

# Technische Universität München

Ingenieur fakultät Bau Geo Umwelt

Lehrstuhl für Bauphysik

## Future Facades – a User-Centered Approach to User-Specific Functionalities and Design Features.

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Vollständiger Abdruck der von der Ingenieur fakultät Bau Geo Umwelt  
der Technischen Universität München zur Erlangung des akademischen Grades eines  
**Doktor-Ingenieurs (Dr.-Ing.)**  
genehmigten Dissertation.

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Die Dissertation wurde am 21.01.2019 bei der Technischen Universität München eingereicht und durch die Ingenieur fakultät Bau Geo Umwelt am 22.03.2019 angenommen.

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Viktorija P. Krastel, M.Sc.

Dissertation

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FUTURE FACADES

# **A user-centered**

Approach to user-specific  
functionalities and design features.





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# THANK YOU.

First of all, I would like to express my sincere gratitude to my advisors Prof. Dr.-Ing. Klaus Sedlbauer and Prof. Dr.-Ing. Winfried Heusler. Throughout the project, the two supported my work via inspiring discussions and helpful words that made me think outside the box. Comments like “One more thought, ...” enriched this dissertation and ensured me that questioning something is the best way to understand it. Thank you!

Furthermore, I would like to thank Dr. Roland Göttig, Sylvia Goletz and all my colleagues at the Chair of Building Physics at TUM. They had my back during the last two and a half years. Without all of them, this dissertation would have not been realized at the pace as it did. A special thanks goes to my partner in crime, Mai-Khanh Nguyen, for passionately discussing even my smallest thoughts and keeping me company in Bielefeld.

Moreover, I would like to thank all of my friends. Over the past ten years former fellow students have grown into today's close friends. We worked our way through days and nights, sharing the good and the bitter moments. All in all, they made Munich a home to me. Thank you!

Last and for most, I would like to thank my beloved partner Markus, my sisters and closest friends Theresa and Carina as well as my highly treasured parents Gernot und Petra. As partner, sisters and parents, they supported me unconditionally and empowered me during all my studies. Thank you for being my closest companions in life! Wuff!



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YOU'VE GOT TO START WITH THE  
**CUSTOMER  
EXPERIENCE**  
AND WORK BACKWARDS  
TO THE TECHNOLOGY  
- NOT THE OTHER WAY AROUND.

*STEVE JOBS*





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# ABSTRACT

Within the scope of this dissertation, the question of improving façade design quality by applying user-centered design methods is addressed. The dissertation poses the question which user-specific functions and design features must be incorporated into future façade designs in order to satisfy diverse sets of user needs and to support the users within buildings. This research question is being answered for hospital buildings. The dissertation aims at raising awareness for the necessity of user-specific façade functions and design features. The core of the dissertation is the development of need-oriented façade functions for various hospital users. Therefore, the research objective is to compile user-driven performance specifications for facades of healthcare buildings and to translate them into future façade functionalities and/or design features. Environmental misfits are used as guiding principles in order to identify necessary functionalities. Environmental misfits are such environmental conditions and design aspects that either do not meet the prevailing user needs in terms of physiological, functional as well as psychological comfort or even pose an additional burden for the users.

Due to the interdisciplinary nature of the dissertation, findings from the fields of Building Physics, Environmental Psychology, Façade Design and User-Centered Design form the state of the art. Thus, the basics of building physics in terms of Indoor Environmental Quality (IEQ) are illustrated and enhanced by hospital-relevant findings from the field of Environmental Psychology. Additionally, facades and their current scope of functionality as well as research findings from the field of adaptive facades are examined. To address the key question of a user-centered development of façade systems, selected design approaches that claim a user-centered design method are briefly introduced. The approaches of universal design and user experience design are of particular importance, as both approaches pay particular attention to appropriate forms of interaction between users and products.

The methodology applied in this work is inspired by the Design Thinking methodology as taught at the Hasso Plattner Institute of Design at Stanford University (d.school). The data is collected during a 360°-research phase, within which the methods of in-situ field observation as well as expert interviews are applied. In order to analyze the collected data, a qualitative content analysis is conducted and the results are put together in form of personas as well as lists on corresponding environmental misfits.

The results show that hospital buildings are subject to a mixed-use mode, combining workplaces such as desk work, diagnosis, therapy and nursing spaces as well as hospitality and accommodation. This mixed-use mode of hospitals results in a large number of diverse users. Across hospitals there are zones that are associated with a certain form of usage and thus, correlate with a certain groups of users. In order to represent these users, personas can be created. To illustrate the method applied within this dissertation and to highlight differences between different user groups, three personas are created. The three personas – two typical patient groups as well as a physician – are selected on the basis of statistical data. Further, the results show that the multitude of users is accompanied by a multitude of diverse environmental misfits. By means of the personas' descriptions significant differences in user-specific characteristics as well as user-specific environmental misfits can be highlighted. The collected misfits can be differentiated into different types of environmental misfits. There are two different types of environmental misfits in the observed hospital: The first group of misfits represents an immediate or mediate result of the façade and/or an interaction with it. The façade directly causes the misfit or is indirectly contributing to these misfits. These environmental misfits are referred to as façade-dependent misfits. The second group of misfits shows no relation to the façade and result from other environmental conditions. These environmental misfits are referred to as façade-independent misfits. Given the sets of environmental misfits, several façade functions and design features can be derived that provide a solution to these environmental misfits. To illustrate, eight different ideas for façade functions and design features that address the environmental misfits of different hospital user groups are presented. All of the introduced façade functions follow the idea of a dynamic and adaptive façade that is based on universal as well as specific user needs.

Against the backdrop of user-specific façade functionalities, an additional form of façade adaptivity is suggested. Usually, adaptive facades are based on the notion of being adaptive to exterior environmental conditions. However, this environmental adaptivity needs broadening in terms of user-centricity. A user-centered adaptive façade can be

envisioned as a façade that ‘recognizes’ the user groups in the room, ‘analyses’ the users’ present abilities and needs and ‘takes action’ in order to compensate prevailing environmental misfits considering temporally, occupationally as well as personally varying requirements. Thus, the dissertation enhances the current understanding of environmental adaptivity with a user-specific adaptivity of the façade. According to the results of this dissertation, an adaptive facade should be both, adaptive to environmental conditions and to the user inside. To put it in a nutshell, this dissertation shows that a user-centered specification of façade design is necessary and should no longer be neglected. With regard to improving the quality of our built environment, nowadays façade constructions hold an enormous potential. Future research in the field of adaptive facades should concentrate on the integration of user-centric design methods that allow for questioning the existing functional scope of facades and their prevailing construction methods.

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# ZUSAMMENFASSUNG

Die Dissertation adressiert die Frage einer nutzerzentrierten Entwicklung von Fassadenkonstruktionen und stellt somit die Anwendbarkeit nutzerzentrierter Designmethoden, wie Design Thinking in den Mittelpunkt. Vor dem Hintergrund zunehmender Nutzerzentrierung wird die Frage gestellt welche nutzerspezifischen Funktionen und Gestaltungsmerkmale zukünftige Fassaden anbieten müssen, um Nutzer im Gebäudeinneren bestmöglich zu unterstützen und gleichzeitig unterschiedlichen Nutzerbedürfnissen gerecht zu werden. Diese Forschungsfrage wird für den Gebäudetypus Krankenhaus beantwortet. Mittels der Dissertation soll ein höheres Bewusstsein für die Notwendigkeit nutzerspezifischer Fassadenfunktionen geschaffen werden. Forschungsziel ist es, nutzerspezifische Funktionsanforderungen an Krankenhausfassaden zu identifizieren und diese in zukünftige Fassadenfunktionalitäten und/oder Designmerkmale zu übersetzen. Diese nutzerspezifischen Funktionsanforderungen werden auf Basis von sogenannten ‚Environmental Misfits‘ identifiziert. Environmental Misfits könnten sinngemäß als umweltbedingte Fehlpassungen in Deutsche übersetzt werden. Im Folgenden wird jedoch weiterhin der englischsprachige Begriff verwendet. Als Environmental Misfits werden jene Umgebungsbedingungen und Gestaltungsaspekte betrachtet, die den vorherrschenden Nutzeranforderungen in physiologischer, funktionaler oder psychologischer Hinsicht nicht Genüge leisten und teilweise sogar eine zusätzliche Belastung für die Nutzer darstellen.

Aufgrund des interdisziplinären Charakters der Dissertation setzt sich der Stand des Wissens aus Ergebnissen der Themenfelder Bauphysik, Umweltpsychologie, Fassadengestaltung und nutzerzentriertem Design zusammen. So werden die bauphysikalischen Grundlagen der Innenraumqualität (Indoor Environmental Quality, IEQ) zusammengestellt und durch krankenhauserrelevante Erkenntnisse aus dem Bereich der Umweltpsychologie ergänzt. Darüber hinaus wird auf den heute gängigen Funktionsumfang von Fassaden sowie Erkenntnisse aus dem Forschungsbereich ‚adaptive Fassaden‘ eingegangen. Um die Kernfrage nach einer nutzerzentrierten Entwicklung von Fassadenkonstruktionen zu adressieren, werden ausgewählte nutzerzentrierte Designansätze vorgestellt. Die Designgrundsätze des Universal Design und des User Experience Design sind hierbei von besonderer Bedeutung. Mittels beider Ansätze kann die Frage nach einer angemessenen Interaktion zwischen Produkt und Nutzer durch entsprechendes Design beantwortet werden.

Die Vorgehensweise und Methode der Dissertation wird vom nutzerzentrierten Innovationsprozess ‚Design Thinking‘ inspiriert. Zur Identifikation der Environmental Misfits sowie der Übersetzung dieser in Funktionsanforderungen finden Methoden aus dem Design Thinking Anwendung. So erfolgt die Datenerhebung in einer 360°-Forschungsphase, bei der die Methoden der In-situ-Feldbeobachtung angewandt sowie Experteninterviews durchgeführt werden. Um die gesammelten Daten zu analysieren, wird eine qualitative Inhaltsanalyse durchgeführt und die Ergebnisse werden in Form von Personas und Sammlungen von Environmental Misfits zusammengestellt.

