, improved quality, reduced risk and automation (RHDHV, 2018).

The tool as described in the research problem is related to this context. Firstly, efficiency can be improved if the tool has the ability to apply common data classification, knowledge sharing and efficient information exchange. Secondly, quality can be improved if the tool provides a better understanding between the design and the client needs. The tool should clarify the expectations of the client for the designer. Thirdly, risks can be reduced if the tool provides a greater level of transparency and openness in the design process for all parties. This can be realised when the focus lays on collaborative working. The tool should contribute on an interactive, client orientated design process. And finally, when the tool can automatically generate alternatives and their consequences, it can be seen as the first step in automation of the design process. Identifying the process-based system of a specific design can be seen as a basis for acceleration in digital engineering.

2.3. Context research field
A literature research is done to get a better view of the current state and developments in the research field.

Principles of hospital design
Design concepts of hospitals have changed over the last few decades. At first, the concept of

‘Function follows design’ existed because hospitals were facilitated in existing buildings and were limited by their layout. Secondly, the concept changed to ‘Design follows functions’, where new facilities were designed with the purpose of the function in mind. Assets like isolation rooms were designed to maximize capacity utilization. When looking at the future, health care assets will be designed according to the idea of ‘Patient first, functions next, design later’ (Sing & Lillrank, 2017). Hereby, providing care for the patient is broader than just functional healthcare. New design functions are added in relation to the patient care needs, focussing on wellbeing and quality of life.

Principles of well-being

In the past the definition of being healthy was characterised by the absence of any disease. Nowadays, the WHO mandates critics who see health as being able to deal with illness and integrate it in life (Huber, 2011). Many studies already focussed on this new definition of health in investigating the perception of patients toward a hospital design. In short, patients prefer a homely atmosphere, a supportive environment, good physical design, access to external areas and provision of facilities for recreation and leisure (Peters, 2017). Well-designed hospital facilities play an important role in improving the perception of patients and it is even suggested that is makes hospitals safer, improves the recovery of patients, and reduces the frequency of hospitals visitations (Sing & Lillrank, 2017).

Principles of isolation room design

In many health care facilities, patients with known or suspected infectious diseases are physically isolated from other patients in rooms called isolation rooms. Especially when the infection can be spread through the air, rooms with airflow-technical measures are needed.
Different types of isolation rooms exist (TNO, 2013):

- Airborne infection isolation rooms, where a negative pressure is maintained to keep the infection contained.
- Protective isolation rooms, where a positive pressure tries to keep infections away from the patient.
- Universal isolation rooms, where the surrounding is protected from the patient and the other way around. This room often has a negative pressured airlock room. This type of isolation room is most common due to its flexibility.

An air-lock is always part of the isolation room. The air-lock prevents a contaminated air flow when entering or leaving the room. Just as normal rooms in hospitals, isolation rooms can have different functions, for example nursing, intensive care or recovery. However, when just looking at the main processes of an isolation room, they all have the same function: Preventing contamination while supporting health benefits.

At this moment, there is a high flexibility in design of isolation rooms in health-care facilities in the Netherlands. Even though there are some design standards, the outcome of a design is mainly based on the designers experience and interpretations. The design standards that do exist are mostly about hygiene and ventilation. The most relevant design standards for Dutch isolation rooms are the following:

- *Handboek ziekenhuisventilatie*, published by TNO, author: Ph. J. Ham. (2002)
- *Bouw- en inrichtingseisen isolatieafdeling Ventilatie isolatieafdeling,* published by WIP (2004) revision 2009 [1]
- *Strikte isolatie,* published by WIP (2006) [1]
- *Het functioneren van isolatiekamers in ziekenhuizen,* TNO 2012 R11119, published by TNO (2013)
- *Richtlijn voor het classificeren en testen van luchtdoorlatendheid van de schil van schone ruimten en gelijksoortige gecontroleerde omgevingen. Versie 1.21,* published by VCCN (2015)
- Guidelines for environmental infection control in Health Care Facilities. Published by U.S. Department of Health and Human Services Centers for Disease Control Prevention (2003)

[1] Both WIP standards are officially not valid anymore. Revision should be done every 5 years, but due to financial problems at WIP, this didn’t happen.

2.4. Research questions

As a result of the objective of the research, the main research question in this report is formulated.

Research question

What are the isolation rooms' processes, functions and their relations and dependencies and how can they be implemented in a collaborative design decision-making tool for isolation room design, preventing a mismatch between design and the client needs?

To give a clear answer to this question, this research question needs to be divided into different sub questions. These sub-questions will clarify the research steps in this report.

1. What does literature tell about the identification of process/function and design consequences?

2. What processes and functions can be identified in an isolation room?
   a. What processes and functions can be identified in literature?
   b. What processes and functions can be identified in practice?

3. What function-carriers relating to these processes and functions can be identified and what are their characteristics?

4. What are the dependencies between these function-carriers and how do they relate to design consequences?
   a. How do the function-carriers depend on one another?
   b. What are the design consequences resulting from decisions in function carriers?

5. What are the requirements and conditions for implementation of this research in a design decision-making tool, enhancing collaboration with the client?

2.5. Research limits and boundaries

The research field connected to the research objective should be well-bounded. The boundaries of the research will define what is included in the research, what is excluded in the research and what abstractions are made. The research boundaries are as follows:

- A single generic isolation room is used in this research. This can be seen as a valid abstraction, because even though isolation rooms can have different purposes, the main processes influencing spatial design are the same.
- A boundary is needed to the amount of functions that are taken into account and the level of detail of these functions, the following statements are made: 1) Functions are broken down until they can be measured or validated. 2) The concept thoughts described earlier in section 2.1 form the basis for the grounds on which processes/functions are identified. This results in a certain abstraction level of the identified functions. This level of detail is chosen because, according to Royal HaskoningDHV, this level is valid as a basis for design decision-making in the early design phase.
- As a result of this research, feasible design solutions and their characteristics, grouped by main criteria, can be presented. Research about the transformation from feasible design solutions to one final design solution using a design decision-making tool is not included in this report. However, an advice on transforming the requirements and constraints of such a tool will be given.
- Analyses will be done on available information. If the researched theory and practice does not provide information about certain research aspects, recommendations will be given for further research.
- The realisation of the final decision-making tool or the design of isolation room prototypes is not a part of this research thesis.

- The boundaries of this research thesis are illustrated in Figure 1 by the green box. The red arrow represents the question ‘how to implement the knowledge in a decision making tool?’

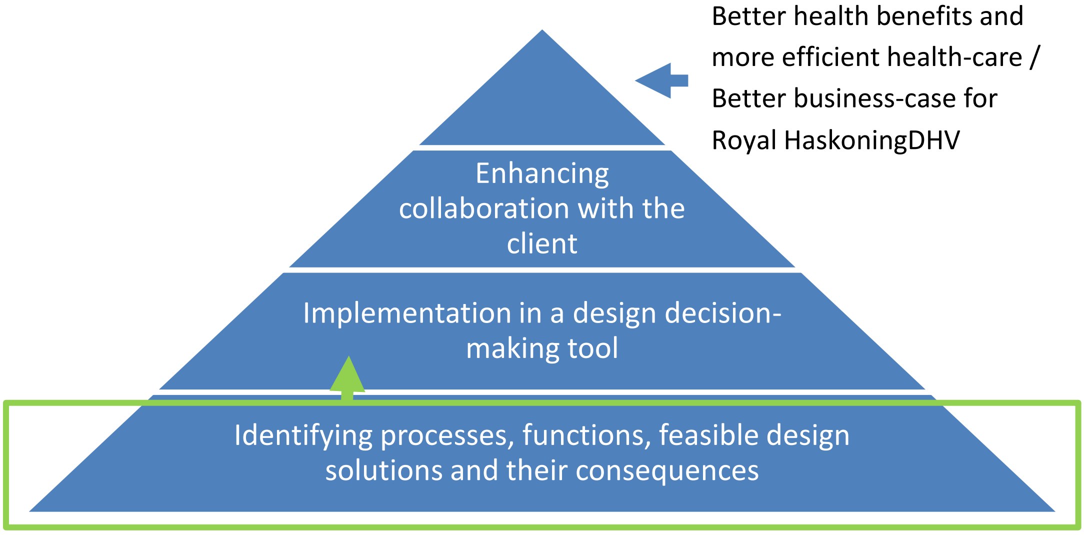

Figure 1 Research objectives and boundaries

2.6. Research setup

When looking at the design of an isolation room, the whole cycle of the design process should be taken into account. This cycle represents a series of steps used in creating a functional design. The steps often need to be repeated after interacting with the client. This report will be structured by the design cycle of an isolation room as presented in Figure 2. The focus lies on the first three steps. Research question one will be answered by the underlying theory of how to realise the first three bold green steps. These three bold green steps representing research question two up and until four, and the arrow with ‘design-decision making tool’ representing research question 5. A step by step explanation of the design process cycle is given below.

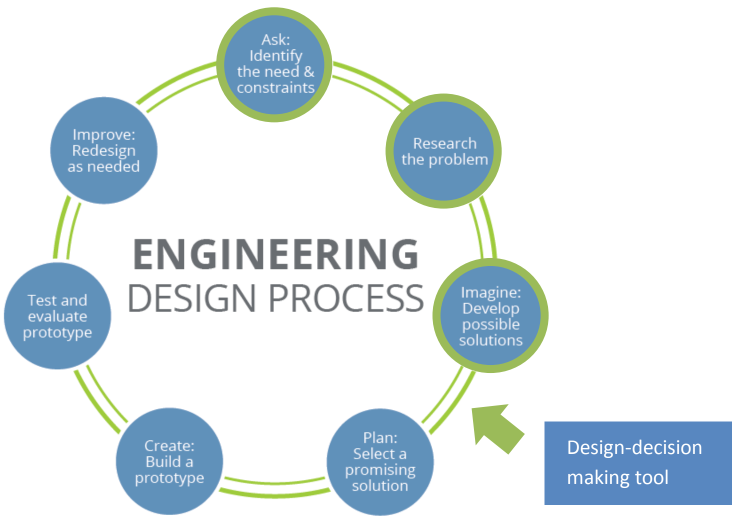

Figure 2 Engineering Design Process (University of Colorado, 2018)

1. ‘Identifying the needs and constraints’ is about asking critical question on what will be created. Who is it for? What processes need to be fulfilled? What functions are wanted? And how are these functions structured?
2. ‘Research the problem’ is about getting a clear overview of what sub-solutions or technologies might be adaptable to the needs and what their characteristics are.

3. ‘Develop possible solutions’ is about creating possible solutions out of the combination of sub-solutions and identifying their consequences. In this step, it should be taken into account that it might not be possible to combine all sub-solutions due to dependencies.
4. ‘Select a promising solution’ is about revisiting the needs and research from the earlier steps, compare the best ideas, select one solution and make a plan to move forward with it.
5. ‘Build a prototype’ is about creating the provisional design. This provisional design verifies whether the design meets the original objectives.
6. ‘Test and evaluate prototype’ is about communicating the results and getting feedback.
7. ‘Redesign as needed’ is about implementing this feedback, making revisions and drawing new designs.

This research describes the first three steps in the design process by theory, practice and an analysis. Chapter three representing the step ’Identify the needs and constraints’, chapter four the step ‘Research the problem’, and chapter five the step ‘Develop possible solutions’.

Finally, in chapter six, the wanted design decision-making tool connecting the third and the fourth step in the design process will be researched by theory, practice and an analysis.

2.7. Research methods

The main research strategy used in this report can be described as desk research in combination with interviews with experts. For this research strategy is chosen because there is a lot of information available on this subject, either in earlier conducted research or in the experience and knowledge of individuals. That is also why a survey is not needed. The first four research questions can be classified as a descriptive research. A descriptive research describes and catalogues the researched subject using predefined systematics (Baarda & Bakker, 2017). The fifth research question can be classified as an explorative research. An explorative research aims at the development of a theory and or sharp formulation of hypothesis. Through explorative research answers to open issues are researched (Baarda & Bakker, 2017).

In this subchapter, research question 1 will be answered. A literature study will be done about the methodologies needed to answer the rest of the research questions.

2.7.1. Identify the needs and constraints

The first research step, identifying the needs and constraints, is directly linked to the different groups that have an interest in the design. To identify the needs and constraints by the viewpoints of the different interest groups, literature research will be done and experts will be interviewed. Afterwards, the system of an isolation room will be summarised in a functional analysis.

Literature research

A literature research is done for identifying the needs of some of the different groups that have an interest in the design of an isolation room. A summary of the relevant information in the found literature will be presented.

Researching the interests of the patient will be mainly done by a literature research, because contact with this group is restricted in an isolation room. Besides that, a lot of patients should be interviewed or a survey should be held to get an overall view of all the needs. There is already a lot of research done about the interests of the patient in hospital design, so this theory can be used.

In-depth interviews

To get an overall overview of all the other interests in isolation room design, interviews are conducted. Biases from individuals and technical preferences will be prevented by consultation of multiple experts. Also, to understand the work field, experience from within a hospital is important.

The theory behind the content of these consultations is based on the design aspects as described by the System Engineering Fundamentals. These design aspects help to make sure the processes for all the interests are covered during the interview (Department of defence, 2001):

- Customer aspects, which consist of the processes resulting from the patient expectations of the system in terms of mission objectives, healing environment, comfort, constraints, and measures of suitability.
- Functional aspects, which consist of the processes following from the necessary task or activity that must be accomplished. This will be processes in terms of services and handling.
- Performance aspects, which consist of the question to what extent a process must be executed, generally measured in terms of quantity, quality, coverage and time. This will be processes in terms of effectiveness, sustainability, flexibility, and risk and budget.
- Design aspects, which describe the relation between spatial aspects and processes. This will be processes in terms of accessibility and spatial requirements.
- Derived/allocated aspects, which consist of processes following from higher-level processes.

An example of the interview setup can be seen in Appendix B.

Functional analysis
A functional analysis is done to summarise the interest of the different groups. The processes and functions following from these consultations are summarized in a FAST diagram, which stands for Functional Analysis System Technique (Woodhead, 2006). This method has some advantages. Firstly, creative thinking is stimulated because functions are solution-free. Instead of the demand for a tap with disinfecting gel, there is a demand for disinfecting hands, which leaves solutions and possibilities for the next step in the design process open. Secondly, working with functions can lead to a better understanding of the system for designer and client. This method has the potential to bring things to mind that weren't thought of in the beginning. A FAST diagram is made using the following steps (de Graaf, 2014).

1. Determine the task

The task can be seen as the main purpose the project has to fulfil, the main need from the client and the reason why the whole system exists. This task defines the main function in the diagram.

2. Determine the functions

Functions need to be identified and will form the basis of the diagram.

3. Determine the function type

This step consists of dividing the functions by type, in basic functions and support functions. Basic functions are essential to carry out the main function or task, as determined in step one. Without basic functions, the system cannot fulfil its purpose and all underlying functions will lose their value. It is possible that there are several layers or degrees of basic functions before they can be linked to supporting functions. Supporting functions are important for the acceptance from the groups having an interest in the final isolation room design. However, they are not essential for the task.

4. Determine the primary function structure

This step is about linking the functions and determining the primary function structure. Beginning with the main function, than the basic functions and by asking the *how* question finishing with supporting functions. The *how* and *why* questions need to be asked to link functions: The *how* question forms the structure from general to specific (left to right in the diagram), the *why* question forms the structure from specific to general (right to left in the diagram).

5. Ordering the functions

This step consists of ordering the functions by different categories. These categories can for example be expressed using colors.

6. Making the diagram

The last step consist of completing the diagram. This includes editing the layout and making a legend.

Summary research methods

Table 1 gives a summary of the used research methods for answering the second research question.

Table 1 Research methods for identifying the needs and constraints

Data source	Data collection method	Structural documentation method
Literature about interest groups	Literature research	Summary
Literature about patient needs		Summary & FAST-method
Expert in integral design	In depth-interviews	Summary
Expert in the patient needs		Summary & FAST-method
Expert in the user needs		
Expert in the owner needs		
Expert in technical design aspects		
Hospital real-estate department		
Infection prevention specialist at a hospital		

2.7.2. Research the problem

The second research step, researching the problem, is about getting a clear overview of what sub-solutions or technologies might be adaptable to the needs and about getting a clear overview of the characteristics of these sub-solutions. The sub-solutions and technologies should all be linked to a function, so they can be seen as function-carriers. Every function-carrier derived from a function has its own characteristics or criteria. On behalf of these characteristics, decisions can be made. Function-carriers and their characteristics will be determined by previous researched literature and by the experience of experts and will be summarised in a Functional Performance Specification (FPS) table. A template for the Functional Performance Specification is shown in Table 2.

Table 2 Template Functional Performance Specification

		Performance characteristics		
ID	Function-carrier	Criteria	Performance level	Bandwidth (regulations/ preferences)

The Functional Performance Specification creates an overview of function-carriers with their corresponding function, performance characteristics (criteria and performance level) and bandwidth. This bandwidth can be given by regulations, but since the regulations of isolation rooms are quite flexible, the bandwidth can also describe a preference. Whenever possible, the performance level should be expressed in quantified terms (de Graaf, 2014). However, because of the abstraction level of this research, some performance levels may be given using the qualitative terms; 'High, Medium or Low'. Qualitative terms can only be used if they are validated with experts or if a good reason is given.

Summary research methods

Table 3 gives a summary of the used research methods for answering research question 3.

Table 3 Research methods for researching the problem

Data source	Data collection method	Structural documentation method
Literature about performance characteristics	Data from previous findings	FPS-method
Experience about performance characteristics		
Integral meeting/ with an expert in system thinking, a hospital planner, a hospital architect, a hospital logistic expert and a hospital installation technique expert	In depth-interviews	Summary & FPS-method

2.7.3. Develop possible solutions

The third research step, developing possible solutions, can be divided into multiple aspects. First should be determined on which areas decisions are needed and what alternatives do exist within these decision areas. These alternatives correspond with the (grouped) function-carriers. Secondly, the dependencies between alternatives need to be identified. Not all combinations of alternatives are valid due to these dependencies. Thirdly, the criteria on which the solutions are tested will be determined. These criteria should take into account the needs of the different interest groups. Fourthly, every alternative should be given a score for each criterion. The values on these criteria follow from the functional performance specification. And finally, alternatives in different decision areas can be combined in solutions with their characteristics.

A feasibility assessment method using decision areas, alternatives and dependencies is AIDA. The purpose of this method can be found in the name: ‘Analysis of Interconnected Decision Areas’. This method transforms many relations involved in complex decisions in a set of multiple decision areas. Important is that this method does not automatically create solutions, but identifies potential solutions (N.F.M. Roozenburg, 1998).

How does AIDA work? The decision areas and the alternatives need to be implemented in a matrix. After that, the dependencies between these alternatives need to be determined and documented in the matrix. Experience of experts is important in defining the feasibility of a design (Tayal, 2013). If two alternatives are negatively dependent, they are incompatible. This means that the two options are technically, economically, aesthetically, or for another reason not possible to combine in one design. AIDA presents these incompatibilities in a so called option graph. A line between options in this graph means that the options are incompatible. When systems are too complex for an option graph, models using an interaction matrix can help to define feasible solutions. Figure 3 gives examples of the possible elements of the AIDA method.