Die Ergebnisse zeigen, dass Krankenhäuser als Gebäudetypus mit Mischnutzung Arbeitsplätze, Diagnose-, Therapie- und Pflegeflächen sowie Bewirtung und Unterkunft miteinander verbinden. Diese Mischnutzung führt zu einer großen Anzahl unterschiedlicher Nutzer. Grundsätzlich können die verschiedenen Krankenhausnutzer mittels fiktiver Personas beschrieben werden. So kann für jede Untergruppe der Gesamtheit der Krankenhausnutzer eine stellvertretende Persona erstellt werden. Die in der Dissertation angewandte Vorgehensweise und Methode wird an drei beispielhaften Personas – zwei typischen Patientengruppen sowie einem Arzt – verdeutlicht. Die drei ausgewählten Personas repräsentieren typische Nutzergruppen eines Krankenhauses. Die Ergebnisse der Dissertation zeigen weiter, dass mit der großen Anzahl unterschiedlicher Nutzer sehr unterschiedliche Nutzerbedürfnisse einhergehen und es so im Krankenhauskontext zu nutzerspezifischen Misfits kommen kann. Mithilfe der Persona-Beschreibungen können nutzerspezifische Eigenschaften und daraus resultierende Environmental Misfits übersichtlich zusammengestellt werden. Die drei ausgewählten Personas zeigen zum einen Unterschiede innerhalb einer Nutzergruppe, aber auch Unterschiede zwischen verschiedenen Nutzergruppen auf. Diese gesammelten Misfits können in verschiedene Arten von Environmental Misfits kategorisiert werden. Die erste Gruppe an Misfits –resultiert direkt aus der Fassade und/oder einer Interaktion mit dieser. Environmental Misfits, die direkt durch die Fassade verursacht werden, werden in der Dissertation als fassadenabhängige Misfits bezeichnet. Ein Beispiel für fassadenabhängige Misfits ist sommerliche Überhitzung des Innenraumes durch zu hohe Solareinstrahlung. Die zweite Gruppe von Fehlpassungen weisen keinen direkten Bezug zur Fassade auf. Diese umweltbedingten Environmental Misfits werden in der Dissertation als fassadenunabhängige Misfits bezeichnet und

entstehen unabhängig von der Fassade. Ein Beispiel für fassadenunabhängige Misfits ist das allgemeine Fehlen von Informationen. Ausgehend von den fassadenabhängigen sowie fassadenunabhängigen Misfits werden neuartige Fassadenfunktionen und/oder Verbesserungen bereits bestehender Fassadenfunktionen abgeleitet. Im Rahmen der Dissertation werden acht verschiedene Ideen für Fassadenfunktionen und Gestaltungsmerkmale beispielhaft vorgestellt. Diesen vorgestellten Fassadenfunktionen liegt die Idee einer dynamischen und adaptiven Fassade, die sich an den Bedürfnissen der Nutzer orientiert, zugrunde.

Als Schlussfolgerung wird, ausgehend von den nutzerspezifischen Fassadenfunktionen, ein neues und erweitertes Verständnis von Adaptivität bei adaptiven Fassaden formuliert. Adaptiven Fassaden liegt in der Regel das Verständnis einer umweltbedingten Anpassungsfähigkeit der Fassade zugrunde. So kann eine adaptive Fassade mit nutzerspezifischer Anpassungsfähigkeit als Fassade verstanden werden, die die Benutzergruppen im Raum „erkennt“, deren vorhandenen Fähigkeiten und Bedürfnisse „analysiert“ und „Maßnahmen ergreift“, um vorherrschende Environmental Misfits unter Berücksichtigung zeitlicher, beruflicher und persönlicher Anforderungen auszugleichen. Die Dissertation ergänzt somit das bisherige Verständnis einer mehrheitlich umweltbedingten Anpassungsfähigkeit um eine nutzerspezifische Anpassungsfähigkeit der Fassade. Nach den Ergebnissen dieser Dissertation sollte eine adaptive Fassade sowohl adaptiv gegenüber Umweltbedingungen, als auch dem Nutzer im Inneren sein. Zusammenfassend lässt sich sagen, dass im Rahmen der Dissertation gezeigt wird, dass eine nutzerzentrierte Spezifikation der Fassadenfunktionen notwendig ist. Im Hinblick auf die Verbesserung der Qualität unserer bebauten Umwelt bieten Fassadenkonstruktionen große Verbesserungspotenziale. Zukünftige Forschung im Bereich adaptiver Fassaden sollte sich auf die Integration einer erhöhten Nutzerorientierung konzentrieren, um den bestehenden Funktionsumfang von Fassaden radikal zu hinterfragen.



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# A INTRODUCTION

## 1 CONTEXT

### **FUTURE FACADES**

Despite all cultural distinctions, humans tend to build shelters to protect them from the negative effects of the exterior environment they are exposed to. This phenomenon can be examined from the early beginning of human kind all over the world. In spite of the different architectural styles and periods as well as the different climates and traditions, the façade has always fulfilled this function of providing shelter. The façade, the building component separating the inside from the outside, is intended to protect the user from extreme temperatures, rain and wind as well as high UV radiation and outside noise. (Klein, 2013; Knaack, Klein, Bilow, & Auer, 2014) However, in addition to providing protection against external influences, the façade should also provide access to the interior of the building as well as enable natural ventilation and lighting. Up to now, there has been no fundamental change in this functional scope of the façade. (Heusler & Kadija, 2017)

In addition to aesthetic considerations, these basic functions represent the primary focus of nowadays façade design optimizations. Thus, during the design process, the façade construction is being optimized

with regard to its protective functions for the predominant boundary conditions, in particular with regard to summer and winter thermal insulation and daylight supply. Advances in the field of 'Adaptive Facades' show this dominance of protection and supply in particular. While the various protective functions of the façade are becoming increasingly intelligent, the initial functional scope of the façade remains the same. (Lazarovich, Capeluto, & Silverstein, 2015)

While the functional scope of the façade has not been significantly expanded over the years, nevertheless there is the question regarding future-proof façade concepts that research groups around the world try to answer. Among other topics, concepts deal with the digitalization of design, construction and production processes. Automating façade functions in form of adaptive façade systems are being researched. Moreover, the possibilities for system integration of different building technologies into the façade is also being investigated. In addition, additive manufacturing techniques are also playing a decisive role and alternative sales strategies, e.g. in the form of façade leasing, also find room for discussion.

## **FROM MEGATRENDS AS EXTERNAL DRIVERS TO USER-CENTERED DESIGN**

Change processes and innovation in today's world, show the enormous and fast-paced influence as well as the associated potential that is inherent to the megatrend of digitization. Digitalization no longer means mobile internet and new online economy, but increasingly manifests in form of the Internet of Things (IoT) and ubiquitous connectivity (Boeing, Burmeister, Neef, Rodenhäuser, & Schroll, 2014). Smart sensors, data analysis and actuators are the key to this world of interconnectivity and intelligence of everyday objects are essential (Alexander, Bernhart, & Rossbach, 2017).

While digitalization is already part of our everyday life, it slowly but surely finds its way into the construction and real estate industry, too. The initiative BE5 'Platform for Built Environment Focused Innovations, Ventures & Enterprises', founded in 2018 in Munich by UnternehmerTUM and various partner companies, underlines the necessity of introducing digital technologies into construction and the built environment. In small increments, agile product development processes are extended to construction products and design processes and thus, trigger a technology-driven development process. Start-ups, like Alasco show that the building industry gets increasingly transformed – especially from outside the industry, by 'former' tech-entrepreneurs. Thus, the wave of digitalization is starting to roll across the construction and real estate industry and brings with it incremental improvements by means of digital tools, but also disruptive business models. The question arises whether the developed concepts of future-proof facades can manage to ride these waves. With regard to the digitalization of facades and in order to future-proof them, conceptual approaches aim for the integration of intelligence into the façade. In this context, new materials as well as sensors and intelligent algorithms for optimization are necessarily being researched.

It is not only the megatrend of digitization and the associated 'ubiquitous connectivity' that are changing processes and everyday products. On the contrary, the rigid implementation of (digital) technology into the façade will not turn the façade into a future-proof building component. With façade technologies, it also applies that the mere application of technology for the sake of technology is, however, not sustainably successful. Thus, the common approach 'the more technology and functionality, the better' needs to be questioned. In contrast, it is more effective to define a suitable degree of façade functionality that meets the user's needs and can be implemented by using new technologies, materials and so on.

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Megatrends are social, political or technological trends that unfold their effects in the course of several decades, are of global importance and will become reality with high probability in the next 15 years.

(Z\_punkt GmbH the Foresight Company, 2014)

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In this context, user-centered design approaches come into play. User-centered design approaches envisage that technology is being used as means to an end, in order to create immediate and sustainable added value for the user (Camacho, 2016). In this sense, technology is never the trigger for a design problem. Instead, the design process starts with the needs of the person for whom one designs and technology can then trigger the design solution. However, in other words, starting point of any design process are users, their abilities and needs.

Megatrends can provide an initial starting point and assistance for the analysis of user needs. Nowadays prevailing megatrends have an impact on the relevant user needs. Considering these mega trends leads to a façade that is suitable for future requirements. While there are many ways to structure future megatrends and many different players, who are conducting trend studies - from university institutions to business related consultancies - some megatrends everybody seems to agree on. For example, megatrends that are mentioned consistently are: demographic change, urbanization, individualization, new work and new mobility. For the built environment, the megatrend of demographic change and thus ageing societies, urbanization, connectivity and individualization are of particular importance. With regard to the built environment these megatrends, their consequences and needs derived from them can be considered a set of design guidelines, on the basis of which design decisions can be evaluated and validated. For example, as society grows older and the elderly make up the largest population share, so the needs that are placed on the built environment change as well. General issues, such as accessibility via ramps, but also more specific topics, such as dementia-friendly design, are increasingly influencing the design