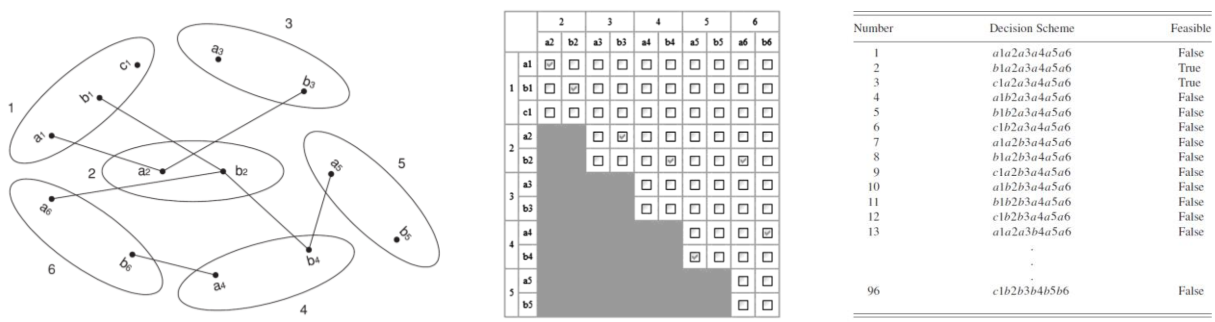

Figure 3 (left) An example option graph, (middle) An example interaction matrix, (right) Example feasible solutions list

AIDA is a relatively old method, resulting from 1965 as a systematic approach to manage complex problems. However, this may not mean it is the method is not relevant anymore. The core principle of AIDA combined with modern computer software, lead to rediscovering the validity of this method. The method is already proven to be useful in urban planning (Campbell, 2004). When implementing sub-functions as decision areas and function-carriers as decision options, the method might be worth rediscovering as a basis for a design decision-making tool.

Why is AIDA used for developing possible solutions? When designers find it hard to deal with complex design relations and dependencies in the early design phase, a lot of times clients are forced to accept drastic assumptions and simplifications. This results in the loss of valuable information. AIDA is a method to prevent this loss of information, as it systematically relates and organizes different design decisions. Besides that, the interaction matrix of AIDA can be extended to link characteristics of solutions by different criteria and compare this with predefined performance needs. These aspects even give the possibility of a heuristic design process, in which clients themselves can learn from the different consequences resulting from design decisions (Campbell, 2004). The ability of AIDA to make this connection, directly relates to the research objective.

Summary research methods
Table 4 gives a summary of the used research methods for answering research question 4.

Table 4 Research methods for developing possible solutions

Data source	Data collection method	Structural documentation method
Previous in depth-interviews and literature research	Data from previous findings	Summary table & AIDA-method

2.7.4. Design decision-making tool

The fourth and final research step, providing a basis for implementing the design system in a collaborative design decision-making tool, is done by making a list of the conditions and requirements for this implementation. This list is based on the context of design decision-making tools resulting from theory, experience of design decision-making tools resulting from practice, and the researched design system resulting from previous findings.

Summary research methods
Table 5 gives a summary of the used research methods for answering research question 5.

Table 5 Research methods for a design decision-making tool

Data source	Data collection method	Structural documentation method
Literature about design tool context	Literature research	Summary / List with conditions & requirements
Expert in computer-based design tools	In depth-interviews	
Potential users of the tool (architects)		

3. Identify the needs and constraints

In this heading, research question 2 will be answered by theory, practice and an analysis. Which processes and functions are identified as relevant depends on the viewpoint from which you look at the design. Therefore, before identification of these relevant processes and functions, the different groups that have an interest in isolation room design will be researched. After that, the needs and constraints will be identified for the interest groups: patients, users, owner and designer.

3.1. Theory

This subchapter describes the identified interest groups and their relevant processes and functions resulting from theory.

Interest groups
Groups that have an interest in the needs and constraints of an isolation room design according to literature can be identified by an example of an integrated hospital design. Before creating this

hospital design, the design team conducted a research about the different interest groups (LiBassi, 2017).

The research was founded on the idea of an evidence-based design, taking into account the needs of all interest groups. This resulted in a successful design of 126 patient rooms in the Cleveland Clinic Foundation's Avon Hospital. The interest groups taken into account were designers, constructors, users, patients, advocacy groups, caregivers (e.g. doctors and nurses), support services professionals (e.g. the physiotherapists or the ICT department of a hospital), the C-suite (e.g. important senior executives as in CEO, CFO, COO, etc.), facilities operations (e.g. the real-estate department of the hospital) and general support services (e.g. cleaners). The mission and objectives came from the design came top down, but input from the research about the core interest groups was crucial to the successful design solution. The final design resulted in a positive impact to the quality of health-care and the working environment (LiBassi, 2017).

The results from the research from the Cleveland Clinic Foundation's Avon Hospital can be seen as a basis of the interest groups of an isolation room. Consultation of all the groups taken into account in this research can be seen as the ideal way of identifying all the needs and constraints.

Interests of the patients

Especially in isolation rooms, the interests of the patients are very important. Because of their separation of other people, limited space and contents, lack of a view outside and closed doors, patients in isolation rooms are being sensitive to feelings of boredom, monotony and anxiety (Barratt, 2011). When talking about the processes and functions that are of the interests of the patient with regard to isolation room design, a big part is about healing environment.

Within healthcare buildings, healing environment is about the physical settings that support the healing process of patients. The idea is that the physical environment can make a difference in how quickly a patient recovers from or adapts to a disease or chronic condition. This might also result in a better working environment for all isolation room users. The design of healing environments is fundamentally based on creating positive emotions (Peters, 2017). If the idea of a healing environment wants to be taken seriously by the owners of the isolation room, it should also be attractive in terms of costs and benefits. Evidence-based research states that it is. A business analysis of a new US hospital consisting of 300 beds, concluded that inclusion of evidence-based healing environment design aspects added 5,3% to the initial building costs. Estimates of savings and revenue gains from these aspects however conclude that these costs would be recaptured in just one year. But not only has the idea of a healing environment a positive effect on the hospital business-case, it also improves well-being and safety of their patients and other hospital users (Berry & Parker, 2004). In the section below, the main evidence-based patient needs resulting from the theory are described.

Connect patient

In normal patient rooms, privacy is a big factor within healing environment. Isolation rooms however are normally single-bedded, which makes the issue of privacy not applicable.

However patients will not influence each other, the patient might be influenced by visitations of friends and family or even staff. Even though visitations from family might be restricted in isolation rooms, evidence shows that visitations and contact with loved ones can improve patient well-being. Also staff communication to the patient is important. Studies have identified poor communication and automated health-systems as a problem that worsens patient satisfaction and health outcomes (Irich, 2006). This specific interest from the patient is mostly based on the culture of the healthcare facility. However, the design should contain space for visitations or a possibility to communicate with staff and loved ones without the risk of contamination. This can be described in the function: 'connect patient'.

Prevent medical errors
Another main concern of patients is that their healing process is extended by human or medical errors. Errors in the health-care can be a result from the health-care process or from the facility design. Two subjects relating to the facility design will be discussed.

Firstly, errors can occur when design of rooms and equipment is different for every facility. When striving for a design preventing medical errors, rooms and equipment should be standardised. When multiple isolation rooms are identical, nurses for example encounter exactly the same distribution, layout and lighting in every room. This makes routine tasks simpler and decreases errors (Grunden & Hagood, 2012). Standardisation of a room is however is directly linked to a flexible room interior. When a room interior is flexible, less specialized rooms are needed and medical errors will decline. A function following from this interest can be described as; 'Flexible/standardised room interior'.

Evidence is also presented that errors can occur from inadequate lighting. Research shows a linear relationship between error and illuminance levels. The research showed for example that an illuminance of 1570 lx at the workspace during medical procedures resulted in an error rate of 2,6%, while 480 lx in the same situation resulted in an error rate of 3,8% (Huisman et al., 2012). A function following from this interest of the patient can be described as; 'illuminate medical actions'.

Comfort patient
There are several evidence-based factors influencing the comfort of the patient. Firstly, Research has concluded that hospitals internationally have to high noise levels when compared to the guidelines as issued by WHO. The WHO suggests that sound levels should not exceed 35 dB with a maximum of 40 dB overnight (Darbyshire & Young, 2013). As a result of noise, patients might encounter sleep loss, high blood pressure and heart rates, which worsen healing time. Also for staff noise can be the cause of stress and in some situations even heighten the risk of error. Noise in hospital rooms is caused by for example overhead gaging, moving bedrails, trolleys, equipment or staff shift changes. These sounds can be loudened by sound reflecting floors and ceilings, which also are the cause of sounds being carried further. Evidence shows that less noise in a hospital is not the result of just changing staff behaviour, but is mainly the result of appropriate design. Some proven design measures are the elimination or insulation of noise sources or the installation of sound-absorbing ceilings tiles (Irich, 2006). A function following from this interest can be described as; 'Reduce noise-levels'.

Another aspect within the process of comforting the patient is their daily rhythm. There is evidence that daylight exposure in hospital rooms reduces depression, because the rhythm of day and night can be experienced. Mimicking natural daylight is also possible, using artificial circadian light in combination with soft colours and subtle movement. A daily rhythm cannot only be experienced in light, but also in temperature. Lower temperatures at night are appreciated by the patients (Peters, 2017). A function following from this interest can be described as; 'Experience daily rhythm'.

Furthermore, research suggests stress and pain is reduced if the internal architecture represents calmness. Reduction of stress and pain can also be obtained if patients are in a surrounding where they have a pleasant view. For example a view of nature, people or one that provides information about outside activities are preferred distractions. Besides that, artwork can be effective for these purposes as well (Giplin, 2003). Besides that, technical elements inside of the room should be hidden (Huisman et al., 2012). Two functions following from this interest can be described as; 'Amuse patient' and 'calm-down patient'.

Self-control environment
Giving patients a choice on some surrounding aspects is proven to reduce stress and anxiety for this person (Huisman et al., 2012). Enhancing control of the patient can for example be done by self-control of the position of the bed, temperature of the room, lighting and distractions (music and television). A function following from this interest can be described as; 'Self-control environment'.

Guarantee safety
Several evidence-based factors influencing the safety and security of the patient do exist. The first factor is about transferring the patient. Even though transferring isolated patients is unusual, transfers should be seen as a threat to patient and staff safety. They are for example the cause of extended lengths of stay, stress, errors and costs. Also, transfers can involve lifting, which risks injuring patient or staff. A study has shown that 10.5% of back injuries in the US are associated with moving and assisting patients (Engst, Chhokar, & Miller, 2005). Besides that, when moving patients outside of the isolation room, contamination is a real threat.

A proven design measure preventing transfers is for example a flexible equipped headwall or acuity-adaptable room. Acuity-adaptable rooms have a treatment model that allows all stages of patient care from the time of admission to discharge. Evidence for this solution is given by Clarian Methodist Hospital, where after moving from specialised rooms to acuity-adaptable rooms, patient transfers decreased by 90% and medication errors by 70% (Singh & Lillrank, 2017). This aspect is directly linked to the aspect of preventing medical errors and also has the same function.

Hygiene
Hygiene is also crucial in order to ensure patient safety. Hygiene is associated with the materials used in a hospital. Many environmental surfaces and features become contaminated near infected patients, and personnel may contaminate their gloves by touches these surfaces. Examples of surfaces that are often contaminated are overbed tables, computer keyboards, infusion pump buttons, door handles, blood pressure cuffs, bedside rails, chairs and other furniture (Huisman et al., 2012). An atmosphere of emotional wellbeing seems to stand in contrast with high standards of hygiene. However, if the architect takes hygiene into account, there is no need to see hygiene and a healing environment as incompatible. A design with tight corners is more difficult to clean than smooth edges. This smooth design may, however, have a negative impact in terms of logistics. Also, smart design materials can be used with functions such as self-cleaning or easy-to-clean, or a photocatalytic antimicrobial coating can be used (Reid, Whatley, & Spooner, 2018). A function following from this aspect is; 'Clean/disinfect room'. Hygiene is not just about hygiene of the room, but also personal hygiene of the users. Research shows for example that hand-cleaning compliance worse when the object linked to this function are positioned several paces away from users' movement paths (Irich, 2006). A function following from this aspect is 'Clean/disinfect users'.

Interest of the users
The needs of this interest group is in theory not described specifically for an isolation room. Besides that, experts have a lot of knowledge available on this subject. Therefore, the interest of the users is researched using in-depth interviews later in this chapter.

Interest of the owner
The needs of this interest group is in theory not described specifically for an isolation room. Besides that, experts have a lot of knowledge available on this subject. Therefore, the interest of the owner is researched using in-depth interviews later in this chapter.

Interest of the designer
Mitigating the risk of contamination by air is something the designer should guarantee in the final design at the end of a design process. Air-change rates tell how many times the air inside of an isolation room needs to be totally refreshed in one hour. Literature states that research of airflow paths is crucial in isolation room design, since the airflow determines temperature distribution, air quality and details about contamination flows (Mahajan, Saco, & Kumar, 2018). For isolation rooms, it is important that airflows are not recirculating inside of the room. This can result in the spread of contaminated air throughout the room, less optimal air temperature distributions and lower air quality. Well positioning of the air supply diffusers and return grills can lead to a cleaner environment without increasing air-change rates (Khankari, 2015). It should be taken into account that airflow

patterns are quite complex and specific to a particular design configuration. A function following from this interest can be described as; 'Minimalize air circulation'.

Further research about the interest of the designer is done later in this chapter.

3.2. Practice

Not all the needs in processes and functions can be identified by theory. Therefore, additional information from practice is researched. To make sure the identified patient needs from theory are valid, an interview is done. Besides that, interests from the other groups are researched by consultation of experts. In Table 6 an overview is given of the consulted experts.

Table 6 Consulted experts for identify needs and constraints

Expert	Expertise	Specialization	Company	Summary
Gerard Jansen	Healthcare business developer	Integral design	Royal HaskoningDHV	Appendix C
Anne Brouwer	Healthcare consultant	Patient needs	Royal HaskoningDHV	Appendix D
Marianca Leeuwenburg – Boonk	Hospital planner	User needs	Royal HaskoningDHV	Appendix E
Frans Lenting	Project manager healthcare	Technical installations	Royal HaskoningDHV	Appendix F
Gerrit Wessels	Head of real-estate department	Real-estate management	Ziekenhuis Groep Twente (ZGT)	Appendix G
Rebecca te Riet	Infection prevention expert	Infection prevention	Ziekenhuis Groep Twente (ZGT)	Appendix G

An example of the interview setup can be seen in Appendix B.

Interest groups

Identification of relevant processes and functions depends on the viewpoint from which you look at the design. The interest groups as experienced in practice can be described as follows; the patient, the user, the owner and the designer. Figure 4 displays the interest groups with their main concerns as experienced in practice (Gerard Jansen, Appendix C).

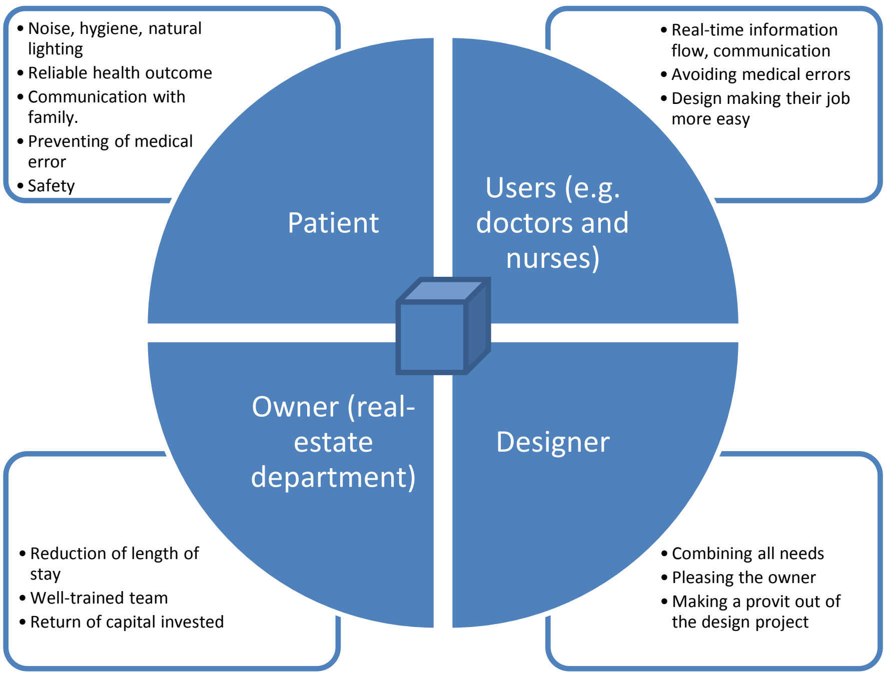

Figure 4 Groups that have an interest in isolation room design with their main needs (Gerard Jansen, Appendix C)

Interest of the patient
The Interests of the patients as described in section 3.1 Theory are discussed and validated by an expert in the patient needs. These identified interests are a good representation of the interests of the patient in practice (Anne Brouwer, Appendix D).

As an addition, the continuity of the whole system can be seen as an important interest of the patient. When a technical system, for example a button to call the nurse, is malfunctioning, the patient can feel unheard or even panic. Especially in an isolation room this is critical. All systems have to be technically correct (Anne Brouwer, Appendix D).

Interests of the users
The users of an isolation room experience the results and consequences of isolation room design first hand. The processes and actions from these isolation room users shape the final design of the room. Functions following from the processes experienced by the users that influence isolation room design are described below.

Receive/dismiss patient
For receiving and dismissing a patient in an isolation room, the patient should be able to get in and out of the room while lying on his/her bed. It is not necessary for the bed to fit into an air-lock (Frans Lenting, Appendix F). A function following from this process is; 'Transport patient'.

Registration patient data
The design should facilitate a place where patient data can be registered and saved. Also information updating the patient health record should be easy to implement. This place should be easy accessible for the user and has a relation to place where the medical interventions are carried out (Gerrit Wessels & Rebecca te Riet, Appendix G). The following function will be taken into account; 'Record patient data'.

Minor interventions
The user should be able to carry out medical actions within the room. To do so, some design features are needed like electricity, medical gasses and extra lighting (Marianca Leeuwenburg – Boonk, Appendix E). This process is described by the function; 'Perform medical actions'.

Research patient
Besides medical interventions, the room should also facilitate the basis needed to research a patient. Normally this is done outside of a patient room, but because of the contamination risk, basic research in isolation rooms should be facilitated in the room itself (Marianca Leeuwenburg – Boonk, Appendix E). A function following from this process is; 'Research patient'.

Rehabilitation exercises on bed, out of bed/ physical therapy
Space for movement is limited when a patient needs to stay inside of one room. Movement is however sometimes necessary van recovery of a patient. For extensive physical training, a patient may be given permission to leave the room, however minor exercises from a physiotherapist need to be carried out inside of the room (Gerrit Wessels & Rebecca te Riet, Appendix G). A function following from this process is; 'Exercise patient'.

Sanitary process
Patients also cannot leave the room during the sanitary process. The facility itself should fulfil this need. Every isolation room for normal patient care should have is own 'wet cell', a space for sanitation and washing (Frans Lenting, Appendix F). Within the sanitary process, multiple relevant functions can be described; 'Sanitise patient' and 'Wash patient'.

Monitoring the patient
Users need to check on the health status of every patient while making their round. It is important that the patient can be seen from within the air-lock or from the hallway (Gerrit Wessels & Rebecca te Riet, Appendix G). A function following from this process is; 'Monitor patient'.