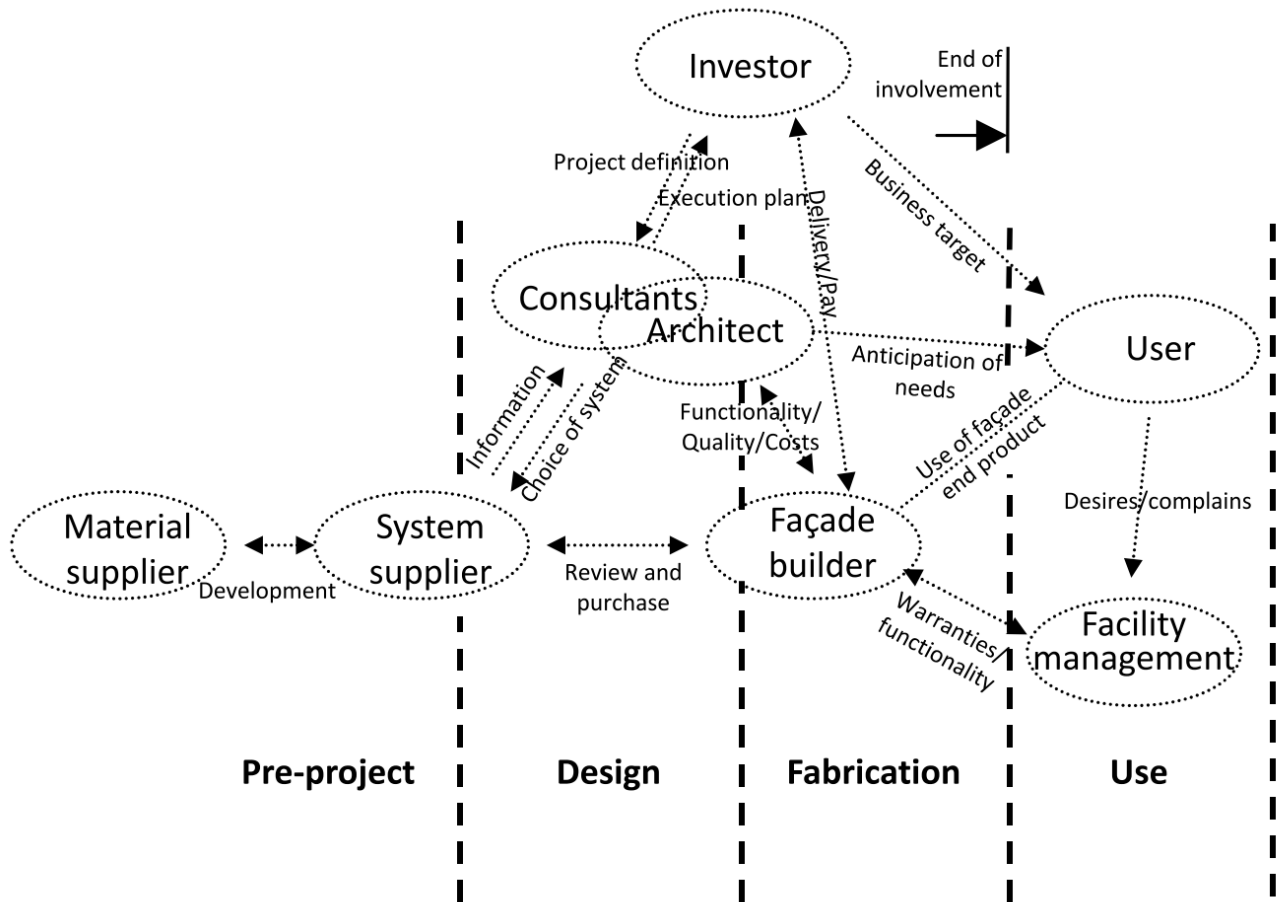


Figure A.1 - Stakeholders within the façade design process (Klein, 2013) – end users are only considered to a limited extent and taken into account on the basis of anticipated needs

process. If these are not taken into account (in time), the building cannot do sufficient justice to the user and fails to protect. This is true at a building level, as well as in relation to the façade.

In the field of architecture, megatrends are not necessarily used as guideposts and input on performance requirements. The architect's and the design team's task includes both, the performance analysis and the translation into technical terminology. Therefore, megatrends should be considered. Klein schematize the façade design process and points out that the user, who is using the building and interacting with the façade, is integrated into the design process solely in the form of needs that are anticipated by the architect (Figure A.1). Anticipated needs are not sufficient to sustainably address user needs and satisfy them by means of user-centered design solutions. With regard to the façade design process, implementing a user-centered design process, requires a shift of user

perception, need analysis and finally, a different form of user involvement.

While in architectural practice this form of user involvement is most commonly realized by means of the architect, this approach poses a considerable danger: the exclusive use of explicit, i.e. by the user explicitly mentioned needs. However, these explicitly stated needs are not sufficient for enabling user-centered design solutions. In addition to the explicit needs of the user, it is important to identify and address any implicit needs that may exist, too. Implicit needs are often triggered by emotions and not expressed by the user, because they might not correspond to social desirability or the user is just not aware of them. However, even if these needs are not explicitly stated and therefore are much less tangible, they can overwrite explicitly expressed needs and even negate them. This can lead to design solutions that might meet the explicit user needs, but still do not

fully satisfy the user, because the implicit needs are not met. In order to counteract, user-centered design approaches, such as Design Thinking, focus on the identification and analysis of explicit and, in particular, implicit user needs. Against this backdrop, designers become detectives, responsible for revealing implicit user needs. Architects and designers are no longer the deliverer of anticipated needs.

User-centered design approaches, such as Design Thinking, seem to be the key to an increased quality of products by usercenteredness and are taught in entrepreneurship centers around the globe, such as Berlin's Hasso Plattner Institute, Stanford's d.school or Munich's UnternehmerTUM. Originally, Design Thinking originated from the field of industrial design, however found its way into other sectors and industries, as well. For example, within the field of software, agile development is combined with user-centered design in form of user-interface design. While software is a non-tangible product, user-centered design research can also improve the quality of processes and services as well as tangible products.

But user-centered design does not stop at the level of consumer goods and services, it can also be applied at a broader scale, such as buildings and their facades. This brings up the question of how user-centered design can improve the quality of nowadays façade design. It can be strongly questioned, if the functional scope of nowadays common façade design sufficiently meets the explicit as well as the implicit needs posed by different building users, now and in the future.

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# 2 RESEARCH QUESTION AND OBJECTIVE

Within the scope of this dissertation, the question of improving façade design quality by applying user-centered design methods is addressed. The underlying motivation is to use the façade's leverage on indoor quality in order to improve the quality of indoor environments with regard to physical, functional and psychological comfort (Vischer, 2008) for all users equally.

Building on a user-centered understanding of design, this dissertation poses the question which user-specific functions and design features facades must be offered in order to satisfy the diverse sets of user needs. This thesis should essentially sensitize to a user specification of façade design.

It is necessary to question the traditional functional scope of nowadays façade designs in terms of user-centered functionality. Instead of improving the energy performance, the facades' user-friendliness is focused on. How can the functions that facades can offer to the user be more user-specific? Due to the nature of user-centered thinking, this cannot be done on a general level and answered universally across all building types, but has to be developed for a certain building typology and its typical users. User-centric functions that claim applicability across all building types are unrealistic. Thus, the question on user-centered façade functions is posed for a specific building type. Within this dissertation, hospitals were chosen as the building type to be addressed. This building type was chosen due to its high complexity, its inherent diversity of user groups and the possibility of extremely competing user needs. Thus, the research question is specified with regard to hospital buildings and can be stated as the following: By applying a user-centered design approach, which user-specific functions and design features are needed to design future facades

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By applying a user-centered design approach, which user-specific functions and design features are needed to design future facades of hospitals that ensure overall comfort to all user groups by reducing their indoor environmental misfits?

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of hospitals that ensure overall comfort to all user groups by reducing their indoor environmental misfits?

Associated with this research questions are the three following hypotheses. The hypotheses are based on the notion that, besides the existing function of protection and separation, the façade can provide additional functions and user-specific design features according to the needs of the different users within the building.



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## **Hypothesis 1**

Future facades need to offer an enhanced set of functionality that exceeds the traditional scope of functionality by means of user-centered functions and design features.

Besides energy optimizations of facades, the design of future facades needs to be optimized for users.

## **Hypothesis 2**

By analyzing user-specific environmental misfits, user-centeredness can be implemented into façade design.

Environmental misfits are user-specific and their analysis allows for a new form of user involvement.

## **Hypothesis 3**

Environmental misfits can serve as a point of reference for new functionalities and design features of façade design.

Future façade functions can be provide an answer to user-specific environmental misfits.

The core of this task is the development of need-oriented façade functions for the various hospital users. Here, incremental improvements of existing functions are not so much considered, but the dissertation rather focuses on extending the existing scope of functions disruptively for the benefit of the various users. However, the focus is not on developing a certain construction in detail or integrating a certain technology, but rather developing a future vision of hospital facades on the basis of an in-depth user need analysis.

The aim is to identify which user groups are of fundamental relevance for façade design in the context of hospitals and which needs arise from these user groups. Both explicit and implicit needs should be identified and taken into account. Environmental misfits can serve as a source of information and a point of reference for possible user needs. Hereby, environmental misfits are taken into account that arise

directly from the façade and its interaction. However, it is not sufficient to only focus on the misfits caused by the façade. Enhancements to existing façade functions take place where services are not yet provided by the façade, but where the façade could provide additional support. So the dissertation's aim is to identify environmental misfits that are not directly caused by the façade, but could be reduced by it.

In summary, the research's objective is to compile user-specific environmental misfits that are encountered by users of hospital buildings and translate them into future façade functionalities and/or design features.

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# 3 OUTLINE AND CONTRIBUTION

After the framework of this research work has been established and the research question has been introduced in the beginning of this chapter, [chapter B](#) will describe the relevant state of the art that needs to be considered. Due to the interdisciplinary nature of the dissertation's topic, [chapter B](#) is very broad in scope and explores four major topic areas: Building Physics, Environmental Psychology, Façade Design and User-Centered Design. The basics of building physics on Indoor Environmental Quality are illustrated and enhanced by hospital-relevant findings from the field of environmental psychology. Facades and their current scope of functionality will be examined. Subsequently, adaptive facades and user-centric design approaches will be addressed. While the different subject areas are presented in excerpts, the main contribution of this dissertation's summary on the relevant state of the art is its interdisciplinary and to highlight the different topic areas against the background of the research question.

Based on the state of the art, [chapter C](#), as the dissertation's chapter on methodology and methods, constitutes the connecting element between the research question and dissertation's results. [Chapter C](#) deals both with the overall approach as well as the methods applied. The Design Thinking process is presented as one representative of user-centered design approaches and its phases are explained. In addition, the phases of the Design Thinking process are aligned with the phases of the abstraction model. An explanation of the data collection process follows as well as a description of the methods used during data analysis. While Design Thinking methodology is established as a user-centric and design approach to solve design problems, especially within the field of industrial design, the main contribution of this work's [chapter C](#) represents the application of Design

Thinking with regard to façade design. By choosing suitable tools for collecting and analyzing user-centric data, this methodology can help to analyze explicit as well as implicit needs that are related to facades.

The results of the thesis are then presented in [chapter D](#). Basic facts about the German hospital landscape as well as relevant megatrends and expected hospital developments are presented. Subsequently, according to the research question and user-centered design approaches, an analysis of prevailing hospital users is presented. This analysis consists of a general compilation of the key user groups. In addition, a detailed analysis for exemplary user groups is presented in the form of personas. For these personas, along with the presentation of skills, limitations and typical daily routines, typical environmental misfits are compiled. Finally, façade functions that can help to reduce these environmental misfits are presented. While adaptive facades are already improving the functional scope and quality of nowadays facades, the main contribution of this dissertation's [chapter D](#) is highlighting and raising awareness for environmental misfits that are the result of an inappropriate façade design or environmental misfits that result from other factors, but can be solved by future functions and design features. Thus, the main contribution within this [chapter D](#) can be subsumed as analyzing explicit as well as implicit needs that are related to hospital facades.

[Chapter E](#) discusses the results. The concept of user-centered adaptivity and the concept of human-façade interaction is introduced. In addition, the limitations of the results are discussed. [Chapter F](#) forms the conclusive chapter of the thesis and answers the research question. Finally, the dissertation is summarized in [chapter G](#) and an outlook for further

research and implications for practice is given in [chapter H](#).

The methodology and results of this dissertation were partially presented during talks at the conference 'Façade 2018 – Adaptive! Final conference COST TU1403' in Luzern and the '14th Conference on Advanced Building Skins, in Basel as well as published in the conference proceedings.

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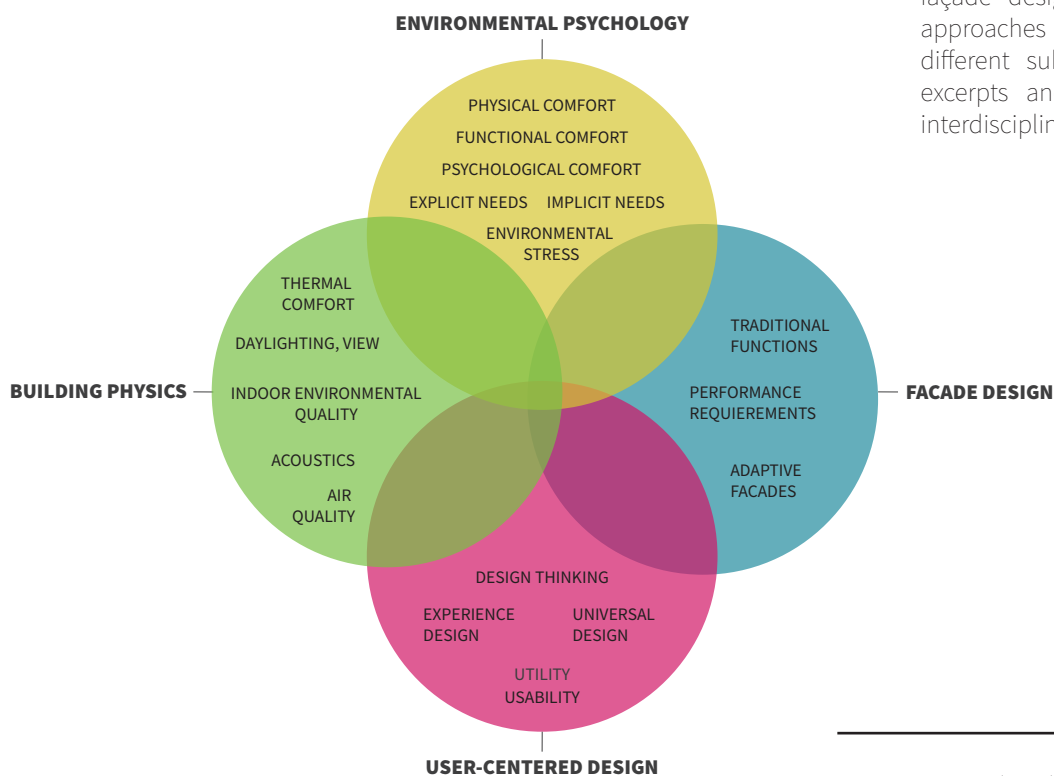
**The main contribution of this thesis is the introduction of a user-centric adaptivity of facades; enabling facades to adapt not only to the environment, but rather to the user within the building.**



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# B STATE OF THE ART

This chapter provides an overview of the relevant aspects from the disciplines of building physics, environmental psychology, façade design and user-centered design approaches in general. [\(Figure B.1\)](#). The different subject areas are presented in excerpts and highlight the dissertation's interdisciplinary character.



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Figure B.1 - Interdisciplinarity of the research field

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# 1 INDOOR ENVIRONMENTAL QUALITY

Within the discipline of building physics, the term “indoor environmental quality” (IEQ) is usually used to assess the quality of a built environment by means of four major environmental factors:

- thermal quality/indoor climate,
- indoor air quality (IAQ),
- acoustic quality,
- visual and lighting quality.

From a building physics point of view, hygiene issues are not being considered separately. Hygiene aspects that are related to mold growth and high humidity fall under the environmental factor of thermal quality. Hygiene in the sense of reducing disease transmission is not taken into account.

By means of these four factors environmental design can be guided and the quality on an indoor environment can be assessed. In order to assess and environment’s quality, each of the four environmental factors is specified via specific performance parameters that can be measured. For example, the quality of an indoor environment’s thermal comfort can be assessed via relative humidity, air velocity and operative temperatures, etc. [Table B.1](#) provides an overview of the four environmental factors as well as associated environmental parameters and issues of concern. In Bluysen’s work on the indoor environment, the four factors as well as the associated sets of parameters are described in detail (Bluysen, 2009).

Initially, research on IEQ started with identifying relations between indoor environmental parameters and the human physiological reaction as well as the prevailing feeling of comfort. The relations found were used to develop comfort models, such as Fanger’s model on thermal comfort (Fanger, 1986),

or used to set limits for certain indoor environmental parameters. While in the beginning the discipline focused on individual parameters and followed component-related approaches to assess the influence the environment has on the user, a shift towards a more holistic approach took place. This more holistic approach acknowledges that it is always a combination of parameters that influences the perception of an environment and that psycho-social effects need consideration (Bluysen, 2009). This change of views goes hand in hand with the idea that building users are active participants, who are searching equilibrium within an environment. Besides being active and showing participation, individual preferences plays a role. The user’s reception of the built environment results from the human sensory system (skin, eyes, ears, etc.) as well as the nervous, endocrine and immune system. While one might assume that these systems are more or less universal across users, Bluysen (2009) emphasizes that due to physical, physiological and psychological differences not every individual receives, perceives and responds to the environment in the same manner.

While these four major factors of indoor environmental quality are original to building physics and allow for a description of the indoor environmental conditions, they usually underestimate or unwillingly overlook the specific and individual user’s needs within a space as well as the user’s influence on the space. Most theories that depict the built environment and environmental conditions of buildings engage in the examination of processes within the building such as interconnections of subsystems, rather than focusing on the building’s user. User-centered theories of the built environment try to invert this approach by putting the user in the center of all examinations. The main question of concern is how building users are effected

	<b>Thermal comfort</b>	<b>Lighting quality</b>	<b>Acoustical quality</b>	<b>Air quality</b>
<b>Parameters</b>	Temperature (air and radiant) Relative humidity Air velocity Turbulence intensity Activity and clothing	Luminance and illuminance Reflectance(s) Colour temperature and colour index View and daylight Frequencies	Sound level(s) Frequencies Duration Absorption characteristics Sound insulation Reverberation time	Pollution sources and air concentration Types of pollutants (allergic, irritational, carcinogenic, etc.) Ventilation rate and efficiency
<b>Control</b>	Heating, cooling and air-conditioning systems Design of building (insulation, façade, etc.)	Luminance distribution Integration Artificial and natural lighting Daylight entrance	Acoustical control Passive noise control Active noise control	Source control Ventilation systems Maintenance Air cleaning Activity control
<b>Issues</b>	Dynamic effects Adaptation Integration systems (façade, floor and ceiling) Energy use	Daylight entrance relation to thermal comfort and energy use Health effects and control	Long-term health effects Vibrations and annoyance Degree of annoyance with type of noise	Interpretation and detection Secondary pollution (indoor chemistry and micro-organisms) (Fine) dust Energy use

Table B.1 - Environmental factors and their parameters, control and related issues (Bluyssen, 2009).

by and interact with the surrounding environments, in which 90% of our lifetime it spent. In other words, the main goal of a user-centered theory of the built environment is to depict the way the user is influenced by the surrounding environment and interacts with it. Vischer developed a user-centered theory of the built environment that provides a helpful framework on the user's experience of comfort within a building. As Vischer's model provides a helpful framework for structuring a user's experience in a built environment and the effects it has on the user. The model will be used within this dissertation and serves as basis to assign environmental misfits.

Existing theories that provide an answer to the question of how users and environments are interconnected, can be classified on the continuum of "Environmental Determinism" at the one end and "Social Constructivism" at the other end (Vischer, 2008a). According to Vischer, a significant amount of research within the field of environmental psychology can be attributed to the deterministic perspective (Vischer, 2008a). While theories assignable to Environmental Determinism follow a stimulus-response logic, arguing that behavioral responses of users are due to the surrounding physical environment, theories relatable to Social Constructivism reason that social context (including individual experiences, feelings, preferences, etc.) determines the user's behavior.

Traditionally, environmentally deterministic research has focused on measuring user satisfaction (through

post-occupancy surveying) in order to describe the interaction and effects between users and their environment. Following the stimulus-response-logic (an environmental, deterministic perspective of the user-environment relationship), the assessment of user satisfaction is based on the notion that behavioral responses are due to the physical environment that surrounds the user. This means that an environmental detail leads to a certain behavioral response. While the underlying logic seems reasonable, the approach falls short on taking notions of social constructivists into consideration. Influences such as individual preferences, experiences and prejudices that influence subjective assessments (Vischer, 2007) are not being considered. In order to overcome this shortage, a paradigm shift has started to spread within the research discipline of environmental psychology. In order to depict the interaction and effects between users and their environment, the user's experience as a "route to learn about built environment" (Vischer, 2008a) is used. By measuring the user's experience rather than merely the user's level of satisfaction, one acknowledges deterministic and constructivist elements constituting the user's experience and enables the measurement of an environment's effects and effectiveness. (Vischer, 2008a)

The user's experience of an indoor environment builds on a deterministic approach as well as a constructivist approach. This means that the environment influences the user's reaction, while individual properties of the user shape this influence even further. From a

systems engineering point of view as taken by Cooper and Dewe (as in Vischer, 2007) person-environment interactions can be described as systems in which users constantly modify the environment and at the same time adjust their behavior in order to fit the environment. Hence, the system is defined by feedback loops. Due to the multitude of interconnected effects and interactions, the relationship between the user and the environment can be characterized as transactional. Within this system's approach, the environmental elements and the user's behavior are interactive, mutually independent and under dynamic change (Vischer, 2008a). The acknowledgment of such a multilayered user experience requires that the interaction and effects between users and their environment are described in a deterministic as well as a constructivist manner (Vischer, 2008a). Vischer represents such an approach in her user-centered theory of the built environment.