Patient Transporting
Even though the contamination risk is high when transporting an infected patient outside of the isolation room, a hospital sometimes chooses to do so. For instance when a medical action needs to take place that cannot be carried out inside of the room. In this case, a patient including the bed needs to be transported. Even though the process of receiving/dismissing is in a different point in the recovery cycle, the process with regard to design can be seen as the same as for patient transportation. In both cases, the patient, including the bed, needs to leave or enter the room. So also the function for this process will be the same, namely; 'Transport patient'.

Providing products
The patient needs to be provided with products needed for their life and health recovery. This can be drinks, food, disposables or medication. The design should support the inflow of these products (Marianca Leeuwenburg – Boonk, Appendix E). This results in the function; 'Inflow products'.

Disposal of waste / medical waste
Produced waste might be labeled as contaminated. Therefore, disposal of waste and medical waste is a careful process (Marianca Leeuwenburg – Boonk, Appendix E). Overall, this function will be described as; 'Outflow waste'.

Cleaning
Hygiene is important inside of isolation rooms. The spatial design should be easy to clean and thereby facilitate support to the cleaner. Cleaning or disinfecting of an isolation room is more important than the cleaning of a normal patient room. That is why besides cleaning by hand, another, more efficient cleaning method is possible. This efficient cleaning method is a way of cleaning a room all in ones is using a machine for the nebulization of hydrogen peroxide. However, not every room can resist hydrogen peroxide fog, especially the ceilings. Also leakage of the room should be really low and the air exhaust should be able to be shut-down in a single room to contain this hydrogen peroxide fog. These are aspects that need to be taken into account when designing an isolation room (Gerrit Wessels & Rebecca te Riet, Appendix G). A function following from this cleaning method is; 'Resist to hydrogen peroxide fog'.

Interests of the owners
The owner of an isolation room in a hospital is most of the time the real-estate department of the hospital. This group is interested in a functional design according to the patient and user their needs, but also looks at the design taking performance into account. Functionality supports the core of the isolation-room, because it addresses the problem that brings the patient to the facility in the first place. Performance is about how effective this function is carried out, looking at the whole life-cycle of the isolation room.

Preventing contamination
The main interest of the owner is in line with the core purpose of the room: Isolating patients to mitigate contamination risk, resulting in the function; 'Mitigate contamination risk'. Contamination can happen in multiple ways, for example through air. The function 'Mitigation air contamination' can be broken down into several sub-functions (Frans Lenting, Appendix F):
- Pressurize room
- Minimalize air penetration walls
- Minimalize room openings
- Filter/clean air
- Humidify air

Another aspect of mitigating the contamination risk is contact contamination, resulting from people walking in and out of the room or through waste and laundry. Contact contamination is the spread of contamination caused by particles carried on objects and persons. Users of an isolation room need to change their clothes in the air-lock to prevent this contact contamination. This air-lock should be big enough to divide 'clean' and 'dirty' objects. Besides that, medical equipment also needs to be disinfected in the air-lock when entering and leaving the room. This is also the reason why in isolation rooms, more medical equipment is stored inside of the room itself (Gerrit Wessels & Rebecca te Riet, Appendix G). Function following from this interest are; 'Prevent contact contamination' and 'Store medical equipment'.

Patient healing
The core purpose of the room however is not just to prevent contamination, but also to improve patient healing in the same time, as is the main goal of the whole hospital. A function following from this interest can be described as; 'Healing patient'. Functions for patient healing are already described earlier in the report. However, the healing process requires inflow of product and outflow of waste. These functions are in conflict with preventing contamination. For this reason, basic actions for the healing process can be carried out by automated systems. A function following from this interest can be described as; 'automate basic care'. Nevertheless, it is important to take into account that automated care is in conflict with comforting the patient by interacting directly (Anne Brouwer, Appendix D).

Flexible room purpose
Furthermore, another interest from the owner can be found in a flexible room design (Marianca Leeuwenburg – Boonk, Appendix E). There are not always patients who are contagious or need protection against contamination. In the ZGT hospital, isolation rooms are around half of the time not used for the purpose of preventing contamination (Gerrit Wessels & Rebecca te Riet, Appendix G). Hospitals do not want isolation rooms to be empty. To use the space efficiently, the owner of a hospital wants to use empty isolation rooms for another purpose, for example for normal nursing rooms. To make sure this is possible, isolation rooms need to be designed for a flexible purpose. A example of a design aspect resulting from a flexible purpose is a small air-lock. Big air-locks can be seen as lost space, since the space is occupied just during really small periods of time, especially when taking into account the room is sometimes used for another purpose. A function following from this interest can be described as; 'flexible purpose room'.

Making profit
For the owner of an isolation room the healing process of a patient can be seen as business. In the end, investments need to be paid back and money needs to be made. This is the concern of the owner of the health-care facilities. Functions following from this interest can be described as; 'Reduce investment' and 'Reduce costs'. Examples of costs can be costs as result of failure, maintenance or energy consumption (Frans Lenting, Appendix F).

Interests of the designer
The job of the designer is to combine all needs from the different groups and implement them in the final design. The designer should know which design solutions are available and which design solutions are possible within the project framework. Ideally, the designer has no interest in the design himself, but he does try to help with the decision making process. It is the responsibility of the designer to fit the design to existing legal requirements. These legal requirements mostly exist to heighten the value of safety above the value of costs. For example, the interest of the owner 'Mitigate contamination risk' can also be seen as a function resulting from the interests of the designer, because it is the responsibility of the designer that the legal requirements for this function are met (Frans Lenting, Appendix F).

Mitigating the risk of contamination by air relates to the interlock time and the air-change rates of the air-lock and isolation room. The interlock time is the time needed between opening the two air-lock doors to prevent contamination. Air-change rates tell how many times the air inside of a room needs to be totally refreshed in one hour. The size of the air-lock is directly linked to the contamination risk, since a bigger air-lock automatically mean that it takes longer to clean all air inside, which results in a longer interlock time. However, a smaller air-lock means less space to separate dirty and clean objects, which results in a higher risk of contact contamination. This is something the designer should take into account (Frans Lenting, Appendix F).

Another thing important for a designer with regard to air contamination is the settlement of the building. After construction, a building can still move a bit due to the applied loads. This may result in a different air permeability of the room over time, which can lead to a higher contamination risk (Frans Lenting, Appendix F).

All the functions identified before can be seen as interests from the designer. Even though the designer has to cope with some regulated technical specifications, there are no functions identified resulting just from the interests of the designer.

3.3. Analysis

Analysing the theory and practice to answer research question 2 is done is this sub-chapter. First, the differences between theory and practice are verified. Afterwards, a functional analysis is done.

Verification theory and practice

It is possible that theory and practice do not give the same information. Therefore the results from literature research and expert interviews are compared.

Interest groups

On an abstract level, theory and practice identify the same interest groups for an isolation room design. However, when going into detail, the experts from Royal HaskoningDHV are not all familiar with the needs of each specific interest group at detail. Especially the interests of users like support services professionals or general support services. The four interest groups that are described in this report are known by theory and practice.

Interests of the patients

The interests of the patients are well known in both theory and practice. Since the focus of healthcare shifted to the patient, a lot of knowledge about the patient needs is produced. Not all theoretical knowledge is however applicable in practice and the interest of the patient might not always go in line with the interests of other groups. These dependencies are more known in practice and less described in theory.

Interests of the users

The interests of the users are in this report researched just by practice. Verification of theory and practice is therefore not possible.

Interests of the owner

The interests of the owner are in this report researched just by practice. Verification of theory and practice is therefore not possible.

Interests of the designer

Ideally, the designer has no interest in the design himself. However, the designer should guarantee the final design does comply with the existing regulations and determined safety level for contamination. In practice, preventing air contamination is done by taking into account air-change rates and interlock times. However, literature states that airflow paths should also be taken into account.

Functional analysis

As a result of the identified needs and constraints, a functional analysis can be done using a FAST diagram. Six steps are made in analyzing the identified processes and functions.

1. Determine the task

When looking at isolation rooms in health care facilities, the main task can be described as infection control or preventing contamination. This describes the process of protecting the isolated patient and the other patients in the hospital for contagious diseases. However, when only this would be the main task, patients could just be locked in to air tight boxes, without paying attention to their healing process. That is why another aspect needs to be implemented in the main task. An isolation room also needs to support the healing process of the isolated patient. So health benefits for all patients in the hospital are improved.

Task: Preventing contamination while supporting health benefits

Preventing contamination can have the purpose of protecting the patient, protecting the surrounding (preventing a contamination outbreak) or both. Even though these purposes can have different technical function-carriers, their main functions are the same. Therefore, the task does not have to make a distinction between these purposes.

2. Determine the functions

The functions are determined by consulting experts. Also, evidence-based functions are determined by assessing literature. The functions as identified in this research are used to create the FAST diagram.

3. Determine the function type

This step consists of dividing the functions by type, in basic functions and support functions. Because of the abstraction level of this research and the freedom of choice with regard to function-carriers, the FAST diagram that will be made focusses mainly on the basic functions.

4. Determine the primary function structure

In this FAST diagram for isolation rooms, functions are broken down until they can be linked to function-carriers that can be validated. The function that follow from the needs of the owner, so the clients' business-case, are an exception to these rule, since these functions do not describe physical objects.

5. Ordering the functions

This step consists of ordering the functions by different categories. These categories will be corresponding to the interest groups the functions are derived from. Hereby the differences and similarities in interests between groups are made visible. This is valuable information when trying to make a design that includes the needs of all interest groups. Because the designer has no specific functional interest in the design himself this group is not taken into account by ordering the functions.

6. Making the diagram

The final FAST diagram offers the possibility to give a clear and structured picture of the system of functions, as experienced by the groups having an interest in isolation room design. The FAST diagram is shown in Figure 5.

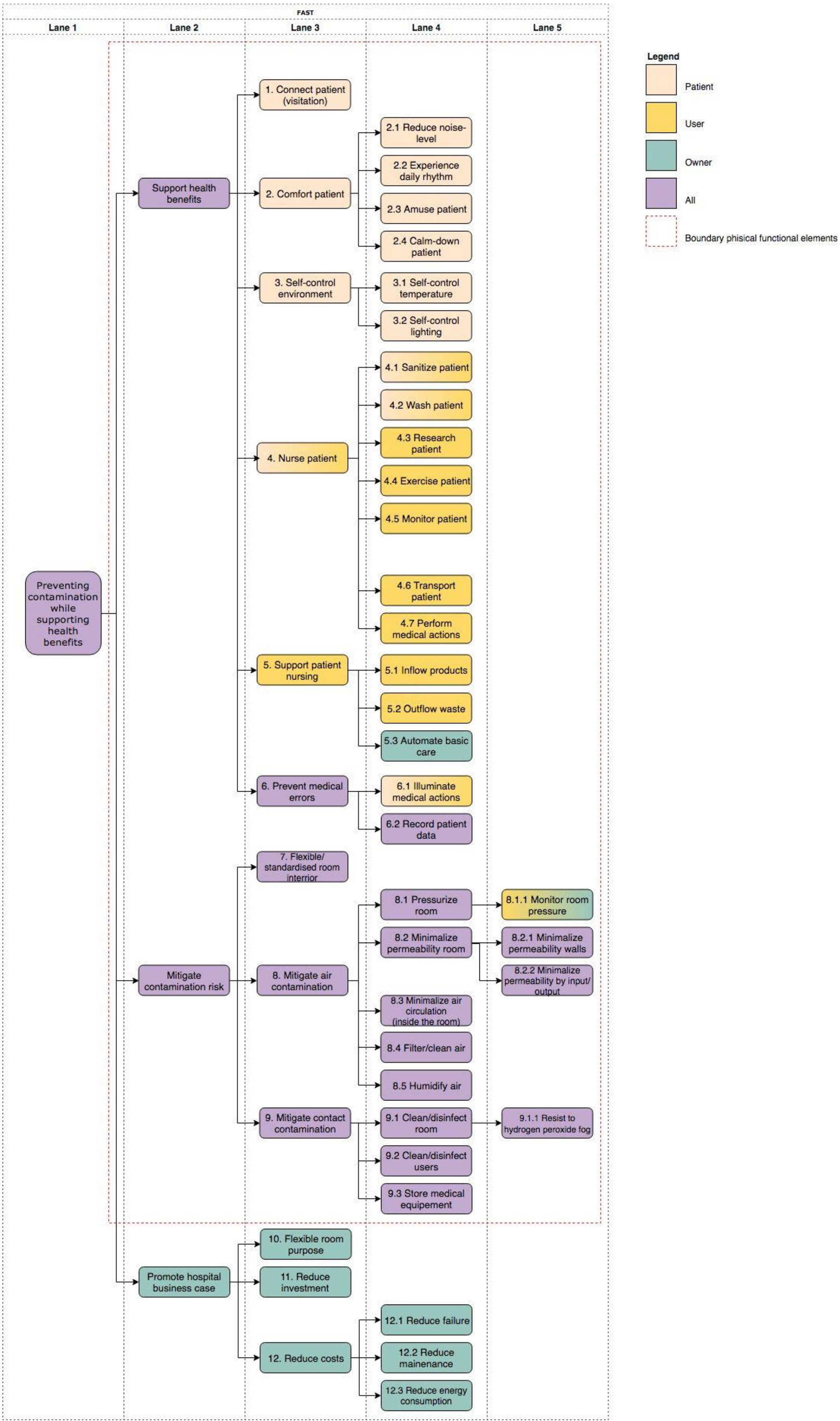

Figure 5 FAST diagram isolation room

4. Research the problem

In this heading, research question 3 will be answered by theory, practice and an analysis. Research will be done to provide an overview of the sub-solutions or technologies which might be adaptable to the different needs.

4.1. Theory

Besides the researched literature in the previous chapter, the WIP design standards (WIP, 2004) & (WIP, 2006) and the RHDHV knowledge document (Lenting, 2017) are used to specify function-carriers, their characteristics and the regulations and preferences. When the researched literature, the WIP documents or the RHDHV knowledge document doesn't give any bandwidth or preference for a criterion, the bandwidth will be left blank.

The result from this research is summarised in a Functional Performance Specification. Because of its size, the diagram is placed in the appendix, Appendix L.

4.2. Practice

To complement the identified function-carriers and their characteristics from theory, also research in practice is done. Besides the function-carriers and characteristics that can be identified as a result of the previous consultations, an integral design meeting is organised. The purpose of this integral design meeting was to identify the performance characteristic of the criterion 'spatial constraint'. In Table 7 an overview is given of the consulted experts.

Table 7 Consulted experts for researching the problem

Expert	Expertise	Specialization	Company	Location summary
Marianca Leeuwenburg – Boonk	Hospital planner	User needs	Royal HaskoningDHV	Appendix H
Frans Lenting	Project manager healthcare	Technical installations	Royal HaskoningDHV	
Freerk Hoekstra	Architect	Industry and buildings	Royal HaskoningDHV	
Jean-Maurice Kuijpers	Architect	Hospital logistics	Royal HaskoningDHV	
Xander van Ruissen	Technical coordinator	System and process thinking	Royal HaskoningDHV	
Theo Franken	Control engineer healthcare	Control engineering	Royal HaskoningDHV	Appendix I

The results from this analysis are summarised in a Functional Performance Specification. Because of its size, the diagram is placed in the appendix, Appendix L.

4.3. Analysis

Analysing the theory and practice to answer research question 3 is done is this sub-chapter. To show relations between the identified functions and the identified function-carriers, these relations are added in the Functional Performance Specification.

The main function 'promote hospital business case' is not included in the functional performance specification, because this function cannot be described in physical objects.
The performance levels of the criteria 'size' are determined by two hospital architects. The size needed for a function-carrier should be seen as the 'hard' size needed for the object itself and the 'soft' size needed around the object together. The values of the sizes are assumptions, because there does not exist one specific standard size for the space needed around most function-carriers and

because this size can vary due to the client demands (Freerk Hoekstra & Jean-Maurice Kuijpers, Appendix K).

Since the performance levels of the criteria 'contamination risk', 'comfort patient' and 'comfort user' are described by qualitative terms, they are validated by an infection prevention expert and the head of real-estate management ZGT.

If literature states something about performance levels or regulations, the source is given. The other performance levels or preferences are resulting from practice. When no performance level, regulations or preferences are given by researched literature or practice, the cell will be left blank. This results in the fact that even though the content of the diagram is likely to be correct, the diagram might not be complete.

Because of its size, the diagram is placed in the appendix, Appendix L.

5. Develop possible solutions

In this heading, research question 4 will be answered. The first step in developing possible solutions is identifying the decision areas and the alternatives. Decision areas and the alternatives can be created out of the identified function-carriers in the Functional Performance Specification. Further research about dependencies, possible solutions and their consequences can only be done when the decision areas and the alternatives are known.

5.1. Theory

The analysis of this chapter will be carried out by using the earlier researched literature from section 3.1 and 4.1.

5.2. Practice

The analysis of this chapter will be carried out by using the data resulting from earlier consulted experts from section 3.2 and 4.2.

5.3. Analysis

Decision areas with their alternatives

Determining the decision areas with their alternatives is the first step in developing possible solutions. The alternatives can be derived from the function-carriers. When no alternative function-carriers are identified for a function, they are not described in a decision area. Also, when all of the sub-functions from a main function have the same dependencies and performance specifications, these sub-functions will be grouped together and described by their main function. The decision areas with their alternatives resulting from the identified function-carriers are presented in Table 8. The grouped sub-functions are described in the column 'Functions included'.

Table 8 Decision areas with their alternatives

ID	Decision area	Functions included	ID	Alternative
D1.	Healing environment	2.1/2.2/ 2.3/2.4	a1.	No focus on design features for healing environment
			b1.	Focus on design features for healing environment
D2.	Prevent medical errors	4.7/6.1/ 6.2	a2.	No extra design features for preventing medical errors
			b2.	Extra design features for preventing medical errors
D3.	Self-control patient	3.1/3.2	a3.	No self-control patient
			b3.	Self-control patient

Extension table 8 Decision areas with alternatives

ID	Decision area	Functions included	ID	Alternative
D4.	Flexible room purpose	10.	a4.	No flexible room purpose
			b4.	Flexible room purpose
D5.	Connect patient	1.	a5.	Interact directly to patient
			b5.	Interact indirectly to patient
D6.	Support patient nursing	5.1/5.2/ 5.3	a6.	Automated basic care
			b6.	Inflow products/ outflow waste
D7.	Monitor patient	4.5	a7.	Monitor patient direct
			b7.	Monitor patient indirect
D8.	Safety	4.6/7	a8.	Transport patient
			b8.	Flexible/standardised room interior
D9.	Pressure monitoring	8.1.1	a9.	Psidac pressure monitor system
			b9.	Kimo pressure monitor system
			c9.	Pedak pressure monitor system
D10	Record patient data	6.2	a10.	PC integrated in bed head panel
			b10.	COW (Computer on wheels)
D11	Extra entrance room (without air-lock)	8.2.2	a11.	No extra door without air-lock
			b11.	Extra door without air-lock
D12	Air lock size	8.2.2	a12.	Relatively small air-lock (< 2,6m²)
			b12.	Relatively big air-lock (> 2,6m²)

Possible solutions

The decision areas and alternatives are used as input for the analysis on developing possible solutions. To do so, it is necessary to determine the dependencies between alternatives. Not all combinations of alternatives are valid or achievable due to these dependencies. Research is done about the feasible solutions that can be chosen. Two or more functions are dependant if choosing one alternative influences the choice on alternatives in the other decision area. If two alternatives are negatively dependant, they are incompatible and cannot be combined in one design. This influences the amount possible solutions. Research about the incompatible alternatives is done by analysing the theory and practise of this research. In Table 9 an overview is given of the identified incompatibilities and their source. These incompatibilities are validated by an infection prevention expert and the head of real-estate management ZGT. Besides that, some incompatibilities are added by these experts.

Table 9 Dependencies

	Dependencies (incompatible)		
ID	**Alternative**	**Alternative**	**Source**
b1./ a3.	Extra measures for healing environment	No self-control patient	'Especially in the Netherlands, self-control is a critical aspect when talking about a healing environment.' (Anne Brouwer, Appendix D)
b1./ a5.		Interact directly to patient	'Evidence shows that visitations and contact with loved ones can improve patient well-being.' (Irich, 2006)
b1./ a6.		Automated basic care	'Studies have identified poor communication and automated health-systems as a problem that worsens patient satisfaction and health outcomes' (Irich, 2006)
b1./ b7.		Monitor patient indirect	'The ZGT experiences that personal contact with the patient is inseparable from a healing environment.' (Gerrit Wessels & Rebecca te Riet, Appendix G)
b2./ a8.	Extra measures to prevent errors	Transport patient	'Transfers should be seen as a threat to patient and staff safety.' (Sing & Lillrank, 2017)

Extension table 9 Dependencies

	Dependencies (incompatible)		
ID	**Alternative**	**Alternative**	**Source**
b4./ b12.	Flexible room purpose	Relatively big air-lock (> 2,6m²)	'So, a big air-lock is also in conflict with the flexibility of the room.' (Gerrit Wessels & Rebecca te Riet, Appendix G)
a5./ a6.	Interact directly to patient	Automated basic care	'… using an automated system … this is contradicting the value of direct interaction and direct monitoring.' (Anne Brouwer, Appendix)
a6./ a7.	Automated basic care	Monitor patient direct	'… using an automated system … this is contradicting the value of direct interaction and direct monitoring.' (Anne Brouwer, Appendix)
a11./ a12.	No extra door without air-lock	Relatively small air-lock (< 2,6m²)	'When a small air-lock is wanted with no space for a bed to pass, a second door is needed.' (Integral design meeting, Appendix)

Figure 6 shows an option graph, giving an overview of the incompatibilities between alternatives. A line between two points means the two alternatives are incompatible.

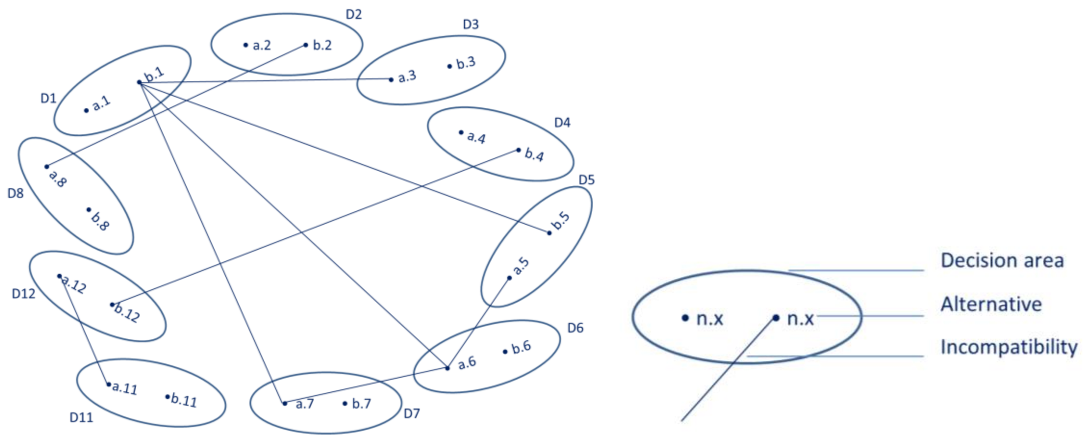

Figure 6 Option graph from the design system of an isolation room

Consequences of solutions

Next, the criteria on which the solutions are being tested can be linked to the alternatives. These criteria describe the main consequences of made decisions. The design solutions should take into account the interests of every interest group. That is why the most important design function of every interest group and the most important common function are taken as criteria, see Table 10.

Table 10 Design solution criteria

Interest group	Main function	ID	Criteria
Patient	Comfort patient	C1	Comfort patient
User	Nurse patient	C2	Nurse patient
Owner	Promote hospital business case	C3	Reduce investment
		C4	Reduce cost
All	Mitigate contamination risk	C5	Mitigate air contamination
		C6	Clean/disinfect room
		C7	Clean/disinfect users

An interaction matrix is made to give an overview of the dependencies between the alternatives and their relation to design criteria. In the matrix, distinction can be made between two types of relations; 1) relations between two design alternatives, 2) relations between a design alternative and a design criterion. When two functions related to design alternatives are dependant, it means that the two functions are incompatible, displayed with a '-'sign in the matrix. When a design alternative is dependant to a design criterion, it does not automatically mean that the two are incompatible or inseparable, but it does mean the design alternative positively or negatively influences the design criterion. This positive or negative relation is displayed with a '+' or '-'sign. The matrix directly defines indirect dependencies. This means that for example a dependency between two design criteria is not displayed. The interaction matrix is shown in Table 11.

The design consequences on the criteria 'investments' and 'costs' are mostly estimations based on experience and logic thinking. Further research on these two subjects is needed to determine the exact impact on these criteria.

Table 11 Interaction matrix

	a1.	b1.	a2.	b2.	a3.	b3.	a4.	b4.	a5.	b5.	a6.	b6.	a7.	b7.	a8.	b8.	a9.	b9.	c9.	a10.	b10.	a11.	b11.	a12.	b12.	C1.	C2.	C3.	C4.	C5.	C6.	C7.
a1. No extra measures for healing environment																										-	-	+	-			
b1. Extra measures for healing environment					-					-	-			-												+	+	-	+		-	
a2. No extra measures to prevent medical errors																										-	-	+	-			
b2. Extra measures to prevent medical errors															-											+	+	-	+			
a3. No self-control patient		-																								-		+		-		-
b3. Self-control patient																										+	-	-	+	+		+
a4. No flexible room purpose																												+	-			
b4. Flexible room purpose																									-			-	+	-		
a5. Interact directly to patient											-															+				-		-
b5. Interact indirectly to patient		-																								-		-	+	+		+
a6. Automated basic care		-							-				-													-	-	-	+	+		+
b6. Inflow products/ outflow waste																														-		
a7. Monitor patient direct											-															+				-		-
b7. Monitor patient indirect		-																								-	-	-	+	-		-
a8. Transport patient				-																						-	-		-	-		-
b8. Flexible/standardised room interior																										+	+	-	-	+	+	
a9. Psidac pressure monitor system																											+			+		
b9. Kimo pressure monitor system																														+		
c9. Pedak pressure monitor system																											+	-		+		
a10. PC integrated in bed head panel																															+	
b10. COW (Computer on wheels)																											+				-	
a11. No extra door without air-lock																								-			-	+		+		
b11. Extra door without air-lock																											+	-		-		
a12. Relatively small air-lock (< 2,6m²)																						-						+	+	+		-
b12. Relatively big air-lock (> 2,6m²)								-																			-	-	-	-		+
C1. Comfort patient	-	+	-	+	-	+			+	-	-		+	-	-	+																
C2. Nurse patient (comfort users)	-	+	-	+		-					-			-	-	+	+		+		+	-	+		-							
C3. Reduce investment	+	-	+	-	+	-	+	-		-	-			-		-			-			+	-	+	-							
C4. Reduce costs	-	+	-	+		+	-	+		+	+			+		-								+	-							
C5. Mitigate air contamination					-	+		-	-	+	+	-	-	-	-	+	+	+	+			+	-	+	-							
C6. Clean/ disinfect room		-														+				+	-											
C7. Clean/ disinfect users					-	+			-	+	+		-	-	-									-	+							
Blue = Alternative																																
Red = Criteria																																

Without taking into account the incompatible options, there are $(2^{11}) * 3 = 6144$ combinations of design solutions with all their own characteristics. So even with just 12 decision areas, there exist a large amount of solutions. This is why a list with solutions and their design criteria is not useful. To get an overview of the solutions and their consequences on the design criteria, an Excel sheet is made that gives a final score on a design criterion when combining different alternatives.

Explanation of the 'consequence summarizer' in Excel

The user interface is depicted in Figure 7, showing a table with three main columns. The left column displays all decision areas, so the subject on which an alternative needs to be selected is known. The middle column displays all the alternatives. By clicking on the cell '[click and choose alternative]…', a drop down list showing all possible alternatives appears. An example of what this looks like is shown in Figure 8. The right column displays the consequences of the combined chosen alternatives on the main design criteria. These consequences are displayed using a number between 0 and 10, zero representing the worst and ten representing the best possible alternative combination for a specific design criterion. When choices are made for all the alternatives, the user interface might look like Figure 9. If changing one specific alternative, the consequences on design criteria are adjusted immediately, Figure 10. This gives a clear overview of all solutions with their consequences on design criteria. The Excel shows all combinations in design solutions, incompatibility of different alternatives is not included. The Excel sheet can be seen as a summary of the 6144 design solutions with the consequences on criteria.

An explanation of how this Excel sheet is made can be found in Appendix M.

			Alternatives	Consequences	
			Choose an alternative by clicking on a cel in the column below		
Decision area [D1]	Healing environment	=	[click and choose alternative] ...		
Decision area [D2]	Preventing medical errors	=	[click and choose alternative] ...	Scale [0 = worst, 10 = best]	
Decision area [D3]	Self-control patient	=	[click and choose alternative] ...	Comfort patient	[-]
				Comfort user	[-]
Decision area [D4]	Flexible room purpose	=	[click and choose alternative] ...	Reduce investment	[-]
				Reduce costs	[-]
Decision area [D5]	Connect patient	=	[click and choose alternative] ...	Mitigate air contamination	[-]
				Clean/ disinfect room	[-]
Decision area [D6]	Support patient nursing	=	[click and choose alternative] ...	Clean/ disinfect users	[-]
Decision area [D7]	Monitor patient	=	[click and choose alternative] ...		
Decision area [D8]	Safety patient	=	[click and choose alternative] ...		
Decision area [D9]	Monitor air pressure	=	[click and choose alternative] ...		
Decision area [D10]	Record patient data	=	[click and choose alternative] ...		
Decision area [D11]	Extra entrance room	=	[click and choose alternative] ...		
Decision area [D12]	Air-lock size	=	[click and choose alternative] ...		

Figure 7 User interface

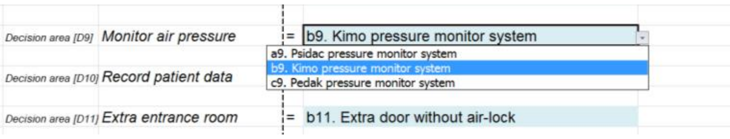

Figure 8 Drop down list of possible alternatives

			Alternatives	Consequences	
			Choose an alternative by clicking on a cel in the column below		
Decision area [D1]	Healing environment	=	b1. Extra measures for healing environment		
Decision area [D2]	Preventing medical errors	=	a2. No extra measures to prevent medical errors	Scale [0 = worst, 10 = best]	
Decision area [D3]	Self-control patient	=	b3. Self-control patient	Comfort patient	8
				Comfort user	6
Decision area [D4]	Flexible room purpose	=	a4. No flexible room purpose	Reduce investment	6
				Reduce costs	4
Decision area [D5]	Connect patient	=	a5. Interact directly to patient	Mitigate air contamination	6
				Clean/ disinfect room	8
Decision area [D6]	Support patient nursing	=	b6. Inflow products/ outflow waste	Clean/ disinfect users	3
Decision area [D7]	Monitor patient	=	a7. Monitor patient direct		
Decision area [D8]	Safety patient	=	b8. Flexible/standardised room interior		
Decision area [D9]	Monitor air pressure	=	b9. Kimo pressure monitor system		
Decision area [D10]	Record patient data	=	a10. PC integrated in bed head panel		
Decision area [D11]	Extra entrance room	=	b11. Extra door without air-lock		
Decision area [D12]	Air-lock size	=	a12. Relatively small air-lock (< 2,6m²)		

Figure 9 Example of a solution and the corresponding consequences on design criteria

			Alternatives	Consequences	
			Choose an alternative by clicking on a cel in the column below		
Decision area [D1]	Healing environment	=	b1. Extra measures for healing environment		
Decision area [D2]	Preventing medical errors	=	a2. No extra measures to prevent medical errors	Scale [0 = worst, 10 = best]	
Decision area [D3]	Self-control patient	=	b3. Self-control patient	Comfort patient	8
				Comfort user	6
Decision area [D4]	Flexible room purpose	=	a4. No flexible room purpose	Reduce investment	5
				Reduce costs	3
Decision area [D5]	Connect patient	=	a5. Interact directly to patient	Mitigate air contamination	5
				Clean/ disinfect room	8
Decision area [D6]	Support patient nursing	=	b6. Inflow products/ outflow waste	Clean/ disinfect users	6
Decision area [D7]	Monitor patient	=	a7. Monitor patient direct		
Decision area [D8]	Safety patient	=	b8. Flexible/standardised room interior		
Decision area [D9]	Monitor air pressure	=	b9. Kimo pressure monitor system		
Decision area [D10]	Record patient data	=	a10. PC integrated in bed head panel		
Decision area [D11]	Extra entrance room	=	b11. Extra door without air-lock		
Decision area [D12]	Air-lock size	=	b12. Relatively big air-lock (> 2,6m²)		

Figure 10 'When changing one specific alternative, the consequences on design criteria are adjusted immediately.' (example: Relatively small air-lock > Relatively big air lock)

6. Design decision-making tool

In this heading, research question 5 will be answered by theory, practice and an analysis. The previous conducted research, the current developments in digital engineering and the experience from different types of experts is used to determine the conditions and requirements for a collaborative design decision-making tool.

6.1. Theory

Decision-making in a design context is influenced by sets of conditions and demands. For example, demands from people interested in the design outcome, or the conditions that a room needs to fit into given spatial boundary. Coming to an agreement with the client should be an interactive process of balancing the clients' needs with the design capabilities and required experience of the designer. However, when decisions need to be made under the pressure of cost and time, quality can get lost because only a few alternatives can be evaluated. Preventing this quality loss can be done by applying design decision-making tools in selecting a promising design solution. With a design decision-making tool, it is possible to evaluate a large amount of alternatives in a short period of time (Eagan, 2001).

The context from the spatial design tools that we know from the past two decades is very much related to software that became popular in the 1980s with the emergence of the personal computer. In future decades, it is expected automation will move our view on designing way beyond design modelling tools like CAD or other BIM authoring tools. In the design theory of computer sciences, these graphic and parametric software systems are considered the most primitive stage of new developments, using smart solution digital services like artificial intelligence, as can be seen in Figure 11. This figure shows how digital developments relate to developments in engineering, with BIM today as a basis.

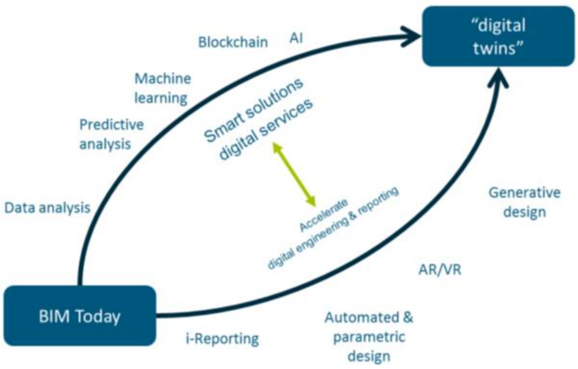

Figure 11 Digital developments vs acceleration in digital engineering & reporting (Snip, 2018)

In this development algorithms are used to learn from data with less human assistance. Diverse systems like automated translation, internet search, managing energy and vehicular traffic estimation are examples of already existing learning algorithms. With this new development in mind, design tools are also moving to more complex systems that are getting smarter. At this point in time, the first steps are made in creating sophisticated algorithms that develop specific intelligence in smart design, building simulation, operation and benchmarking. For example developments in parametric design, a process based on algorithmic thinking that uses parameters and rules for relationships between elements to manipulate the design of complex structures. Also for design decision-making tools, evaluation of alternatives might become a self-learning loop to acquire knowledge useful in decision making (Frazer, 2016). To facilitate this new way of design decision-making, it is necessary to identify the complex system of design relations, dependencies and consequences (Andia & Spiegelhalter, 2014).

6.2. Practice

To answer the question how implementation in a collaborative design decision-making tool can be facilitated, experts are consulted on identifying the conditions for this implementation. One consultation is done with an expert who has experience in the programming of design tools and one consultation is done with architects that might use the tool in practice. In Table 12 an overview is given of the consulted experts.

Table 12 Consulted expert for identifying the conditions for implementation of this research in a design decision-making tool

Expert	Expertise	Specialization	Company	Location summary
Pieter Schreurs	Architect, programmer and BIM engineer	Process and product innovation based on new applications for computer-based design methods	Royal HaskoningDHV	Appendix J
Freerk Hoekstra	Architect	Industry and buildings	Royal HaskoningDHV	Appendix K
Jean-Maurice Kuijpers	Architect	Hospital logistics	Royal HaskoningDHV	Appendix K

Implementation of this research in a design decision-making tool

An ideal design decision-making tool should combine the choice on 'what to do?' and 'where to do it?' The following three aspects of function-carriers are key when choosing alternatives in design; geometry, position and characteristics (Pieter Schreurs, Appendix J). The aspect 'geometry' is the length, width and height needed for a function-carrier to be realised. The aspect 'position' is the configuration of function-carriers inside the room. The aspect 'characteristics' includes the dependencies between function-carriers, the dependencies between function-carriers and the surrounding, and other functional performance characteristics of the function-carrier itself on which criteria can be linked. A design decision-making tool with the purpose of determining the 'what' and the 'where' question for the whole design can only be realised when the geometry and characteristics of the specific function-carriers that can be chosen are known (Freerk Hoekstra & Jean-Maurice Kuijpers, Appendix K).

Determining the geometry of function-carriers is quite a challenge. Since a function-carrier is connected to a space around it to provide room for usage, the space needed cannot be seen as a fixed parameter within a design tool. For some function-carriers, there does exist regulations about the amount of space around an object, however the users always have another opinion about the space that is really needed. That is why assumptions about the needed space around an object need to be made and documented. When a client does not agree with this assumption, the space needed for a function-carrier should be easy to adjust in the tool (Freerk Hoekstra & Jean-Maurice Kuijpers, Appendix K).

Determining the characteristics of function-carriers should be done by a combination of research from theory and practice (Pieter Schreurs, Appendix J).

First, the 'what' question needs to be answered. Choices need to be made on what function-carriers are wanted. These decisions are made using criteria and taking into account dependencies and feasibility of solutions. When the content of a design is chosen, the two basis aspects 'geometry' and 'characteristics' of the chosen function-carriers can be used in determining the 'where' question.