Vischer's theory postulates that when capturing the user's experience of an indoor environment, one notices that a mere assessment and maximization of ambient environmental conditions in terms of physical comfort is neither sufficient, nor satisfying. In the context of hospital buildings, a growing body of research in the field of 'Evidence-Based Health Care Design' acknowledges that other indoor environmental conditions have a considerable influence on the user's health, well-being and medical outcomes. These are, for example, safer as well as more healing environments for inpatients that decrease stress as well as increase effectiveness for staff members (Devlin & Arneill, 2003; Rashid & Zimring, 2008; Roger S. Ulrich et al., 2008). The study conducted by Ulrich (1984) examined the influence of viewing nature on patient's postoperative recovery rate, length of hospital stays, perception of pain and pain medication intake. It found that viewing nature instead of brick walls was beneficial for patient's recovery rate, minimized the length of hospital stays as well as reduced pain perception and medication intake. Therefore, the evaluation of the user's experience requires a more complex comfort model that besides physiological comfort incorporates additional modes of comfort.

According to Vischer (2007), a user's experience of a built environment and the resulting feeling of overall environmental comfort is a result of three related, complementary categories of comfort: physical comfort, functional comfort, and psychological comfort. As is yet to be shown, the discipline of building physics with its research field of user comfort and indoor environmental quality addresses topics that are subject to physical as well as functional comfort. With questions regarding thermal quality/indoor climate, visual and lighting quality, indoor air quality or acoustic quality, the line between physical or functional comfort cannot always be drawn clearly.

The distinction between mere user satisfaction and task support can be helpful here. Vischer (2008b) points out that traditional comfort models – such as Fanger's Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) or the Adaptive Comfort Model by the University of Berkeley – assess user satisfaction with regard to varying environmental conditions. The domain of environmental psychology assess how an environment affects the user's performance and overall well-being. Thus, one needs to keep in mind that the understanding of comfort – in particular functional comfort – is not concurrent to the definition of comfort used within the field of traditional building physics and post-occupancy evaluations on building user satisfaction. The concept of functional comfort goes beyond user satisfaction and links these performance indicators to concrete outcome measures, such as task performance – exceeding the traditional discipline of building physics.

The three categories of comfort – physical, functional and psychological comfort – form an analytic framework to assess the performance, quality and effectiveness of a built environment (Vischer, 2008a). In addition to the three comfort modes, Vischer introduced a habitability threshold ([Figure B.2](#)). This threshold can be understood as minimum physical requirements that need to be fulfilled in order to make a building habitable. Vischer's theory was developed for the context of workspaces, however, within the scope of this thesis it is transferred to hospital buildings.

The highest environmental comfort and quality of an environmental space is achieved, whenever comfort is simultaneously assured across all three comfort modes. Even though maximizing each comfort mode is aspired, the relevance of each comfort mode depends on the context and the associated usage as well as user-specific conditions. Based on the context and building type, the importance, scope and complexity of comfort requirements vary and the three comfort modes have different shares in contributing to the experience of overall comfort. For example, the highest hygiene standards (physical comfort) are requested within the context of operating rooms, whereas inpatient rooms set higher requirements in regard to a feeling of belonging and control by the user ([Figure B.3](#)).

While most aspects of physical comfort can be regarded as universally applicable, the specific requirements of functional and psychological comfort can be generalized only to a limited extent. Achieving high levels of functional and psychological comfort require extensive contextualization and an in-depth analysis of user (sub-)groups, including users' abilities, restrictions, dominant activities and needs.



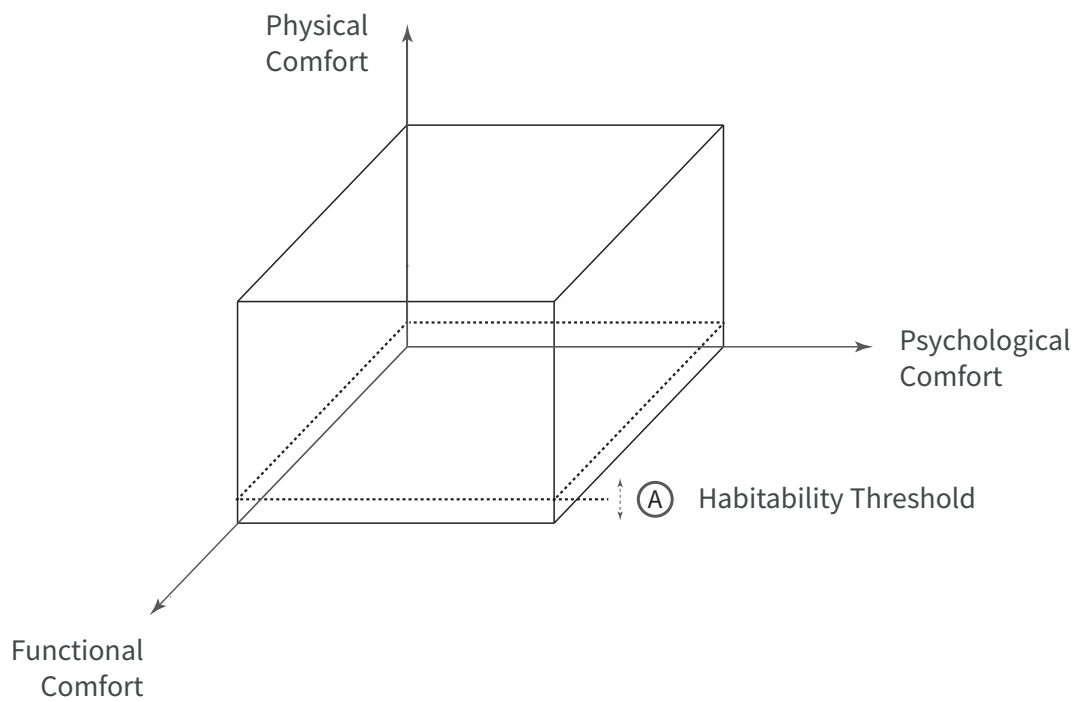
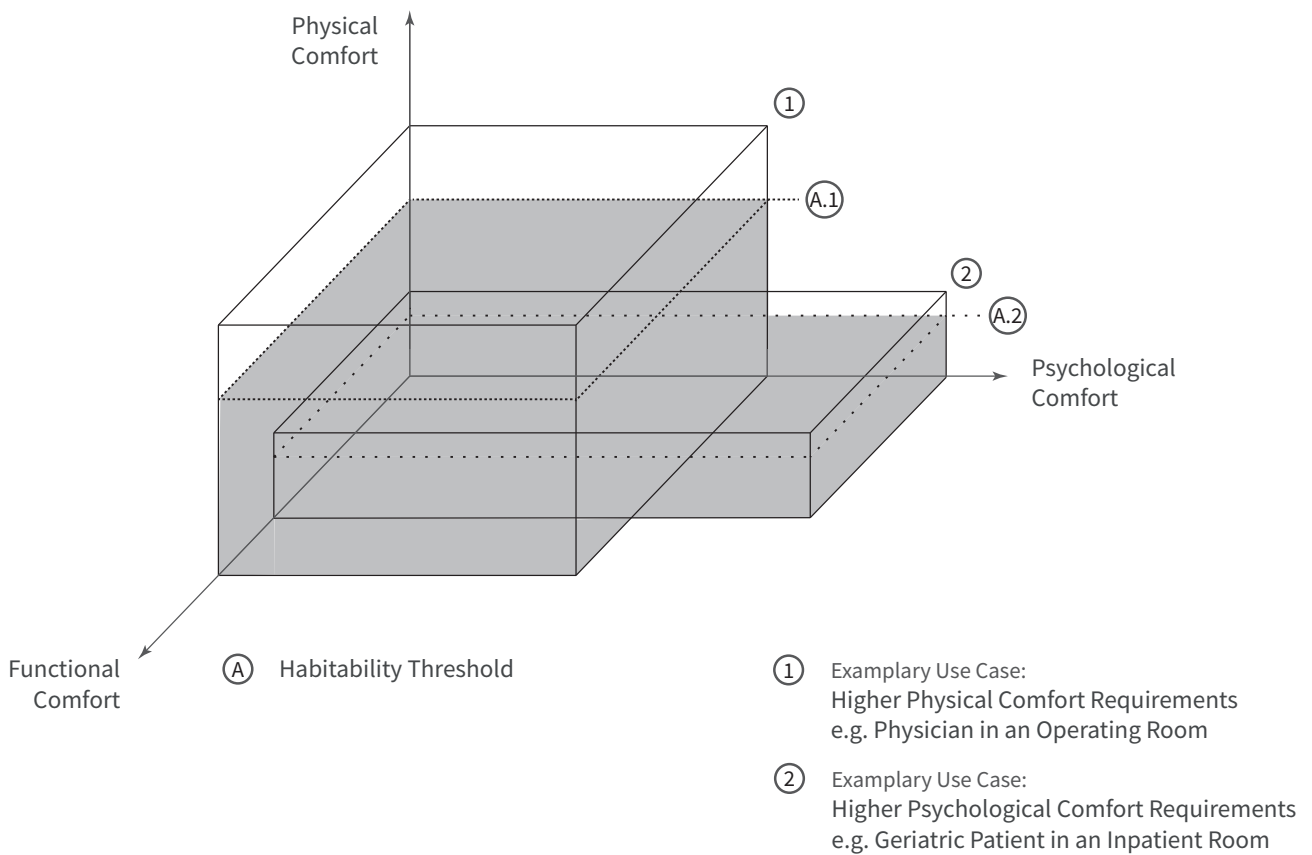


Figure B.2 - Dimensions of overall environmental comfort; based on the user-centered theory of the built environment by Vischer (2007) (own illustration)



- ① Exemplary Use Case:  
Higher Physical Comfort Requirements  
e.g. Physician in an Operating Room
- ② Exemplary Use Case:  
Higher Psychological Comfort Requirements  
e.g. Geriatric Patient in an Inpatient Room

Figure B.3 - Exemplary use cases and the varying importance of different comfort modes; based on the user-centered theory of the built environment by Vischer (2007) (own illustration)

# 1.1 PHYSICAL COMFORT

In general, physical comfort typically addresses health, safety, hygiene and accessibility issues (Vischer, 2008b). These requirements are addressed within building codes and can be understood as minimum comfort levels that describe habitability thresholds. The notion of physical comfort serves as a basis for any comfort assessment and can be understood as a prerequisite for environmental comfort in general. Indoor environmental conditions that do not fulfill the physical performance requirements lead to an uninhabitable or non-usable building. Consequently, these requirements are mostly universal, addressing general human needs and, therefore, do not necessarily incorporate user-specific abilities or needs.