The 'where' question will determine the design aspect; 'position'. Besides the two needed aspects resulting from the 'what' question, the spatial dependencies are needed, expressed in optimum curves. When seeing the aspect 'position' as a variable, the alternatives of configurations in the different chosen function-carrier volumes within given spatial constraints can be researched. These spatial constraints represent for example the boundaries of a room. Within these spatial constraints, a lot of alternatives can be simulated. These alternatives can again be evaluated by criteria, taking into account the feasibility of solutions (Pieter Schreurs, Appendix J).

It should be taken into account that the space needed around two objects may possibly be allowed to overlap when searching for an ideal configuration. For example, the space needed for opening a door to a storage closet may possibly overlap with the space for transport of the patient. That is why the space needed for a function-carrier should be defined in; 1) 'hard' space needed for the object itself. 2) 'soft' space needed for using the object. In the spatial dependencies should be included from which function-carriers the space needed around an object may overlap and from which function-carriers not. These two definitions of space promote an efficient design solution resulting from the tool (Freerk Hoekstra & Jean-Maurice Kuijpers, Appendix K).

6.3. Analysis

This research can be seen as the first step needed for a design decision-making tool taking into account the current developments as described in theory. The conditions and requirements for a collaborative design decision-making tool resulting from the previous conducted research, the developments in digital engineering and the experience from different types of experts are summarised below.

Boundary conditions:

- The database of possible function-carriers is complete, up-to-date, and verified by theory and practice.
- The database of functional performance specifications linked to the function-carriers is complete, up-to-date, and verified by theory and practice. This database includes geometries expressed in spatial coordinates, and characteristics: the spatial dependencies between function-carriers expressed in optimum curves, spatial dependencies between function-carriers and the surrounding expressed in optimum curves, and functional performance characteristics on which criteria can be linked.
- Geometries are divided in 'hard' space needed for the object itself and 'soft' space needed for using the object. In the spatial dependencies should be included from which function-carriers the space needed around an object may overlap and from which function-carriers not.
- The database of dependencies between alternatives is complete, up-to-date, and verified by theory and practice.
- Criteria of design consequences are determined in collaboration with the external interest groups.
- The spatial boundaries of a design, if present, are known expressed in spatial coordinates.

Requirements:

- The database of function-carriers is easy adjustable/extendable.
- The database of performance specifications is easy adjustable/extendable.
- The database of dependencies is easy adjustable/extendable.
- The 'soft' space needed around an object is easy adjustable.
- The tool provides direct feedback about consequences of design decisions.
- The design evaluation is transparent.

A recommendation for implementing these boundary conditions and requirements in a use-case diagram, as the first phase in transformation to software development, is given in Appendix N. Further research is recommended about the validity of this use-case diagram.

7. Discussion

In this section of the report, the made assumptions are summarized. Besides that, the integrity of each sub-section, the general applicability of the research and the added value of the research are discussed. Finally, recommendations are added.

7.1. Assumptions

In this research, a few assumptions are made. These assumptions are displayed in this section.

- For identifying the functions and processes on the determined abstraction level of this research, no distinction need to be made between positive, negative or flexible pressured isolation rooms. A generic isolation room is used.
- The most imported needs for isolation room design can be identified when the interest groups are specified in; patients, users, owners and designers.
- Functions relating to the business-case of the hospital are functions that cannot be connected to a specific physical function-carrier.
- Assumptions are made for the scores on the design criteria 'investments' and 'costs'.
- Two architects have made experience based assumptions for the criteria 'size' in the FPS.
- Every alternative is just as important for the final score on a design criterion. Priorities in decision areas are not taken into account.

7.2. Integrity

Identifying the needs and constraints

The FAST diagram is made as a result of the researched literature and the given information by some experts. The FAST diagram should be seen as a value-free representation of the identified needs from interest groups. This makes it impossible to label the content of a FAST diagram as right or wrong. Research from different teams or in different times will result in different diagrams. The final diagram is a clear scheme of an integral and balanced representation from all researched interest in isolation room design at the current time of the research (de Graaf, 2014).

Philosopher of science Thomas Kuhn suggested that research entrenched in a paradigm always ends up reinforcing that paradigm, because anything that contradicts it is ignored or considered not relevant until it conforms to already established ideas (Shuttleworth & Wilson, 2008). This thesis describes the identification of the processes and functions of an isolation room as known within the current paradigm. They are identified according to the existing knowledge from experts and architects. The question can be asked if the existing knowledge is reality itself. It has to be taken into account that experts are subject to ideologies, preconceptions and assumptions. The risk of this subjective reality is however mitigated by consulting multiple and different types of experts and by comparing theory with practice.

Research the problem

The functional performance specification is made as a result of the researched literature and the given information by some experts. This results in the fact that the functional performance specification is not complete. For a complete analysis about the performance of function-carriers, further research is needed. Also, it is important to look at the integrity of the identified function-carriers in the field of time. Are they up to date or are their also other innovative solutions?

In the end, the design project team is responsible for the level of completion of the identified function-carriers. Even though designers might feel offended by this attitude, they should ask themselves if they are recommending a specific design (or even design approach) because they are the experts and have always done it this way or because it is the best option available at this moment in time. Designers always need to explore and validate design options and approaches that serve the current requirements of everyone interested in the design.

Develop possible solutions
The amount of identified alternatives is directly linked to the level of completion of the functional performance specification. Because the functional performance specification is not complete, not all alternatives are identified. After more in depth research, expansion of the alternatives is possible.

The identified dependencies are based on theory and practice, and are validated by experts in a hospital. This makes it likely that the identified dependencies are correct for the given alternatives. The design consequences on the criteria 'investments' and 'costs' are mostly estimations based on experience and logic thinking. Further research on these two subjects is needed to determine the exact impact on these criteria. The other design consequences are based on theory and practice, and are validated by experts in a hospital. This makes it likely that these consequences are correct for the given solutions.

Select a promising solution
The conditions and requirements are identified on an abstract level and can possibly be broken down and specified further when extended research is done. Besides that, the conditions and requirements are made with little knowledge in software development. However, an expert with knowledge in software development is consulted and conditions and requirements are not presented in software terms.

Extended research is needed about the use-case diagram in Appendix N. Before implementing these findings in a design decision-making tool, further research is needed about the validity and content of the use-case diagram.

7.3. Deduction

This heading is about how the results of the research can be applied more generally. Even though this research is about the design of an isolation room, the methodologies used can be applied to the design of other facilities as well. Furthermore, the conditions and requirements for implementation in a collaborative design decision-making tool are not specified for an isolation room. A generic design decision-making tool could result from the identified requirements.

7.4. Added value of the research for RHDHV and the client

This research looked at the design system of an isolation room and how to implement this system in a collaborative design decision-making tool. The added value of this research for Royal HaskoningDHV and the client is summarized in three value points. The first point is the value of knowing the needs of all the interest groups. The second value is about giving a structure for the interactions in the decision-making phase using the system of dependencies. And the last value is about the possibility to document all the data in relation to the decision-making process. This chapter will give further explanation of the added value of these three points.

The value of the first point has to do with the value of collaborative design. By taking into account all the groups which have an interest in the final design of isolation rooms, a clear view of the room its actual purpose is created. The value of this design approach can be found in the satisfaction of the client. Due to the collaborative design, the client has the feeling of being understood. Also, Royal HaskoningDHV has a better understanding of the client needs. This makes communication easier and results in more made decisions in the early design phase.

The second point focuses on this conceptual design decisions made in the early design phase. As a result of this research, the main consequences of some design decisions are known in this early design stage. This reduces the chance for both Royal HaskoningDHV and the client to be confronted with surprises, and thereby reducing discussions and design costs. Opportunity for making changes in design at the least costs happens early in the design processes (American Institute of Architects, 2007). This research helps Royal HaskoningDHV in shifting decisions to the early design process due to two key concepts: integration of early input from all interest groups, and the ability to early simulate the consequences of design decisions. These two concepts enable the design to be brought to a higher level of completion before the construction documents are made.

The value of the third point has to do with the value of the identified data or knowledge in this research. The identified data can be analyzed for insights that lead to better decisions and strategic business moves. Within a world where documented data becomes more and more important, the process of design decision-making will not be left unchanged. Documenting the data in relation to the decision-making process strengthens the position of Royal HaskoningDHV in knowledge production. The used methods in this research give an example of a structured way to capture data. For example using the interaction matrix, data can easily be documented, accessed and extended. When data and knowledge production changes from the knowledge of individual experts to a more collective stored knowledge, knowledge growth is stimulated.

8. Recommendations

First, recommendations for extended research are given. After that, an overall recommendation about the problem statement is added.

Recommendations for extended research

- Extended research about the process and functions as identified by the different interest groups.
- Extended research about the Functional Performance Specification. This includes research about possible function-carriers but also research about the performance of criteria.
- Research about the performance level of the criteria ‘investments’ and ‘costs’.
- Extended research about the performance level of the criteria ‘size’. Making a distinction in hard and soft geometries. A hard geometry needed for the object itself and a soft geometry needed around the object.
- Extended research about the performance level of the criteria ‘spatial constraints’. Identifying spatial constraints described by optimum curves and specifying for which function-carriers the soft geometries may overlap and for which function-carriers not.
- Extended research about dependencies. Does a negative dependency always mean that two function-carriers are incompatible or are their cases in which incompatibilities can be solved when adding another function-carrier?
- Research about adding accreditation as criterion, so the consequences on these certificates are known in the early design phase.
- Research about the scores on criteria of design consequences when choosing alternatives. For example by determining the level of priority of a decision area.
- Extended research about the implementation of the design system in a collaborative design decision-making tool. For example transforming the use-case diagram in a more specific UML diagram.
- Moving design decisions upstream requires rethinking of typical project phases. The design process as displayed early in this report by Figure 2 will not apply anymore after implementation of a collaborative design decision-making tool. Research about the impact of a collaborative design decision-making tool on the design process is recommended.

Recommendation about the problem statement

Part of the problem statement is that Royal HaskoningDHV wants a collaborative design decision-making tool for an isolation room to create a better relation with the client. There are three recommendations I would like to give by thinking critically about this problem statement.

- The first recommendation is about the isolation room itself. When looking critically at the core purpose of isolation a patient, mitigate contamination risk, the question can be asked why this should be done with air pressure or why it should be done with a room at all. Is an isolation room used for preventing contamination because it is the best solution for the given goal, or are we thinking inside of a paradigm, blinded for what might be possible because the wrong questions are asked or the wrong persons are answering the questions? Critical thinking about these questions is recommended.
- The second recommendation is about the fact that a design decision-making tool is wanted. Such a tool might improve collaboration with the client. However, it is important to discuss with the client if they think this tool is useful. Maybe the client thinks it is not their job to intervene in the design process? When really wanting to enhance collaboration with the client, research about the client whishes in collaboration is recommended.
- The last recommendation is about working with the wanted tool. At this moment designers of Royal HaskoningDHV are accustomed to making design decisions using the experience of experts, rather than relying on tools based on data. There is jet no way of easily sharing the data needed for this tool among Royal HaskoningDHV and healthcare facilities. Also sharing knowledge within Royal HaskoningDHV is still a challenge. For fully experiencing the value the collaborative design decision-making tool, critical thinking of Royal HaskoningDHV about a new design strategy and about data sharing is recommended.

9. Conclusion

This research was about identifying the isolation rooms' processes, functions and their dependencies and providing a method for implementing this knowledge in a tool improving collaboration in design decision-making.

To review the processes and functions of an isolation room, a FAST diagram is made. For reviewing their dependencies, a distinction is made in relations between alternatives and relations between alternatives and criteria. This research has identified nine incompatible relations between alternatives. The results of this research with regard to the relations between alternatives and criteria are presented by a created Excel sheet, using performance specifications.

To review the implementation of this knowledge in a tool improving collaboration in design decision-making, a list of six boundary conditions and six requirements is created. Besides that, a recommendation is given for the software structure using a use-case diagram.

Despite the identification of the basis of the design process of an isolation room, extended and more in depth research about this aspect is recommended. Besides that, extended research about the implementation of this design system in a collaborative design decision-making tool, using the identified conditions and requirements, is recommended.

The findings of this research should not only be seen as the first step needed for further developments of digital engineering, but also as a contribution to a better healthcare. Let's hope that with mutual understanding of the hospital and the designer, the risk of a disaster like the outbreak of the Norovirus, as described in the introduction, will mitigate.

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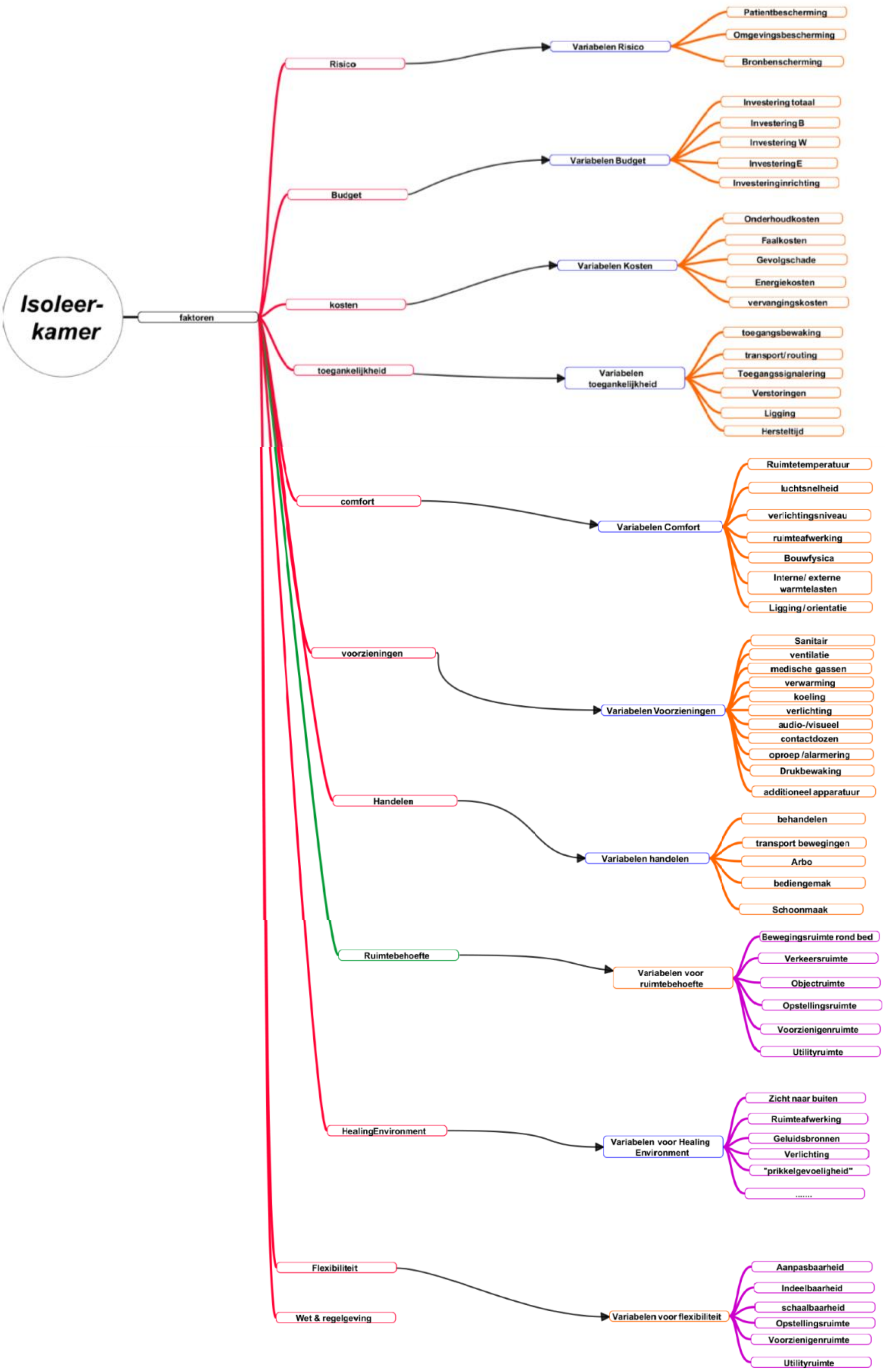
Appendix A

In collaboration with Royal HaskoningDHV, the following concept thoughts are identified.



Appendix B

Background of the interviewee (Example)
This interview will be conducted with [Name], [function]. [Name] has expertise in [expertise].

Objective of the interview
The overall objective is; Enhancing collaboration with the client in decision-making in the early design stage, by identifying feasible solutions and their consequences resulting from the process-based design of an isolation room. So, the first step is identifying the processes that take place in an isolation room, according to the isolation rooms' interest groups. This first step will be the objective of the interview.

Structure of the interview
The structured interview format will be used, in which the main questions are predefined. Because of a possible restricted time period, it is important that the questions cover the whole research field. Even though the main questions are fixed, interaction and flexibility will be key aspects in this interview. This will help in trying to cover all the aspects and processes in isolation rooms. Below the fixed questions, presented further in this appendix, some points that can help as a support during the interview are described. To get a clear picture of the discussed processes and not lose the overview, an A3 paper or whiteboard/screen will be used to take notes during the interview. This overview of notes also has the potential to bring things to mind that weren't thought of in the beginning.

Type of questions and implications
Open questions will be asked, so the interviewees can elaborate on their answers. However, this might make it a little more difficult to compare different interviews. The first two questions will be used as an introduction and to get a better idea of the view the interviewee has on the research area. If permission is given, the interviews are recorded.

To promote interaction and avert the risk of a language barrier, the interview will be executed in Dutch. Because the interview will be done in Dutch, the interview content will be presented in Dutch as well.

Introductie
Introductie van mezelf
Doel van het onderzoek
Doel van het interview
Manier van interviewen, Interview duur, mogelijkheid van geluidsopname
Wat gebeurt er met de resultaten van het interview

Hoe zou je uw werkveld in het kort kunnen beschrijven?

Op welke manier bent u in aanraking geweest met, en heeft u kennis opgedaan over het functioneren van isolatie kamers?
Het lijkt me interessant om de processen in isolatiekamers te doorlopen vanuit drie gezichtspunten. Dit zijn processen met de focus op het gezichtspunt vanuit de patiënt, de business-case vanuit het ziekenhuis (dus vanuit functionaliteit en prestatievermogen), en vanuit het ontwerp aspect. Het zou kunnen dat de geïnterviewde van bepaalde gezichtspunten minder kennis heeft dan van anderen. In dat geval kan diegene dit aangeven en naar beste weten antwoorden. Hier zal dan in verder onderzoek rekening mee worden gehouden.

Wat zit u als het hoofd proces/het meest belangrijke proces in een isolatiekamer?
Dit hangt samen met het doel van de kamer

Wanneer gekeken wordt vanuit het gezichtspunt van de patiënt, wat zijn dan de belangrijkste processen binnen een isolatiekamer?
Processen met betrekking tot de verwachting van de patiënt
Processen met betrekking tot een genezende omgeving
Processen met betrekking tot comfort
Processen met betrekking tot de maatstaven van geschiktheid

Wanneer gekeken wordt vanuit het gezichtspunt van de gebruiker van een isolatiekamer, wat zijn dan de belangrijkste processen binnen een isolatiekamer?
Processen met betrekking tot de kosten
Processen met betrekking tot de service
Processen met betrekking tot handelingen

Wanneer gekeken wordt vanuit het gezichtspunt van de business-case van een ziekenhuis, dus vanuit de eigenaar van de isolatie kamer, wat zijn dan de belangrijkste processen binnen een isolatiekamer?
Processen met betrekking tot de effectiviteit
Processen met betrekking tot de flexibiliteit
Processen met betrekking tot duurzaamheid
Processen met betrekking tot het risico
Processen met betrekking tot onderhoud
Processen met betrekking tot het budget

Wanneer gekeken wordt vanuit het gezichtspunt van het ontwerp, wat zijn dan de belangrijkste processen binnen een isolatiekamer?
Processen met betrekking tot de toegankelijkheid
Processen met betrekking tot de ruimtelijke eisen

Welke functie dragende ontwerp aspecten kunnen de eerder genoemde processen vervullen?