The discipline of building physics addresses indoor environmental conditions – also referred to as indoor environmental quality (IEQ) – that provide for physical comfort. For example, by providing suitable operative temperature levels and appropriate levels of relative humidity the risk for mold growth and resulting health risks are limited. The Harvard School of Public Health with its Center for Health and the Global Environment (2017) summarized evidence on healthy buildings with regard to ventilation, air quality, water quality thermal health, dust and pests, lighting and views, noise, moisture as well as safety and security.

# 1.2 FUNCTIONAL COMFORT

A mere representation of comfort conditions via physical comfort would not account for the constructivist dimension of perception and experience of an environment: Each user engages with the environment by bringing along individual feelings, memories, expectations, etc. (Vischer, 2008a). The dimension of functional comfort is necessary to assess whether or not and to which degree users can perform tasks in an environmental space. It allows for an evaluation of the space's appropriateness in terms of task performance. Functional comfort results from environmental conditions that support the user's task and enhance user performance (Vischer, 2007).

In other words, functional comfort requirements address all elements of the environment and how they support or fail to support the user's tasks and activities (Vischer, 2007). Functionally uncomfortable environments draw energy from the user (Vischer, 2007). The degree to which energy needs to be procured by the user depends on the tasks that are performed and the effect the environment has on this particular task.

Requirements that fall into the category of functional comfort are derived from three main disciplines: ergonomics, (interior) architectural design and building physics. These three disciplines highlight functional comfort on different scales, with different foci and in terms of different qualities. While ergonomics or human-factors engineering focuses on interactions among humans and objects, the discipline of interior design and architecture poses implications in terms of layout, floor plans, colors, surface materials (haptics), visuals, signage, etc. The discipline of building physics addresses intangible components of an environment, such as thermal conditions, lighting and views as well as acoustics or air quality. From a building physics point of view, functional comfort can be ensured through an appropriate setting of indoor environmental performance parameters so that tasks are supported. For example, for functional comfort from a building physics point of view is the reduction of glare, especially at computer work stations.

As one can see, in contrast to physical comfort and its more universal conditions, functional comfort goes along with rather task-, usage- and user-specific conditions. The functional comfort conditions cannot be consolidated across various use cases and scenarios.

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**“The concept of functional comfort links users’ environmental assessment of their environment to the requirements of the tasks they are performing; (...). While building users’ physical comfort refers to meeting the basic human needs, such as safety, hygiene and accessibility, without which a building is uninhabitable, functional comfort is defined as environmental support for users’ performance of work-related tasks and activities.”**

(Vischer, 2008b, p. 99f)

## 1.3 PSYCHOLOGICAL COMFORT

The modes of physical and functional comfort are complemented by the mode of psychological comfort. It expands the dimensions of comfort by feelings of belonging, ownership as well as control issues (Vischer, 2007). According to Vischer psychological comfort determines environmental quality in terms of psychosocial human needs, such as territory, privacy and control (Vischer, 2008b). In this way, the ‘Social Constructivism’ approach is taken into account in particular. While the feeling of psychological comfort is to a certain degree dependent on the individual’s habits and socialization, some aspects can be shared across user (sub-)groups.

For this dissertation, the aspect of control and its effects on the perceived level of comfort should be emphasized. Vischer distinguished between two

forms of control: mechanical or instrumental control and hand empowerment. Empowerment here refers to opportunities to participate in decision-making processes and will not be further described in this thesis. Mechanical or instrumental control on the other hand relates to the direct, immediate change of certain environmental properties. It can be distinguished between available control, exercised control and perceived control (Paciuk as cited in Boerstra, Beuker, Loomans, & Hensen, 2013). While ‘available control’ describes the degree, type as well as access to control interfaces that are made available to the user to modify the environment. ‘Exercised control’ describes the frequency of which control was actually taken by the user within the building to modify the environment. Examples for available controls are operable windows or vents and thermostats. ‘Perceived control’

represents the influence of a building's occupant on the environment and results from a combination of available control and exercised control. Does the action of taking control via control modules influence the environment and/or does the user actually have the chance to influence and manipulate the environment? Following the classification of 'control' by Paciuk, it was examined that people, who perceive more control over indoor environmental conditions, such as operative room temperature, indoor air quality and noise levels, perceive the indoor environment as more comfortable (Boerstra et al., 2013). In detail, a distinction can be made between control of indoor temperatures, ventilation and noise. Users who have control over the interior temperatures, generally experience greater comfort in winter and summer (overall comfort) and evaluate the prevailing temperature and air quality as better. Control over ventilation leads to a better assessment of the air quality in winter and summer as well as a greater feeling of comfort in summer (overall comfort). The possibility for the user to control background noise also leads to an increased feeling of comfort during winter. (Boerstra et al., 2013) A number of other studies confirm similar findings (Bluyssen, Aries, & van Dommelen 2011; Boerstra et al. 2013; Brager & Baker 2009).

Strongly linked to the aspect of control is the aspect of interaction and automation. Following a definition by Parasuraman, Sheridan und Wickens (2000) automation can be understood as a "(...) full or partial replacement of a function previously carried out by the human operator. As the degree of automation increases, the user's participation and control is likely to decrease (Figure B.4). This implies that automation is not all or none, but can vary across a continuum of levels, from the lowest level of fully manual performance to the highest level of full automation." Besides the different degrees of automation, Parasuraman et al. (2000) differentiate between the phases of information acquisition, information analysis, decision selection and action implementation. Automation can take place in one of these phases, across several phases or across the entire action chain, and always to varying degrees.

Parasuraman et al. describe ten levels of automation of decision and action selection, starting on level 1: „Computer offers no assistance“ up to level 10: „Computer decides everything, acts autonomously, ignoring the human.“ (2000) (Figure B.4). The degree of automation should be suitable for the users' needs and abilities. In a study Ahmadi-Karvigh et al. (2017) were able to establish that different degrees of automation also depended on the complexity of the action and its influence on personal decision-making. Users preferred fully automated systems in particular for those tasks that do not necessarily provide hedonistic or comfort-related added value, but

represent useful or even necessary measures, such as “turning off unneeded lights or unneeded appliances”. It should be noted that the degree of automation does not have to be rigidly defined across all stages of the decision-making process. On the contrary, different degrees of automation can be chosen to realize data acquisition, data analysis, decision as well as action. For example, while the data acquisition and data analysis can be fully automated via sensors and smart algorithms, the decision and action can remain at the discretion of the user. The automation of the individual stages can be adapted to the prevailing user needs that are contextual depending on the prevailing situation. Such a flexible adaptation of automation is referred to as adaptive (Parasuraman et al., 2000) or adjustable (Ahmadi-Karvigh et al., 2017) automation. An adaptation of automation to user needs thus corresponds to an individualization of automation and should be based on preferences and abilities of the users. In this way, psychological comfort can be provided through adaptive degrees of control that is neither overwhelming nor disabling.

Besides control patients need information. A large study by Jenkins, Fallowfield and Saul (2001) shows that most cancer patients want as much information as possible. This includes information on diagnoses as well as treatment options. As Jenkins, Fallowfield and Saul put it “Failure to disclose information out of a belief that patients prefer not to know is untenable (...)”. A study by Hawkins et al. (2004) examined the effect of providing progress information on therapists and patients. Their study suggests that, as “patients expressed a very strong interest in receiving information about their progress in treatment”, providing information and feedback between the patients and therapists may enhance the patient's medical outcomes (Hawkins, Lambert, Vermeersch, Slade, & Tuttle, 2004). A study by Lauri, Lepistö and Käppeli (1997) examined the needs of patients in hospitals and concludes that patients' primary need for information covers information on their illness, treatment and recovery.

Besides Vischer's comfort model and its mode of psychological comfort, other theories from the field of environmental psychology stress the influence the built environment has on the users' mental state of mind and its general well-being just as much. The research within the discipline of environmental psychology spans from traditional work on the built environment and its traditional appearance to work on the effects of nature on our emotional well-being and how to incorporate nature into buildings. Findings from works, such as the Attention Restoration Theory by Kaplan and Kaplan, are increasingly being taken into account and implemented by following biophilic design guidelines (Browning, Ryan, & Clancy, 2014; Joye, 2007).

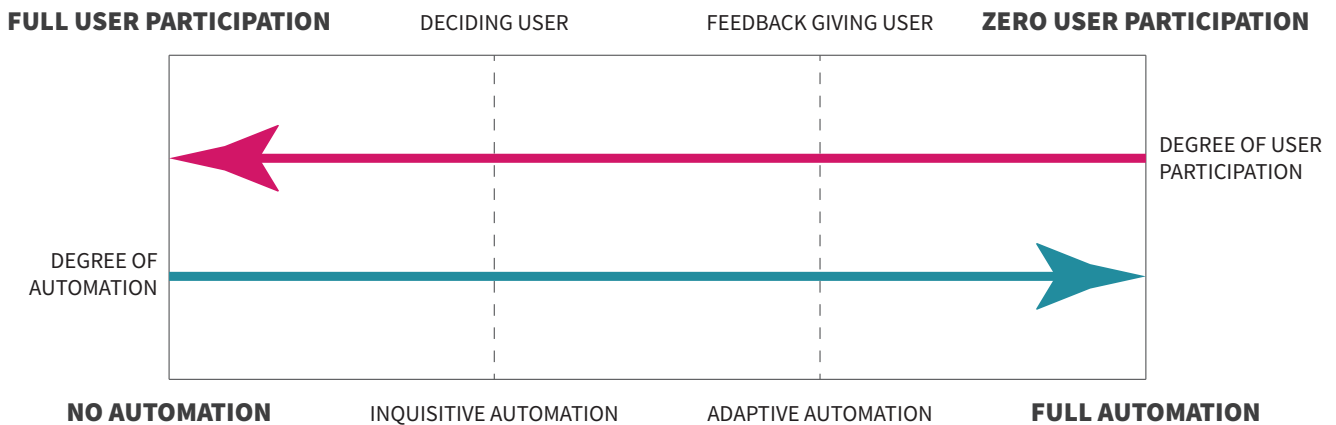


Figure B.4 - Degrees of automation and corresponding degrees of user participation; according to (Ahmadi-Karvigh, Ghahramani, Becerik-Gerber, & Soibelman, 2017)

## 1.4 ENVIRONMENTAL MISFIT AND STRESS

The term ‘environmental stress’, as used within this thesis, can be defined as a consequence of a non-suitable environment and resulting environmental misfit (Vischer 2007). Within the discipline of environmental psychology, an ‘environmental misfit’ defines adverse environmental effects that occur within environments and do not fit the users’ abilities and needs, but rather place additional and excessive stress on the user (Vischer 2007). Bluysen (2014) distinguishes physical stressors, such as lighting, thermal conditions and noise, from psychosocial stressors, such as discrete and chronic events. Following Bluysen, these stressors result from environmental conditions, which can be physical as well as psychosocial, and lead to certain effects that affect the physical, the psychosocial as well as the physiological state of the user (Figure B.5). Vischer (2007) as well as Bluysen (2014) refer to similar types of stressors and effects, but use different wordings. Using the Vischer’s terminology, environmental misfit and thus also environmental stress can occur within the modes of physical, functional as well as psychological comfort.