Welke afhankelijkheden tussen processen kunt u naar aanleiding van uw ervaringen identificeren?/ Welke processen zijn met elkaar verweven?

Wat zijn de voordelen of beperkingen van deze relaties?
Relaties kunnen positief of negatief zijn.

Wilt u nog iets toevoegen aan dit interview?
Als de geïnterviewde nog bepaalde opmerkingen heeft die niet direct een antwoord waren op één van de vragen, maar wel interessant zijn voor het doel, geeft deze vraag de mogelijkheid dit te melden.

Afsluiting
Mogelijkheid tot het geven van een korte feedback op het interview.

Appendix C

A summary of the consultation of Gerard Jansen.

About Gerard Jansen

Gerard Jansen is adviser integral building concepts and business developer healthcare at Royal HaskoningDHV. Gerard Jansen has expertise in the field of reliability, energy consumption, sustainability and co-creation with the purpose of optimal facilitating buildings.

Groups that have an interest in the design of an isolation room

Firstly, Gerard Jansen mentions that the hospital programmers from the designing/consulting company, in this case Royal HaskoningDHV, are the people that stand at the top with regard to interest about isolation room design. This group is influenced by the needs of the owners of the room (mostly the real-estate department of a hospital), the users of the rooms and the patients.

The real-estate department is the group communicating with the designers/consultants in the design of an isolation room. This group is guarding the business-case of the hospital with regard to choosing design options, but also listens to the needs of the users and patients. This might however sometimes result in conflicting goals. It might be useful to give all of the isolation rooms every technical installation. Due to the business-case however, technical installations are shared with multiple rooms to reduce the costs.

As mentioned above, another group is the users. These are for example the nurses, the ones who are directly dealing with the functionality of the final design during their work. At last, the patients themselves have an interest in the design of isolation rooms. Quite some research already exists about the patient needs under the name of ‘Healing environment’, so conducting interviews with patients should not be necessary. A literature research about the interests of this group should be sufficient.

According to Gerard Jansen, the isolation room design is however also influenced by the legal framework. People from the healthcare tend to think inside of this legal framework and inside of technical solutions. Also the users tend to think in technical solutions, since they are also thinking inside of this framework. Alternatives are not really mentioned. Take this into account when talking to them.

Identifying processes and functions

Gerard Jansen mentions he can place himself in the shoes of all of the interest groups. The designer needs to combine all the needs and wants to make a profit out of the design project, the owner acts on behalf of the hospital business-case, the user wants to make his work more easy and the patient benefits from a healing environment. However, when identifying what the specific needs of the different interest groups are and which specific processes and functions these groups acknowledge, Gerard Jansen says that this is not really in line with his work. His discipline is more general applicable. When wanting more detailed information about the group hospital programmers (designers), it might be interesting to talk to Rene Emmen, a hospital programmer from Royal HaskoningDHV. When having questions about the relation between designers and the real-estate department of a hospital, it might be interesting to talk to Marianca Leeuwenburg. And to facilitate an expert who knows the view on functionality of isolation rooms with regard to the users, Gerrit Wessels will be contacted. Gerrit Wessels is the head of the real-estate department of ZGT, ‘Hospital group Twente’.

Norms/ quality certification of isolation rooms
There are quite some quality certifications for hospitals and they also evaluate some aspects of isolation rooms. It might be interesting to look at how they test and how they evaluate. There should be some quantitative validation and this might also be done by looking at processes/functions. An example of such a certification is the JCI accreditation. According to Gerard Jansen, Rene Emmen, the hospital programmer mentioned before, might also be interesting to contact about JCI accreditation and its evaluation process.

Application
Gerard Jansen mentions that the 'VU medisch centrum Amsterdam' is interested in getting an overview of different design solutions. But as an addition, they want to compare these design options to multiple norms and quality certification. When identifying feasible design solutions with their characteristics. Linking to norms and quality certification might be a possibility. However, it is important that all the characteristics necessary to validate the design with these norms and quality certifications are taken into account.

Appendix D

A summary of the consultation of Anne Brouwer.

About Anne Brouwer

Anne Brouwer is a consultant at the healthcare department of Royal HaskoningDHV, specialized in integral hospital design projects and implementing healing environment in design solutions. He has experience in design following from the patient needs. Not just on an architectural level, but also the technical aspects. Anne Brouwer has walked along multiple days in a hospital to experience first-hand what really matters in an isolation room.

Interests of the patient

Anne Brouwer agrees with the main functions from the viewpoint of the patient as described in section 3.1 Theory. According to Anne Brouwer, designing with the patient needs into mind might even be more important in isolation rooms than in all other hospital rooms. In an isolation room, the aim is to minimize the visitations from family and friends, but also from nurses. These visitations are strictly regulated because of the contamination risk. Besides that, patients are not allowed to leave the isolation room. They are contained in the small room for multiple days or weeks, which can result in a feeling of boredom and depression. This is why the environment of an isolation room is so important. It doesn't have to be that difficult, when searching for the needs of the patient. Creating an attracting environment is actually every days' business. We are for example constantly adjusting the temperature and the lighting in our house, we make sure our garden looks nice. It is just logic thinking. The goal is pretty simple: Within an isolation room you want to create a homely atmosphere within the constraints of safety and budget.

Some statements about the identified functions of the patient as given by Anne Brouwer:

- Guarantee safety and prevent medical errors are functions also of interest of the hospital itself.
- Comfort. Besides the functions that are mentioned, patients also really look forward to their meals. You can almost describe it as the highlight of the day. A nice meal can positively change the mood of a patient. However, this interest doesn´t really apply to isolation room design. However there should be a way to transfer the meal to the patient.
- Connect patient. Especially with friends and family, but also with nurses. Nurses themselves also think interaction is important when checking the status of patients. The value interaction by visitations is contrary to the value of safety, contamination risk. That is why indirect contact is also possible, using for example a webcam.
- Self-control. Especially in the Netherlands, self-control is a critical aspect when talking about a healing environment. Dutch people like having control over their surroundings and like to do things themselves. A technical solution preventing contamination and providing control might be found in a system with basic self-care. Easy medical actions, like taking pills and measuring patient temperature, can sometimes be done by the patient themselves with a nurse just monitoring and giving advice from outside of the room or using an automated system. This will result in a lowered contamination risk. However, this is contradicting the value of direct interaction and direct monitoring.
  Another technical solution of self-control might be a graphic screen controlled by the patient with possibilities to provide interaction, receive mail, requesting medical info, display calming pictures or provide entertainment.
- Continuity. It is important that technical systems do not fail. When for example a button to call the nurse is malfunctioning, the patient can feel unheard or even panic. All systems have to be technically correct.

Anne Brouwer states: A healing environment can be linked to almost all technical design aspects.

Anne Brouwer tells he conducted a workshop about the interests of the patient with regard to the indoor climate in the Prinses Máxima Centrum. Main points that came out of this research that might also be applicable for isolation rooms are the following:

- Fresh air
- Draft-free ventilation system
- Easy handling, self-regulated temperature as an option
- Pre-programmed basis temperatures
- Daily rhythm in light and temperatures
- Self-regulated light
- Different lights for different moments
- One button for emergency situations, resulting in maximum lighting
- Controllable sun shades at the windows
- Orientation lights at night
- Minimizing noise (for example from ventilation)
- Homely feeling

Interests of the owner

At this moment hospitals are still a bit reserved when talking about the implementation of aspects resulting from a healing environment. The term is often used at the front end, but has a low priority during the actual design process. This is partly because the results of a healing environment are hard to quantify. Also, the system of the Dutch health insurance companies does not focus on long term health. According to Anne Brouwer, the client primarily focusses on the costs and with regard to isolation rooms and on safety, the contamination risk. All the rest is a side issue, even the value of sustainability. An isolation room uses of course a lot of energy to maintain the air pressure. Even though the techniques and insights do exist to provide sustainability and low costs side by side, Anne Brouwer states that the client does not see it this way at this moment.

Interests of the designer

Even though the WIP doesn´t exist anymore, Anne Brouwer says that these requirements still are used as technical boundary for isolation room design. However, these requirements are not well-grounded. For example the interlock-time, this is the time between opening the doors of the air-lock from an isolation room. There is no strict requirement for a minimal interlock-time relating to air-lock characteristics. This time is needed to prevent contaminated air to flow in or out of the room and depends on the size of the air-lock and the ventilation power. Ventilation power however in conflict with sustainability, air-lock size is in conflict with efficient space use and time is in conflict with hospital staff efficiency. This makes interlock-time versus contamination risk a difficult decision concerning design.

Another example is the fact that the bed needs to be able to ride in and out of the room. However, the bed does not necessarily have to go through the air-lock since the patient most of the time only enters or leaves the room in the beginning and end of the isolation treatment. This makes a second door next to the air-lock, big enough for the bed, another design possibility. Isolation rooms are not always in use. This second door also provides flexibility, since this door provides easy access when the room is used as normal patient room.

Sometimes the contaminated patient has to leave the room for research or treatment, resulting in contamination risks. To prevent this, more flexible isolation rooms can be made. Anne Brouwer tells that flexible patient rooms, also sufficient for patient treatment, are recently realized at the Erasmus MC and that this might also be an interesting possibility for isolation rooms. Due to the costs of the installations that are not efficiently used, heavy medical operations or CT-scans cannot be included in the flexible design. How strict a hospital needs to deal with a patient may depend on the level of contamination risk from a certain patient, which can highly differ.

Anne Brouwer states that Royal HaskoningDHV has no interest in the design of an isolation room themselves. Royal HaskoningDHV just looks independent at the interests of the patients, users and owners, without any collaboration with technical or material suppliers that might result in design preferences. Royal HaskoningDHV does however try to help the client with the decision making process and fitting the design into existing legal requirements.

Appendix E

A summary of the consultation of Marianca Leeuwenburg – Boonk.

About Marianca Leeuwenburg – Boonk

Marianca Leeuwenburg – Boonk is a hospital planner at Royal HaskoningDHV specialized in the applying the needs of the user in hospital design.

Interests of the user

According to Marianca Leeuwenburg – Boonk, an isolation room can be seen as a patient room with just an additional layer of functions on the management level. However, the basic functions of the room are the same as the functions needed in a normal patient room. In this way, the users of a normal patient room are also in basis the users of an isolation room. However, in an isolation room visitations from these users are minimalized. Marianca Leeuwenburg – Boonk has identified the following users for a patient room:

- Nurse
- Specialist (visit)
- Assist-employee
- Nutrition assistant
- Manager / Head of department
- Activity supervisor
- Secretary
- Cleaner
- Doctor assistant
- Co-assistant
- Physiotherapist

When looking at the processes that take place inside of these rooms with regard to the users, Marianca Leeuwenburg – Boonk states they can be divided in processes following from the patient recovery cycle and supporting processes. These processes can be influenced by design or by the hospital culture. Processes following from the patient recovery cycle as experienced by the users are as follows:

- Receive/dismiss patient (Design)
- Inform / guide patient (Hospital culture)
- Explain admission and stay (Hospital culture)
- Registration patient data (Design)
- Doctor/medical staff visitation (Design)
- Minor interventions (Design)
- Research patient (Design)
- Enter information / record file (Design)
- Rehabilitation exercises on bed, out of bed (Design)
- Physical therapy, limited (Design)
- Receiving visitations (Design)
- Receiving presents (Design/Hospital culture)
- Sanitary process (Design)
- Wash patient, on bed or in sanitary (Design)
- Monitoring the patient (Design)
- Transport patient (Design)

Supporting processes as experienced by the users are as follows:

- Dressing and undressing patient (Design)
- Providing food/medication (Design)
- Providing medication (Design)
- Change laundry (Design)
- Disposal of waste / medical waste (Design)
- Cleaning (Design)
- Supply of medicines / disposables (Design)
- Supply food (Design)
- Doing the dishes (Design)
- Clean bed (Design)

Interests of the owner
According to Marianca Leeuwenburg – Boonk, flexibility is an aspect that is important from the viewpoint of the owner. Because isolation rooms are not always needed and space need to be used efficiently, hospital owners want to use the empty rooms for something else, for example for normal hospital nursing rooms.

Interests of the designer
Marianca Leeuwenburg – Boonk states that the design process of an isolation room could be for a large part generic. Almost all processes needed inside the room are for every design the same. However, small design changes and side conditions can have big consequences. This makes it difficult to document existing knowledge and data. Knowledge, based on experience, is mostly inside of the heads of the designer.

It might be interesting to organize a meeting with experts from different backgrounds that are linked to isolation room design. For example pulling together a consultant, a hospital planner, an architect, an installations adviser, an engineer and a logistic expert. Only then you have all the knowledge together in one room.

Appendix F

A summary of the consultation of Frans Lenting.

About Frans Lenting

Frans Lenting is a project manager at Royal HaskoningDHV for projects in the health-care industry with regard to installations. Frans Lenting is the editor of the knowledge document for isolation room design recently used by all projects within Royal HaskoningDHV relating to isolation rooms.

Interests of the user

To prevent contamination, users in isolation rooms need to follow protocols. These protocols influence design. During the design process of an isolation room, some standard protocols are taken into account. These standard protocols are in the heads of the designers, resulting from their experience. Besides that, the quality of the design is guarded by discussions with the client. The protocols from specific hospitals are unknown. Frans Lenting states that talking with the hygiene-service of a hospital can be interesting when interested in these protocols.

According to Frans Lenting, the pressure hierarchy of an isolation room, using a negative or positive pressure, has not that much of an influence on the actions of the users of an isolation room. However, some functions can be carried out a bit differently. For example, determining the location for waste disposal or a bedpan washer. In a positively pressured isolation room, these facilities could be placed outside of the protected area. In a negatively pressured isolation room however, these objects are labelled as contaminated and need to be placed inside of the room or in the air-lock.

Interests of the owner

Frans Lenting tells that lowering the risk of air contamination can be divided into several sub functions like pressurizing the room, minimalizing air penetration through the walls or through openings in the rooms like doors and filtering the air. It is possible to see an isolation room as three different rooms who all have their own functions; the air-lock, the wet cell (bathroom/sanitary) and the patient room itself. These rooms all have their own pressure hierarchy. This air pressure itself is important for design aspects, especially the size of the rooms, since bigger sized rooms result in more air that need to be pumped around. Pumping around air has an average price tag of €12,- per cubic meter. However, is important to keep the room big enough for medical equipment. For example, ideally (when looking at contamination risk) a CT-scan has to fit inside of an air-lock. Nevertheless, a hospital sometimes chooses to accept the contamination risk of opening the air-lock doors at the same time or to open a second door as entrance to the room without an air-lock. Also in the patient room itself, space need to be reserved for medical equipment, especially if the room needs to be flexible. For this reason and for the fact that unused equipment is stored in a contaminated area, flexibility in an isolation room is very expansive.

Frans Lenting states that a function that cannot be forgotten is air humidification. The air in a hospital usually is being humidified around a percentage of 45-60 percent. At this percentage, viruses spread the least and contamination risk is the lowest. Besides that, the mucous membranes of humans work better at higher air humidity. This makes patents less capable of contamination. Air humidification is however quite expansive, due to high energy costs. For this reason, some countries like Denmark and Belgium humidify the air less or even not at all.

Interests of the designer

At the end of a design process, Frans Lenting says, the designer should guarantee the safety of his design with regard to air contamination. At this moment, air contamination is mostly taken into account using air-change rates and permeability constraints. It is for the designer important to take into account the settlement of the building with regard to air permeability. After construction, a building can still move a bit due to the applied loads. This may result in a different air permeability of the room. Air flow simulations are not used for isolation room design.

Appendix G

A summary of the consultation of Gerrit Wessels and Rebecca te Riet.

About Gerrit Wessels and Rebecca te Riet

Gerrit Wessels is the head of the real-estate management at the ZGT. He guarantees that the technical input for isolation room within his hospital in relation to their business-case.

Rebecca te Riet is an infection prevention expert at the ZGT. In the past she had been a nurse, but now she trains nurses to deal with preventing contamination in isolation rooms.

Interest of the patient

Even in an isolation room, the healing process from the patient is the most important. This results in the fact that the importance of the contamination risk sometimes comes second. For example, in the ZGT a patient can have permission to go outside of his room. A walk in the park can really help in the recovery of a patient. Also, the physiotherapist can take the patient to the hallway to do some exercises that are impossible in the room itself. Besides that, it can also happen that the patient needs to go outside of the room for other specialized care. These exits all happen according to the protocols and the frequency of these exits depends on the type of patient.

With regard to the importance of the interest of the patient, the ZGT experiences that personal contact with the patient is inseparable from a healing environment. Besides that, when designing a healing environment, it is really important to take into account hygiene, since these two aspects can be in conflict.

Interest of the user

There are a lot of user types when talking about the users of isolation rooms. For example people from the lab, technicians, nurses, doctors, mental health experts, physiotherapists. Basically all the health care groups in the hospital. It depends on the individual patient, which experts need to enter the room during their stay.

The collection of patient data is really important for keeping track of their health process. However in the ZGT, saving data from a patient inside of an isolation room is not done inside of the room. A COW (computer on wheels) is positioned outside of the room. This is done because the hospital cannot afford a COW in every room and disinfecting/cleaning the COW every time it enters or leaves the room is too much work. Gerrit Wessels and Rebecca te Riet think an integrated PC in the bed head panel of isolation rooms is an interesting idea, especially if the display can handle all the cleaning products.

With regard to contact to the patient, two contradicting phenomenon occur. On the one side, intercoms are barely used because they are impersonal and for the patient hard to listen to (they are mostly old people). On the other side, users prevent going in the isolation room during their round because the changing of clothes is a lot of work. Sometimes nurses just make gestures through the small window to check if the patient is okay. Also, medical activities are carried out in one visitation. This happens however more because it saves time and effort than because it prevents contamination.

Interest of the owner
Separation of dirty and clean objects in the air-lock can be hard, especially when the dimensions of the air-lock are small. Storage space inside the air-lock is limited. With regard to preventing contact contamination and the functionality of the air-lock, large dimensions of an air-lock are needed. However, this is in conflict with the risk of contamination by air. Also, a big air-lock can be seen as lost space since the space is occupied just during really small periods of time. In addition, when the isolation room is flexible and used for the purpose of nursing without the need of isolation, the space for the air-lock will become invalid at all. In the ZGT, over half the time an isolation room is used as a normal nursing room. So, a big air-lock is also in conflict with the flexibility of the room.

When designing a second non air-locked door to let through the bed, the air-lock can be smaller. However, this second door has a contamination risk since it may not be locked due to fire measures. This results in the reality that the door is illegally used as an easy entrance. This is the result of the laziness of the users. Besides that, two entrances take a lot of space.
The ZGT is thinking about air-lock lock doors with big windows instead of an interlock system. Using doors with big windows, the user can estimate if the air-lock is safe to enter and leave or not, which results in more comfort for the user. At this moment, the ZGT has air-locks with sliding doors and also with hinged doors. They found out that manually opening these doors is experienced by the users as heavy work, resulting in physical complaints and even absenteeism. Automatic doors are however expansive.
For the protocol of entering and leaving the air-lock, the WIP guidelines are used. Even though they are old, the guidelines are still sufficient for guarding the contamination risk. When the protocols are followed, the contamination risk is sufficiently limited.

With regard to a flexible interior, besides the equipment of the nurses, almost no equipment is stored inside of the room, because of the high costs of this measure. When equipment enters or leaves the room, it should be disinfected. Besides that, disposable equipment is also used to prevent contact contamination.

An efficient way of cleaning a room all in ones is using a machine for the nebulization of hydrogen peroxide. However, not every room can resist hydrogen peroxide fog, especially the ceilings. Also leakage of the room should be really low and the air exhaust should be able to be shut-down in a single room to contain this hydrogen peroxide fog. These are aspects that need to be taken into account when designing an isolation room. For easy cleaning, it is of course also important to minimalize the ridges and edges in an isolation room design.

Monitoring the state of the room is really important. ZGT expects that in the future, data about the state of the room with regard to for example air pressure or interlock times needs to be captured and saved.

Appendix H

As a basis for identifying the spatial dependencies and consequences of design decisions, an integral design meeting was organized with the title: 'Who cares? – The design process, from knowledge to information'. In this meeting different types of experts were put together to form an integral discussion group. Experts included where; an expert in system thinking, a hospital planner, a hospital architect, a hospital logistic expert and a hospital installation technique expert. After a short introduction presentation, these experts where asked to bring their personal knowledge to the table in identifying the relations and constraints between 2D functional zones in isolation rooms. Also, the consequences from the choices of different function-carriers for these zones where discussed. Questions that where key in this meeting where;

- What should be seen as the most important reference point(s) for isolation room design?
- What interests need to be taken into account in isolation room design?
- Which functional zones can be identified inside of an isolation room?
- What are their geometry, position and spatial conditions?
- What are their relations to law and regulations?

A summary of this meeting is given below.

A summary of the integral design meeting

Reference point of isolation room design: On the one side you can see the bed as reference point of an isolation room and design the whole room in relation to the bed. This is however an ideal situation without spatial constraints. In reality, isolation rooms need to fit within a predetermined physical boundary. This boundary is the cause of the designed walls and columns in the general hospital design phase. During this general hospital design, the detailed content of the interior of isolation rooms is not completely taken into account jet. This is why the room, with the bed as reference point, needs to be optimized using spatial dependencies, taking into account the spatial constraints. Also the hallway and the facade are important for these dependencies between spatial zones. For example a window in the facade has a positive relation to the bedding zone, because of light, view and daily rhythm. In some exceptions, for example a room used for IC (intensive care), this relation is less important. However, when not taken into account, the flexibility of the room purpose is reduced.

At an abstract level, the following zones can be identified: Bedding zone, wet cell zone, air-lock zone, storage medical equipment zone and transport zone.

Bedding zone: It is important to give a clear definition of the bedding zone. The bedding zone should be seen as the space for the bed, plus the bed head panel, plus space needed to walk/work around the bed. It can be stated that the bedding zone includes the whole area that moves directly with the bed, if the bed is designed differently.
In a patient room, the bedding zone is always against a wall, to make sure the bed head panel can be linked to the electricity network and other external networks. However, preferably this wall is not the facade or the wall on the opposite side of the facade due to lighting and logistic reasons. At an IC however, the bedding zone should not necessarily be located against a wall.
The bedding zone includes a PC system, which can be placed in the bed head panel to provide easy cleaning, or can flexible. A flexible PC system is called a COW (computer on wheels). The COW needs however storage inside of the room as a result of contamination measures.
Besides that, the bedding zone has a relation to the air-lock zone and wet cell zone. For example, a nurse needs to have a clear view from the air-lock to the patient bed. Also the walk lines to the

bedding zone are important. The bed site next to the facade is mostly used for comforting the patient and the bed site next to the air-lock is mostly used for storage of medical equipment.

Wet cell zone: A wet cell is preferably not located against the facade. A wet cell against a facade occupies the space that can be used for a window. The wet cell zone is always directly linked to the transport zone or the bedding zone.

Air-lock zone: The size of the air-lock zone is dependent on the choice if the bed needs to be able to go through the air-lock or through another door when entering or leaving the isolation room. When choosing to design a second, non-air-locked door for the bed, the size of the air-lock can be smaller. Nevertheless, it should be taken into account that this second door can take the space of the wet cell, resulting in a wet cell against the facade.
Furthermore, the air-lock should always provide space for medical equipment to get disinfected before entering or leaving the room. The size is also dependant on changing space, storage space and facilities. Due to the comfort of the user and the risk of contact contamination, the air-lock needs to be spacious. However, due to the risk of contamination by air and the long interlock-times, the air-lock needs to be as small as possible.
Besides that, the size of the air-lock zone depends on the used type of doors, hinged or sliding doors. It is important to keep into mind that hinged door create more air movement, resulting in a higher contamination risk. However, for sliding doors a minimum width around 2,4m is needed if the bed needs to go through the door. When a small air-lock is wanted with no space for a bed to pass, a second door is needed.
The air-lock zone is always connected to the transport zone or the bedding zone. There should be a line of sight between the air-lock zone and the bedding zone. However, this line of sight is sometimes realised using cameras.

Storage medical equipment zone: This zone is explicitly important in isolation rooms. Medical equipment can, in contrast to normal patient rooms, not leave the room without getting disinfected or resulting in a high contamination risk. This is why the equipment needs space inside of the isolation room itself. Taking into account the walking lines of the room users, the medical equipment should be stored in between the bedding zone and the air-lock zone, or at least as close as possible to these areas.

Transport zone: The transport zone includes the area for bed transport and the area for walking. The transport zone has no fixed geometry, since it is dependent of the positioning of the other zones. When zones are not connected, the transport zone should link them. When connecting the bedding zone and the air-lock zone, turning circles of the bed needs to be taken into account.

It is difficult to identify the geometry of a specific zone. When you take for example two doctors and ask them about the ideal space they need next to the bed to perform optimal medical handling, they will give different answers. It might be interesting to see design as fixed functional zones, with flexible dimensions and then discuss these dimensions with the client. When the dimensions are known, a parametric design tool can make the ideal configuration of functional zones. Besides that, when talking about functions, we can talk about a generic isolation room. But when talking about geometries of zones, their exist differences between the room purposes. An IC for example has a bigger bedding zone than an patient room. This should also be taken into account.
However, it is interesting to see the impact of spatial constraints on design alternatives. Besides that, it gives also a better picture about the ideal isolation room design configuration, which might be helpful for architects.

Appendix I

A summary of the consultation of Theo Franken.

About Theo Franken

Theo Franken is a control engineer at the healthcare department at Royal HaskoningDHV. Theo Franken has experience in the installation of technical regulating installations.

Performance specification

Theo Franken mentions that, with regard to isolation room design, he only has experience in the sub-function; 'Monitor room pressure'. Regulating air pressure is directly linked to the purpose of mitigating contamination risk. Theo Franken mentions that there are a few things that might be interesting to take into account with regard to monitoring room pressure.

At first, it is quite common that an isolation room is protected by a negatively pressurised air-lock, but pressure in the room itself is the same as the ambient pressure. In this case, the pressure difference can be monitored between the air-lock and the room or between the air-lock and the hallway. A pressure difference between the room and the hallway cannot be measured because there is none. It should be taken into account that this imposes the risk of not knowing the existence of air-leakages between the room and the hallway, which imposes a risk for contamination.

Secondly, there are different pressure monitoring systems. Theo Franken states that he always uses Psidac; a fully digital system, from sensor to display, with a user friendly coloured LCD touchscreen for around €800,-. From his experience he can tell that this system is the best available at this moment with regard to price/performance ratio. However, there are some alternatives. Another room pressure monitoring system is called Kimo; with a sensor implemented in the 2-lined display. The price from this system is almost the same as for the Psidac system, the system is however less user friendly.
The last room pressure monitoring system Theo Franken mentioned is Pedak; an system using analogue signals, with a user friendly TFT Touchscreen. This system is user friendly, but relatively expensive.

Appendix J

A summary of the consultation of Pieter Schreurs.

About Pieter Schreurs

Pieter is specialized in parametric design, BIM and integrated design solutions, from the very early phases of the design process. He is an expert in process and product innovation based on new applications for computer-based design methods.

Implementation of the research

Documentation of a design system can be seen as the basis needed for a parametric design. Parametric design is already used inside of Royal HaskoningDHV. For example to make estimations of large-scale design projects.

An ideal design tool should combine the choice on ‘what to do?’ and ‘where to do it?’ For this design tool, the following three characteristics are key; geometry, position and spatial conditions. First, choices need to be made on what function-carriers are wanted. These decisions are made using criteria and taking into account dependencies and feasibility of solutions. When the content of a design is chosen, the two basis characteristics for the design tool, ‘geometry’ and ‘spatial conditions’, are known. The characteristic ‘geometry’ is the length, width and height needed for a function-carrier to be realized. The characteristic ‘spatial conditions’ includes the dependencies between function-carriers, the dependencies between function-carriers and the surrounding, and the function-carrier characteristics. This characteristic should be determined by a combination of research from theory and practice.

After that, the last characteristic, ‘position’, needs to be determined. When seeing the characteristic ‘position’ as a variable, the alternatives of configurations in the different chosen function-carrier volumes within a given spatial constraint should be researched. This spatial constraint represents the boundaries of a room. According to Pieter Schreurs, using parametric volume planning, a lot of spatial alternatives can be simulated within the spatial constraints of a room. These alternatives can again be evaluated by criteria, taking into account the feasibility of solutions. A software program in which a tool like this can be made is Grasshopper. Grasshopper is able to give restrictions to objects, for example linking them to walls. Dependencies will make sure fewer alternatives are feasible, but do not guarantee one design. When a lot of spatial alternatives are presented in grasshopper, criteria need to be linked to finally decide which alternative in function-carrier configuration is best in a certain case. In this way, all the design decisions can be optimized.

Pieter Schreurs is at this moment working with Jamal van Kastel on the question ‘where to do it?’ with regard to generating alternatives in the configuration of objects. A lab with general objects is used for this project. Pieter Schreurs said it would be interesting to link both of the researches, so the ‘what’ and the ‘where’ question can be combined.

Appendix K

A summary of the consultation of Freerk Hoekstra and Jean-Maurice Kuijpers.

About Freerk Hoekstra and Jean-Maurice Kuijpers

Freerk Hoekstra and Jean-Maurice Kuijpers are both architects who might work with a design decision-making tool within the healthcare department of Royal HaskoningDHV if it were fully functional.

Implementation of the research

Making automatic decisions in where to position the geometries of function-carriers in a design is difficult, because determining the geometry of function-carriers is quite a challenge on itself. Since a function-carrier is connected to a space around it to provide room for usage, the space needed cannot be seen as a fixed parameter within a design tool. For some function-carriers, there does exist regulations about the amount of space around an object, however the users always have another opinion about the space that is really needed.

Besides that, even when only taking into account the space needed by regulations, the geometry of abstract functional zones cannot be specified. This is caused by the fact that the abstract functional zones consist of different function-carriers. These function-carriers can be configured in a lot of different shapes. Especially the air-locks are hard to express in one fixed geometry since the space of this zone has large contradicting values relating to the interest of the client. The only functional zone which might be fixed is the bedding zone, because this zone is not that flexible in configuration.

There does not exist one library with function-carriers or objects and spaces needed to implement them in a design. When designing, geometries are determined specifically for a single project. This is done because there are a lot of alternatives in function-carriers and a lot of differences in wanted extra space around an object.

However, it might be possible to parameterize an isolation room when looking at the level of detail of the specific function-carriers that need to be in the room. The chosen function-carriers should be fixed and the space needed around the specific object should be fixed by assumptions. When a client does not agree with this assumption, the space needed can be changed in the parametric model. From drawings average and expectable geometries can be determined. It is important to note which assumptions are taken for a certain geometry and then identify its values. When first choosing the needed function-carriers with their wanted spaces, an ideal configuration of these spaces can be modeled. If the configuration is not satisfying, changes can be made in geometries or chosen function-carriers.

When searching for an ideal configuration, it should be taken into account that space needed around an specific object is possibly allowed to overlap with the space needed around another object. The space needed for a function-carrier should be defined in; 1) ‘hard’ space needed for the object itself. 2) ‘soft’ space needed for using the object. In the spatial dependencies should be included from which function-carriers the space needed around an object may overlap and from which function-carriers not. In this way, efficient use of space can be parameterized.

Appendix L

Table 13 Functional performance specification

			Performance characteristics		
ID	**Function**	**Function-carrier**	**Criteria**	**Performance level**	**Bandwidth (regulations/ preferences)**
1.	Connect patient (visitations)				
1.1	Interact directly to patient	Space for visitation (chair/table)	Contamination risk	High	
			Comfort patient	High	
			Comfort user	N/a	
			Spatial constraint	Next to the bed side, opposite side of the air-lock	
1.2	Interact indirectly to patient	Webcam system	Contamination risk	Low	
			Comfort patient	Low	
			Comfort user	N/a	
			Spatial constraint	View line to patient bed area	
2.	Comfort patient				
2.1	Reduce noise-level	Sound-absorbing ceilings tiles	Contamination risk	N/a	
			Comfort patient	High	
			Comfort user	High	
		Anti-vibration measures	Contamination risk	N/a	
			Comfort patient	High	
			Comfort user	High	
2.2	Experience daily rhythm	Window	Contamination risk	N/a	
			Comfort patient	High	
			Comfort user	High	
			Spatial constraint	In the facade	
				View line to patient bed area	
		Artificial circadian light	Contamination risk	N/a	
			Comfort patient	Medium/Low	
			Comfort user	Medium	

		Pre-programmed fluctuating temperatures	Contamination risk	N/a	
			Comfort patient	High	
			Comfort user	Medium	
2.3	Amuse patient	Window	View		Nature, people or one that provides information about outside activities (Giplin, 2003)
			Contamination risk	N/a	
			Comfort patient	Medium	
			Comfort user	Medium	
			Spatial constraint	In the facade	
				View line to patient bed area	
		Painting	Content		Nature or people (Giplin, 2003)
			Contamination risk	N/a	
			Comfort patient	Medium	
			Comfort user	Medium	
			Spatial constraint	View line to patient bed area	
		Interacting screen and control panel	Contamination risk	N/a	Possible combination with 1.2
			Comfort patient	Medium	
			Comfort user	Medium	
			Spatial constraint	Straight view line to patient bed area	
2.4	Calm-down patient	Window	View		Nature, people or one that provides information about outside activities (Giplin, 2003)
			Contamination risk	N/a	
			Comfort patient	Medium	
			Comfort user	Medium	

			Spatial constraint	In the facade	
				View line to patient bed area	
		Painting	Content		Nature or people (Giplin, 2003)
			Contamination risk	N/a	
			Comfort patient	Medium	
			Comfort user	Medium	
			Spatial constraint	View line to patient bed area	
		Interacting screen and control system	Contamination risk	N/a	Possible combination with 1.2
			Comfort patient	Medium	
			Comfort user	Medium	
			Spatial constraint	Straight view line to patient bed area	
		Hidden technical elements	Contamination risk	High	
			Comfort patient	High	
			Comfort user	Medium	
3.	Self-control environment				
3.1	Self-control temperature	Control panel	Contamination risk	N/a	
			Comfort patient	High	
			Comfort user	Medium	
			Spatial constraint	Next to patient bed area	
3.2	Self-control lighting	Control panel	Contamination risk	N/a	
			Comfort patient	High	
			Comfort user	Medium	
			Spatial constraint	Next to patient bed area	
4.	Nurse patient	Patient bedding area	Size [mm]	Width: 3400 Length: 3150	
			Spatial condition	Against a wall (for normal patient room)	Preferably not the facade or wall opposite to the facade

4.1	Sanitize patient	Space for toilet (possibly combined with 4.2)	Air exhaust [m3/h]		75-100 (Lenting, 2017)
			Size [mm]	Width: 900 Length: 1200	
			Spatial condition	Against a wall	Preferably not the facade
				Enclosed by walls (possibly combined with 4.2)	
		Tap/sink system			
4.2	Wash patient	Space for shower (possibly combined with 4.1)	Air exhaust [m3/h]		75-100 (Lenting, 2017)
			Spatial condition	Against a wall	Preferably not the facade
				Enclosed by walls (possibly combined with 4.1)	
4.3	Research patient	Space for research patient	Size	Included in size, nurse patient	
4.4	Exercise patient	Space for (limited) exercise patient	Size	Included in size, nurse patient	
4.5.1	Monitor patient direct	No specific function-carrier	Contamination risk	High	
			Comfort patient	High	
			Comfort user	Medium	
			Spatial constraint	View line to the bed area	
				Within the wall connected to the hallway	
4.5.2	Monitor patient indirect	Webcam System/ look through in wall or door	Contamination risk	Low	
			Comfort patient	Low	Especially no comfort of old patients
			Comfort user	Low	
			Spatial constraint	View line to the bed area	
4.6	Transport patient	Bed on wheels	Contamination risk	High	
			Comfort patient	Low	
			Comfort user	Low	
			Spatial constraints	turning circles of the bed	

4.7	Perform medical actions	Space for medical actions around the bed	Size	Included in size, nurse patient	
5.	Support patient nursing				
5.1	Inflow products	Inlet room	Contamination risk	High	
			Comfort patient	Medium	
			Comfort user	Medium	
5.2	Outflow waste	Outlet room	Contamination risk	High	
			Comfort patient	Medium	
			Comfort user	Medium	
		Bedpan washer			
5.3	Automated basic care	Basic care system	Contamination risk	Low	
			Comfort patient	Low	
			Comfort user	Low	
6.	Prevent medical errors				
6.1	Illuminate medical actions	Extra light for medical actions	Illuminance [lx]		Minimal 1600 (Huisman et al., 2012)
			Contamination risk	N/a	
			Comfort patient	High	
			Comfort user	High	
6.2	Record patient data	PC in bed head panel	Contamination risk	Low	
			Comfort patient	N/a	
			Comfort user	Medium	
		COW (computer on wheels)	Contamination risk	High	
			Comfort patient	N/a	
			Comfort user	High	
7.	Flexible/ standardised room interior	Extra space for medical equipment	Contamination risk	Low	
			Comfort patient	High	
			Comfort user	High	
8.	Mitigate air contamination				
8.1	Pressurize room	Air supply diffusers	Air change rate per hour	8	Minimal 6 (Lenting, 2017)

		Constant Air Volume controller			
		Overflow valves			
8.1.1	Monitor room pressure	Psidac system	Display	LCD Touchscreen	
			Possible displayed parameters	1	
			Input from sensor	Digital (MOD-bus)	
			Typical accuracy	0,5 pa (full range)	
			Cost (sensor + display)	€800,- *	
			Comfort user	High	
		Kimo system	Display	2-line display/ buttons	
			Possible displayed parameters	3	
			Input from sensor	Integrated in display	
			Cost (sensor + display)	€800,- *	
			Comfort user	Medium	
		Pedak system	Display	TFT Touchscreen	
			Possible displayed parameters	4	
			Input from sensor	Analog	
			Cost (sensor + display)	€1300,- * (Pedak helpdesk, 2018)	
			Comfort user	High	
8.2.1	Minimalize permeability walls	Window	Layers	3	Minimal 3 (Lenting, 2017)
			Openable	No	No (WIP, 2014)
		Facade	Percentage air leakage from air supply		Maximal 5% (WIP, 2014)
		Wall	Percentage air leakage from air supply		Maximal 5% (WIP, 2014)
			Leakage class		L00 or Lo (Lenting, 2017)

8.2.2	Minimalize permeability by input/output	Relatively big air-lock	Air change rate per hour		Minimal 10 (Lenting, 2017)
			Size [m]	Width: 1,2 (in case of hinging doors) 2,4 (in case of sliding doors)	
			[m^2]	> 2,6 'More space for efficient functional use'	'Big enough for medical equipment (closed doors)' (WIP,2014)
			Contamination risk	By air: High, by contact: Low	
			Comfort patient	N/a	
			Comfort user	Low (long interlock-time)	
			Spatial constraints	Clear view line to bed	
				Against the wall next to the hallway	
		Relatively small air-lock	Air change rate per hour		Minimal 10 (Lenting, 2017)
			Size [m^2]	< 2,6	'Big enough for medical equipment (closed doors)' (WIP,2014)
			Contamination risk	By air: Low, by contact: High	
			Comfort patient	N/a	
			Comfort user	Normal	
			Spatial constraints	Clear view line to bed	
				Against the wall next to the hallway	
				Second door for entrance bed needed	
		Optional extra door without air-lock	Contamination risk	High	'Sensitive for abuse in use'
			Comfort patient	N/a	
			Comfort user	High	

8.3	Minimalize air circulation (inside the room)	Air return grills	Size grills	Dependent on room design, simulation of airflow needed	
		Variable Volume controller			
8.4	Filter/clean air	HEPA filter (H14)	Percentage eliminated particulate matter (0,3 µm)	99,975% (EN 1822)	
			Maintenance	Validating every year	Prevent polluted filter, results in pressure change/ accumulation of bacteria (Lenting, 2017)
		Plasma/ isolation air cleaner (ASPRA)	Filter efficiency	95-99% (Lenting, 2017)	
8.5	Humidify air	Airwasher	Mobility	Small and mobile	None
		Central hospital air humidifying system			
9.	Mitigate contact contamination				
9.1	Clean/disinfect room	Smooth edges			
		easy-to-clean material			
		photocatalytic antimicrobial coating	Years active	1-5	Minimal 1 (Lenting, 2017)
9.2	Clean/disinfect users	Tap/sink System	Spatial constraint	Close to user walk-lines	
		Disinfecting gel dispensers	Spatial constraint	Close to user walk-lines	
		Space for PPE	Spatial constraint	Close to user walk-lines	
9.3	Store medical equipment	Space for medical equipment	Spatial constraints	In between bedding zone and air-lock	

Appendix M

This appendix will explain in four steps how the Excel sheet that gives the consequences of choosing design alternatives works.