The perceived environmental misfits depend on the user. While a certain aspect of the environment leads to an environmental misfit and stress for one user

group, this does not mean that it applies equally to all user groups of the building. The perception of environmental misfit and stress depends to a large extent on the users’ psychological constitution as well as the functional demands that result from the individual’s activities and are placed on the space. Differences in terms of demographics, such as age, gender, ethnicity, social status, income and education, motivation and emotion at a certain point in time and personality traits over a longer time; life style and health status as well as genetics, events and exposures influence the perception and sensation of environmental stress. (Bluysen, 2014)

Besides the individual responses, stressors need to be differentiated with regard to their presence and duration as well as according to their corresponding effect. While some stressors are only present for a short period of time (seconds to a few minutes), stressors can also occur for the duration of minutes to hours (medium term) or even long term immediate, meaning days to years. Bluysen uses the two categories of chronic stressors and discrete stressors with a beginning and ending. (Bluysen, 2014) (Table B.2)

Likewise, the resulting effects on the user can occur as an immediate cause-effect relation or delayed within minutes, hours, days or even years. Bluysen (2014) gives a detailed description of the different stressors, their time dependency and effects that are being caused.

The objective of any comfort optimization – regardless of contexts and usage specific boundary conditions – is to maximize the overall level of comfort. This can be achieved by eliminating environmental misfits. While most aspects of physical comfort can be regarded as universally applicable, the specific requirements of functional and psychological can only be generalized to a limited extent. Achieving high levels of functional and psychological comfort requires extensive contextualization with in-depth analysis of user (sub-)groups, including users' abilities, restrictions, dominant activities and needs. As Vischer (2008b,

p.100) puts it: “Balancing environmental demands with the skills and abilities of users to act on their environment is a way of defining optimal workspaces for creativity and flow.”

## 1.5 ENVIRONMENTAL EFFECTS ON USERS

Following the definition by the Center for Health Design (2018), “Evidence-Based Design (EBD) is the process of basing decisions about the built environment on credible research to achieve the best possible outcomes.” While this idea is rather general, EBD tends to draw evidence from research on the influence of the built environment and environmental conditions on the user. EBD has its origin in the planning of hospital buildings and postulates the making of design decisions on the basis of measurable effects of architecture on people, i.e. patients and hospital staff (Ulrich, 2006).

One can notice that EBD research shares the ideas behind Vischer's user-centered theory on the built environment. In particular, evidence on the influence that the built environment has on patients and/or staff in terms of physical, functional as well as psychological comfort is being researched. In particular, research with regard to psychological benefits are undertaken. Thus, a growing body of research in the field of EBD acknowledges that indoor environmental conditions have a considerable influence on the user's health, well-being and performance outcomes (Devlin & Arneill, 2003; Rashid & Zimring, 2008; R. S. Ulrich, 1984). An extensive literature review by Ulrich et al. (2008) collected evidence on environmental influence on performance outcomes with regard to different user groups. The review distinguishes between patients and medical staff within a hospital and summarizes evidence with regard to certain

performance outcomes. With regard to patients, the review summarizes evidence on improving patient safety issues, such as infection, medical errors and falls. Additionally, evidence on pain, sleep, stress, depression, length of stay, spatial orientation, privacy, communication, social support and overall patient satisfaction is provided. With regard to the medical staff evidence is provided on environmental injuries, stress, work effectiveness and satisfaction.

In the following the four major areas of IEQ and their effects on users are described.

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Indoor environmental conditions have a considerable influence on the user's health, well-being and performance.

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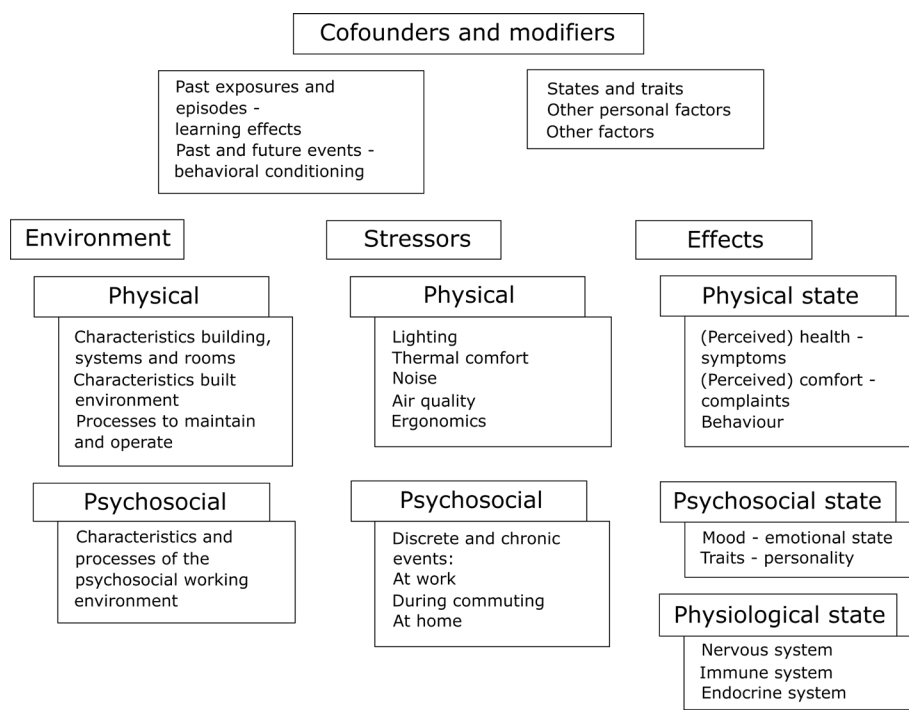


Figure B.5 - Framework for environmental stressors and effects (Bluyssen, 2014)

Category of stressors	Stressor
<b>Psychosocial stressors</b>	
<i>Discrete stressful events or stressors</i>	
– Major life events	<i>Positive events:</i> e. g. marriage, birth of a child. <i>Negative events:</i> e. g. job loss, death of family member.
– Minor daily events	e. g. oral speech, catching bus on time.
<i>Chronic stressors</i>	
– Community stressors	<i>Locally:</i> e. g. crowding (neighbourhood), social disorganisation, neighbourhood quality, safety (crime and violence) and poverty. <i>Nationally:</i> e. g. fear and economic deprivation, social support, racial segregation and income inequality <i>Worldwide:</i> e. g. fear for climate and energy related problems, epidemic diseases and economic depression.
– Individual stressors	<i>At work:</i> e. g. working hours, high demands and low control, flexible versus same working place and working pattern. <i>At home:</i> e. g. financial stress, access to health care, family turmoil, marital problems, cold-harsh parenting and separation from family. <i>During commuting conditions:</i> e. g. travel time, queuing and transportation means.
<b>Physical stressors</b>	
<i>Noise or acoustical quality</i>	Influenced by outside and indoor noise as well as vibrations.
<i>Indoor air quality</i>	A complex phenomenon comprising odour, indoor air pollution, fresh air supply, etc.
<i>Visual or lighting quality</i>	Determined by view, illuminance, luminance ratios, reflection and other parameters.
<i>Thermal comfort or indoor climate</i>	Comprising parameters as moisture, air velocity and temperature.

Source: Cohen *et al.*, 1995; Gee and Payne-Sturges, 2004; deFur *et al.*, 2007; Pieper, 2008; Bluyssen, 2009a

Table B.2 - Categories of stressors (Bluyssen, 2014)

## THERMAL QUALITY

The ASHRAE handbook (2017) refers to the ASHRAE standard's original definition of thermal comfort as "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation". When thermally comfortable, there is no need to feel warmer or cooler. In terms of physical parameters and performance indicators, thermal comfort is about more than temperatures. Building codes and standards, such as ASHRAE-55 and ISO 7730, measure thermal quality through several other parameters, such as mean radiant temperatures, velocity and turbulence intensity as well as moisture in form of relative humidity. The combination of these parameters constitutes for thermal comfort. For example, lower temperature levels have been found to improve the impression of air quality (Mishra, Loomans, & Hensen, 2016)

While the user's experience of an indoor environment results from the combination of the four environmental as well as other influences, several studies validate that thermal comfort has the greatest influence on improving the user's satisfaction with the indoor environment (Rupp, Vásquez, & Lamberts, 2015). A review by Frontczak and Wargocki (2011) shows further that thermal comfort is ranked to have slightly higher importance than acoustic comfort and satisfaction with air quality, and considerably higher importance compared with visual comfort.

Within the context of hospital buildings, the two basic thermal comfort models for assessing thermal comfort, Fanger's whole-body thermal-balance comfort model and the adaptive comfort model, can be used to different extents.

First, Fanger's whole-body thermal-balance comfort model with the indices predicted mean vote (PMV) and predicted percentage dissatisfied (PPD). Under steady-state conditions Fanger's model calculates the heat exchange between a human body and the surrounding environment as a function of air temperature, mean radiant temperature, relative air velocity and air humidity as well as the two user-related

variables activity level and clothing. (Monika Frontczak & Wargocki, 2011; Rupp et al., 2015) Such steady-state conditions are not generally applicable in hospital contexts. For example, nursing staff are continuously on the move and thus, steady state conditions are not applicable (Derks, Mishra, Loomans, & Kort, 2018).