Step 1.

The first step is the selection of an alternative in a drop down list. This is done with the Excel function 'data validation', validation criteria: Allow = 'list', Data = 'between', Source = 'cells_alternative[x]'.

Step 2.

When selecting an alternative, Excel needs to know which data it should use. The relations described by '+' and '-' in the interaction table are diverted to '+1' and '-1'. To select data, three helpers are used, Figure 12.

'Helper 1' gives a number to each row of data.

'Helper 2' consists of the following formula;

=IF('selected_alternative'='alternative_in_this_row';'number_helper_1';""). This helper shows only the numbers of the selected alternatives. In the case of Figure 12, the chosen alternatives are: b1, a2, b3, a4, a5, b6, a7, etc.

'Helper 3' consists of the following formula;

=IFERROR(SMALL('rows_helper_2';ROWS('rows_helper_2':'cell_helper_3'));""). This helper orders all the numbers of helper 2 in one column.

Now Excel knows which data to extract out of the matrix.

		C1	C2	C3	C4	C5	C6	C7	Helper 1	Helper 2	Helper 3
Alternative [1]	a1. No extra measures for healing environment	-1	-1	1	-1				1		2
	b1. Extra measures for healing environment	1	1	-1	1		-1		2	2	3
Alternative [2]	a2. No extra measures to prevent medical errors	-1	-1	1	-1				3	3	6
	b2. Extra measures to prevent medical errors	1	1	-1	1				4		7
Alternative [3]	a3. No self-control patient	-1		1		-1		-1	5		9
	b3. Self-control patient	1	-1	-1	1	1		1	6	6	12
Alternative [4]	a4. No flexible room purpose			1	-1				7	7	14
	b4. Flexible room purpose			-1	1	-1			8		17
Alternative [5]	a5. Interact directly to patient	1				-1		-1	9	9	19
	b5. Interact indirectly to patient	-1		-1	1	1		1	10		21
Alternative [6]	a6. Automated basic care	-1	-1	-1	1	1		1	11		24
	b6. Inflow products/ outflow waste					-1			12	12	26
						-1			13		
Alternative [7]	a7. Monitor patient direct	1				-1		-1	14	14	
	b7. Monitor patient indirect	-1	-1	-1	1	-1		-1	15		
Alternative [8]	a8. Transport patient	-1	-1		-1	-1		-1	16		
	b8. Flexible/standardised room interior	1	1	-1	-1	1	1		17	17	
Alternative [9]	a9. Psidac pressure monitor system		1			1			18		
	b9. Kimo pressure monitor system					1			19	19	
	c9. Pedak pressure monitor system		1	-1		1			20		
Alternative [10]	a10. PC integrated in bed head panel						1		21	21	
	b10. COW (Computer on wheels)		1				-1		22		
Alternative [11]	a11. No extra door without air-lock		-1	1		1			23		
	b11. Extra door without air-lock		1	-1		-1			24	24	
Alternative [12]	a12. Relatively small air-lock (< 3m^2)			1	1	1		-1	25		
	b12. Relatively big air-lock (> 3m^2)		-1	-1	-1	-1		1	26	26	

Figure 12 Sorting data

Step 3.

Excel makes a new matrix from the chosen alternatives. To do so, the following formula is used; =INDEX('rows/columns_data_matrix';'number_helper_3';COLUMNS('selected_range')). The function INDEX returns a value or the reference to a value from within a table. In this case, the formula gives all values from the interaction matrix from the rows presented in 'Helper 3'. This data is presented in a new matrix, Figure 13.

		C1	C2	C3	C4	C5	C6	C7
b1. Extra measures for healing environment		1	1	-1	1	0	-1	0
a2. No extra measures to prevent medical errors		-1	-1	1	-1	0	0	0
b3. Self-control patient		1	-1	-1	1	1	0	1
a4. No flexible room purpose		0	0	1	-1	0	0	0
a5. Interact directly to patient		1	0	0	0	-1	0	-1
b6. Inflow products/ outflow waste		0	0	0	0	-1	0	0
a7. Monitor patient direct		1	0	0	0	-1	0	-1
b8. Flexible/standardised room interior		1	1	-1	-1	1	1	0
b9. Kimo pressure monitor system		0	0	0	0	1	0	0
a10. PC integrated in bed head panel		0	0	0	0	0	1	0
b11. Extra door without air-lock		0	1	-1	0	-1	0	0
b12. Relatively big air-lock (> 3m²)		0	-1	-1	-1	-1	0	1

Figure 13 Matrix of selected data

Step 4.

Finally, the scores of the consequences to design criteria need to be assigned. These scores are values in between 0 and 10. Input for these scores is the SUM of the '+1' and '-1' values from the alternatives. Because not all criteria have the same range in amount of possible '+1's and '-1's, every criteria has its own diversion formula to make sure the scores are equally divided between 0 and 10, Figure 14. The final score on each criterion can now be given when making selections in alternatives. Scores are rounded off to whole numbers.

Scores on design consequences are equally divided between 0 and 10. This means that when few alternatives influence a certain criteria, the steps between scores are bigger, which suggests the impact of a change in alternatives is bigger. This is however not the case since the scores just give a comparison between alternatives, not an amount of performance.

Max '+1'	Max '-1'	Formula	Criteria	Score
6	-7	((SUM('Data_criterion')+7)/13*10)	Comfort patient	[-]
6	-8	((SUM('Data_criterion')+8)/14*10)	Comfort user	[-]
6	-11	((SUM('Data_criterion')+11)/17*10)	Reduce investment	[-]
8	-6	((SUM('Data_criterion')+6)/14*10)	Reduce costs	[-]
5	-8	((SUM('Data_criterion')+8)/13*10)	Mitigate air contamination	[-]
2	-2	((SUM('Data_criterion')+2)/4*10)	Clean/ disinfect room	[-]
4	-5	((SUM('Data_criterion')+5)/9*10)	Clean/ disinfect users	[-]

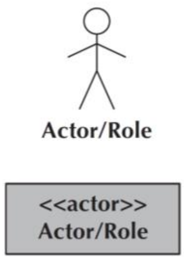
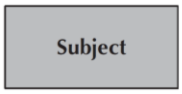
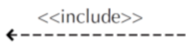
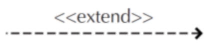
Figure 14 Assigning scores

Appendix N

A use case diagram is used to display the system of a software tool, because it is an abstract way to better understand the functionality of a system. The diagram is useful for defining requirements because it is a clear way of communicating exactly what a system needs to do. It is an advantage that the use case diagram, unlike many other diagram techniques, is composed of narrative text. In this way the system can be better understood by non-technical stakeholders. This means that feedback for the tool can be obtained at an early stage of development from customers and users.

The elements of a use-case diagram are actors, use cases, system boundaries and a set of relationships. Each of these elements is described in Table 14.

Table 14 Elements of a use case diagram (Dennis, Wixom, & Tegarden, 2015)

Element	Symbol
Actor: - A person or system that interacts with the system. - Is depicted as either a stick figure or, if the actor is nonhuman, a rectangle with <<actor>> in it. - Is placed outside the system boundary.	
Use case: - Represents a major piece of system functionality. - Can extend or include another use case. - Is placed inside the system boundary. - Is described by a verb-noun phrase.	
System boundary: - Depicts the name of the system inside and on top. - Represents the scope of the system.	
Association relationship: - Links an actor with the use case/use cases with which it interacts.	
Include relationship: - Represents the inclusion of the functionality of one use case with another. - Has an arrow drawn from the base use case to the used use case. - Is depicted with the text *include* or *use.*	
An extend relationship: - Represents the extension of the use case to include optional behavior. - Has an arrow drawn from the extension use case to the base use case. - Is depicted with the text *extend* or *return.*	

Within this use case diagram, the area which is covered by this research is marked red. However, due to the abstraction level of this research, further research in this area is still necessary before realising the tool. Also, research about the validity of the use-case diagram is needed before further transforming the diagram in a software tool. The use-case diagram is described and presented below.

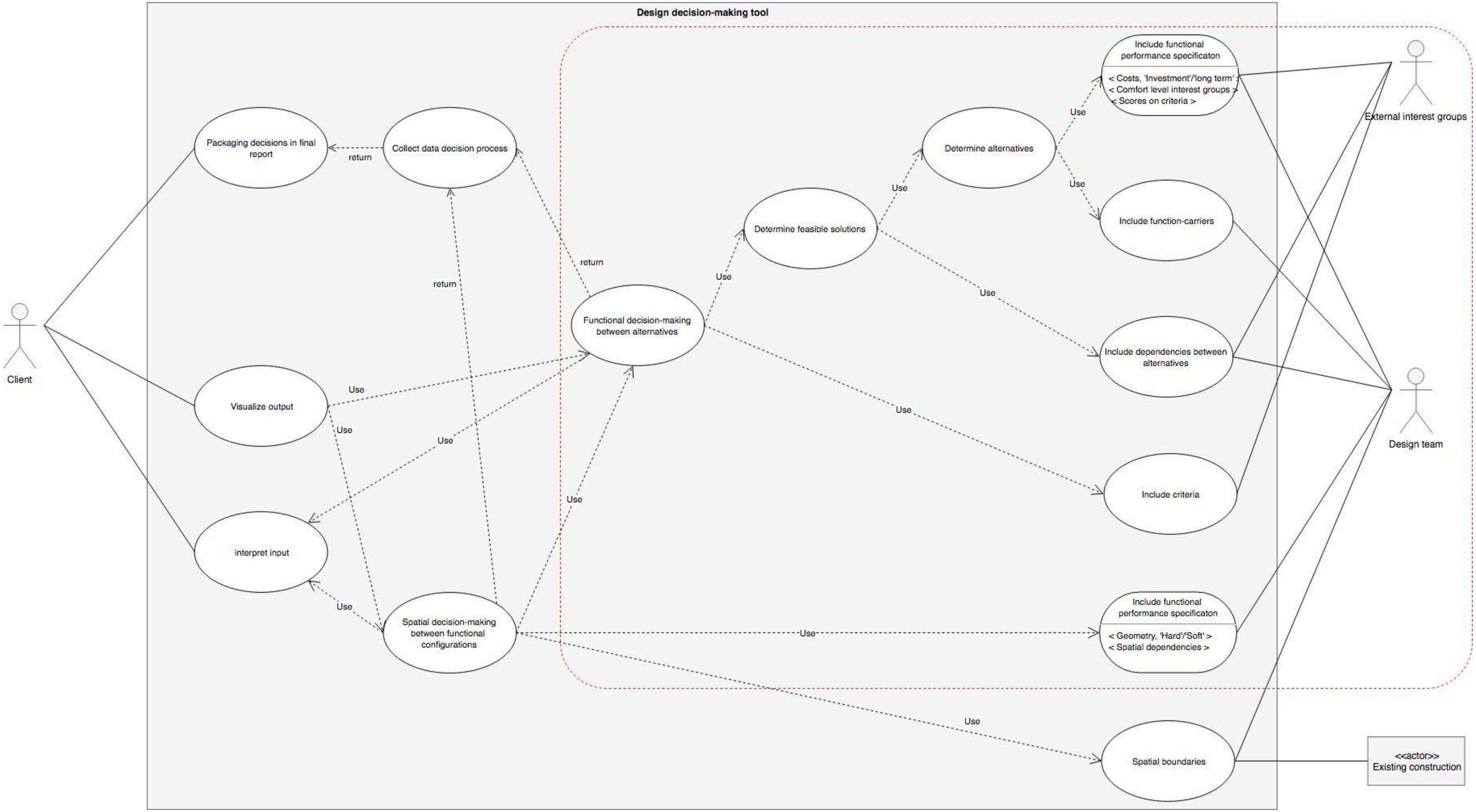
Objective use-case diagram:

The client in this use-case diagram has the need of getting insight in the design decision-making

process. A collaborative, client orientated design process will enhance the understanding between the client and Royal HaskoningDHV. The use-case diagram presents a tool which will directly show the consequences of different alternatives and will give freedom of choice on essential design criteria. This makes it possible for the client to co-create his own spatial design and give feedback easily and quickly. The use-case diagram of a design decision-making tool is the basis for an interactive, information driven solution generator, responding to client input and presenting design consequences of the decisions made in terms of scores on criteria and spatial configurations.
The design of concern is in this case an isolation room, but the use case diagram and the conditions/requirements are generative for other design projects.

Use Case Breakdown

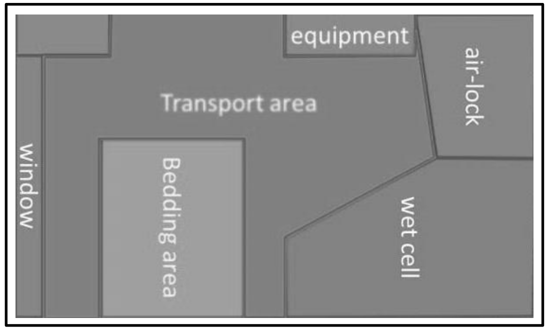
1. The primary actor of the system is the *Client*. The client initiates the use of the system and is the actor the system is made for. The secondary actors of the system provide input so the system is able to work. The secondary actors are *External interest groups*, for example the users and the owner of a design, the *Design team*, for example architects, cost management experts, technical installation experts, and the *Existing construction*. The existing construction is a possible actor; the system can also work without this actor, but if it exists its input is needed.
2. The client is in three ways connected to the system of the tool. Firstly, the client gives input to the system, giving his preferences in design aspects. This input should be interpreted by the system. Secondly, the system gives output to the client by visualisation of design consequences. And thirdly, the system could give output to the client by a final decision report.
3. The input of the clients is used by two different use cases, *Functional decision-making between alternatives* and *Spatial decision-making between functional configurations*. First, the tool should facilitate the functional decision-making between alternatives, since the made decisions from this use case are input for the decision-making between functional configurations.
4. Besides the input from the client, the use-case *Functional decision-making between alternatives* uses the feasible solutions with their function-carriers and performance specifications, and the design criteria as input. By combining these three elements, consequences of decisions can be visualised and adjustments in decisions can possibly be made.
5. The use-case *Determine feasible solutions* uses the alternatives and the dependencies between alternatives as input. By knowing which alternatives are incompatible, the feasible solutions and their functional performance is known.
6. The use case *Determine alternatives* uses the functional performance specification and the function-carriers as input. When function-carriers have the same functional performance specification, they can be grouped in one alternative.
7. From the results of point 3, the chosen function-carriers are used as input for the use case *Spatial decision-making between functional configurations.* To analyse spatial consequences, these function-carriers need to be combined with their functional performance specifications about geometry and spatial dependencies. Also the boundary in which the design should be realised, if present, is needed as input.
8. Finally, the system has the possibility to log the decision process in the use case *Collect data decision process.* The history of the functional decision-making between alternatives and the history of the spatial decision-making between functional configurations is recorded in this use case, so lessons can be learned from the decision process. A final report can be made from this collected data. An example final report is made in Appendix O.


Design decision-making tool
Client
Packaging decisions in final report
return
Collect data decision process
Visualize output
Use
Use
Use
return
interpret input
Use
Spatial decision-making between functional configurations
return
Functional decision-making between alternatives
Use
Use
Determine feasible solutions
Use
Determine alternatives
Use
Use
Include functional performance specificaton
< Costs, 'Investment'/'long term' >
< Comfort level interest groups >
< Scores on criteria >
Include function-carriers
Use
Include dependencies between alternatives
Use
Include criteria
Use
Include functional performance specificaton
< Geometry, 'Hard'/'Soft' >
< Spatial dependencies >
Use
Spatial boundaries
External interest groups
Design team
<<actor>>
Existing construction

Appendix O

Selected design decisions -> Consequences spatial configuration

+ + + + + =



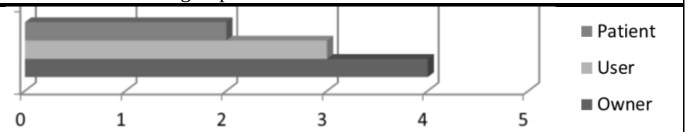
Main effects on hospital business-case

Positive	Negative
-	-
-	-
-	-
-	-

Main effects on certifications/accreditations

Possible certifications/accreditations	Excluded certifications/accreditations
-	-
-	-
-	-
-	-

Functional performance specification

			Performance characteristics			
ID	Function	Function-carrier	Criteria	Performance level	Bandwidth/regulations	Satisfaction interest group
-	-	-	-	-	-	
			-	-	-	
			-	-	-	
-	-	-	-	-	-	-

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Result overview design decisions isolation-room

[Client x]

Project nr.	26
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