Second, an adaptive thermal comfort model, such as the one by de Dear and Brager (2002), is used to incorporate people's ability to adapt to the thermal environment by means of behavioral or psychological adjustments. (Rupp et al., 2015) Adaptive models are based on the premises that in case of thermal discomfort, occupants restore their comfort level by means of adaptation, such as through adjusting clothing and activity levels as well as using operable windows, fans, etc. For example, occupants can adjust to operative temperatures up to 29°C by means of clothing (Mishra, Loomans, & Hensen, 2016). Within the context of hospitals these behavioral adaptations can only be executed by staff and patients, who are healthy enough to do so and not physically restricted. Immobile, physically impaired patients need help from the nursing staff for such behavioral adaptations. This limitation of lacking the ability to adapt can lead to discomfort within patients.

De Dear and Brager (2002), two advocates of an adaptive thermal model, make the case for variations within thermal environments. They point towards the predominant variability in our natural environments and the user's needs for sensory stimulation. Rupp et al. (2015) point out that static and homogeneous environmental conditions lead to thermal monotony. According to Mishra, Loomans and Hensen (2016), the stimuli needs to address all senses in terms of light, sounds and temperatures. This necessity of variation is of particular importance in situations of high density occupancy for sustained periods of time, such as lecture halls. However, this also applies for inpatient rooms within hospital wards. During their hospital stay, patients usually spend most of their time within their room and are isolated from natural variations and stimuli (Rupp et al., 2015). Personalized comfort systems that allow for stimuli and bring about certain

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**“A more dynamic thermal environment (both spatial and temporal components), pushing the boundaries of comfort zones, would be able to provide occupants with the required thermal comfort.”**

(Mishra et al., 2016)



non-uniformities should be installed.

While thermal comfort is one out of four factors of indoor environmental quality, the main concerns of hospital design are hygiene and safety issues, pushing thermal comfort assessments into the background (Derks, Mishra, Loomans, & Kort, 2018). This is light-headed for several reasons. For one thing a direct link can be observed between temperature as well as humidity and the growth of bacteria, and activate or deactivate viruses (ASHRAE, 2017). Moreover, indoor air movements can be actively used to control the spread of infection within hospitals (Skoog, 2006). With regard to personal health and well-being a literature review by Khodakarami and Nasrollahi (2012) summarized that low humidity ratios can result in immediate physiological symptoms, such as drying nose, throat, eyes and skin. Much more implicit for patients are increase restlessness, aggravate pain, shivering, inattentiveness, muscular and joint tension as well as decreasing overall patient satisfaction as a consequence of cold as an uncomfortable sensation. In contrast, providing a comfortable thermal environment helps stabilizing emotional moods of patients and supports the personal healing process. (Khodakarami & Nasrollahi, 2012) As for nursing staff, the effect of uncomfortable thermal conditions can result in slightly obstructed self-assessed work performance (SAWP) (Derks et al., 2018). By reviewing available literature on environmental comfort in hospitals, Khodakarami and Nasrollahi (2012) concluded that thermal comfort affects the working conditions, well-being, safety and health of the medical personnel who work in these environments.

Hospitals pose special challenges to thermal comfort. Challenges arise on an intra- as well as interindividual level. There are different needs when comparing different user groups, as well as within a single user group. The different groups of hospital users have such widely varying thermal comfort requirements that they are often difficult to accommodate in one space (Khodakarami & Nasrollahi, 2012).

For one, patients are likely to have different thermal requirements from the medical and nursing staff. As Derks, Mishra, Loomans and Kort (2018) put it, the differences between patients and staff are due to their health related effects, difference in clothing levels, and markedly different activity levels. For example, as draft sensitivity is greatest for naked body parts, such as head, neck and shoulders as well as ankles, feet and legs, patients in typical hospital robes are more prone to discomfort than staff (Mishra et al., 2016). In general, due to lower levels of activity patients need a higher operative temperature. With regard to different activity levels, Khodakarami & Nasrollahi (2012) reviewed studies on thermal comfort in hospitals. With regard to operating rooms the review presented conflicting

thermal requirements. As temperatures should not drop below 21°C to prevent thermal risk for the patient and temperatures above 23°C are intolerable for the surgical staff, a conflict arises. Several studies of the review confirmed that depending on the type of surgery, different numbers of equipment, lights as well as different levels of activity result for different staff. However, the conflict also relates to the surgical staff themselves. While surgeons and table nurses usually feel hot, the anesthesiologist is prone for the sensation of cold.

Second, just as patients and hospital personnel do not have the same needs, neither can patients be generalized as a single group. While patients are likely to have different thermal requirements from the medical and nursing staff, in an inpatient room there are usually different types of occupants, who compulsorily must stay in the same room. Thus, it is not surprising that Wargocki, Lan, Lian, & Wyon (2018) point out that preferred bedroom air temperatures vary greatly between individuals. Mishra, Loomans and Hensen (2016) summarized within their literature review on variations in thermal comfort that subjective thermal sensations and behavioral responses have been reported to have a circadian rhythm. Temperature minima are reached pre-noon, while maxima are required during late evenings. According to their study, thermal sensations of too cold or too hot make it difficult to fall asleep and to stay asleep. While one can generalize that sleep quality seems to be enhanced when bedroom temperatures are warm when falling asleep and when waking, but cool in between, the exact set points vary. Another striking example is the set of diverse needs present at neonatal intensive care units (NICU). Teuwen, Mishra, Loomans, Vaan, & Kort (2017) point out that while the health and well-being of premature infants can be positively impacted through appropriate thermal conditions, hospital personnel and parents have different thermal comfort requirements. In order to ensure steady conditions that are suitable for the incubators of the premature infants, the ambient temperatures in NICU wards are set to  $\pm 25^{\circ}\text{C}$  consistently. Combined with high activity, these rather high ambient temperatures lead to uncomfortable conditions for the nursing staff. (Teuwen, Mishra, Loomans, Vaan, & Kort, 2017)

While the original ASHRAE definition is vague and does not specify any conditions, it points out that comfort is a cognitive process that represents an integration of physical, physiological, and psychological components. According to the literature review by Rupp, Vásquez and Lamberts (2015), the sensation of thermal comfort is influenced by cultural and behavioral aspects, age, gender, space layout, possibility of control over the environment, user's thermal history and individual preferences.

Karjalainen (2012) reviewed the available literature on gender influences on thermal comfort sensations. The results show that women are more sensitive to deviations from an optimal thermal environment and generally express more dissatisfaction than males in the same thermal environments. This comes particularly true in cooler environmental conditions. This gender-specific differences in thermal sensations can be explained with differences in average body mass, body fat and less surface area than males as well as psychological and cultural factors such as gender roles.

Additionally, besides gender, age and personal fitness plays an important role. It is commonly agreed on that the ability to regulate the body temperature decreases with age and reduced fitness; increase of illness and disabilities. With regard to elderly people, Mishra, Loomans and Hensen (2016) summarize the reasons for this reduced thermal regulation as reduced responses in terms of sweat output, skin blood flow, and cardiac output volume to heat stress, reduced muscle mass and oxygen consumption.

## INDOOR AIR QUALITY

As we humans spend approximately 90% of our time indoors, continuously inhaling indoor air, the largest exposure to pollutants occurs indoors. Across literature, significant relationships are shown between polluted indoor air and negative respiratory health outcomes (Annesi-Maesano et al., 2013; De Oliveira Fernandes et al., 2009). Literature reviews on the effects of polluted air confirm that poor indoor air quality has been repeatedly linked to asthma, allergies, bronchitis, and chronic obstructive pulmonary disease (Fernandes et al., 2009; Harvard T.H. Chan School of Public Health, 2017). Besides health related issues, poor indoor air quality negatively promotes sick building syndrome (SBS) symptoms and decreases perceived air quality in terms (Seppänen & Fisk, 2004). With regard to SBS, symptoms such as headache, fatigue, shortness of breath, sinus congestion, cough, sneezing, eye, nose, throat, and skin irritation, dizziness, and nausea can result from poorly ventilated rooms (Harvard T.H. Chan School of Public Health, 2017). Within a literature review on the health effects of polluted indoor air, Tham (2016) takes up the distinction between non-specific symptoms, respiratory infections and allergenic diseases.

However, poor indoor air quality does not only negatively affect health and perceived air quality, but also cognitive functions, which are economically relevant, such as task performance and productivity (Seppänen & Fisk, 2004). According to a literature review by the Harvard T.H. Chan School of Public Health (2017), a growing body of research has found that fresh air adequately circulated and distributed increases productivity and health of employees or students compared to users in poorly ventilated rooms.

Given these effects, the goal is to minimize hazardous inhalation by increasing the indoor air quality. The quality of indoor air is a function of the concentration of pollutants present in the indoor air. The main groups of pollutants found in indoor air are chemical and biological pollutants ([Table B.3](#)) (Bluyssen, 2009). Important inorganic gases that are present in all buildings are nitrogen dioxide (NO<sub>2</sub>), sulphur dioxide (SO<sub>2</sub>) and ozone (O<sub>3</sub>). The important organic gases are carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>) and different forms of volatile organic compounds (VOCs). According to a literature review by Tham (2016), the most significant pollutants are tobacco smoke, nitrogen dioxide, carbon monoxide, biological agents, formaldehyde, VOCs and radon.

The concentration of pollutants within indoor air depends on the production or emission rate of pollutants, the ventilation rate applied to dilute pollutants that are generated by occupant and

<b>Groups</b>	<b>Subgroups</b>	
Chemical	Gases and vapours	Inorganic: CO, CO <sub>2</sub> , NO <sub>x</sub> , SO <sub>x</sub> , O <sub>3</sub> Organic: volatile organic compounds (VOCs), formaldehyde
	Particulate matter	Fibres: asbestos (natural fibres), mineral wool (sythetic), ceramic (vitreous and crystalline structures) Respirable suspended particles (RSPs), PM10 Particulate organic matter (POM): biocides and polycyclic aromatic hydrocarbons (PAHs)
	Radioactive particles/gases (radon and its daughters)	
	Biological	Micro-organisms, mould, fungi, mycotoxins, bioaerosols pollens, mites, spores, allergens, bacteria, airborne infections, droplet nuclei, house dust.

Source: adapted from Bluysen, 1996

Table B.3 - Main groups of air pollutants and subgroups (Bluysen, 2009)

products, and the concentration of the pollutants in the ventilation air. Bluysen (2009) points out that indoor air quality does not depend upon a single product and its emissions, but rather many sources as well as appropriate ventilation.

Sources of indoor pollutants are manifold: building materials and furnishings, consumer products and equipment as well as processes and occupant-related activities. A distinction can be drawn between primary and secondary emission. While primary emissions originate from the product itself, secondary emissions arise during the in-use phase of the product. Examples of primary emissions are VOCs that are intermittently released due to the environmental conditions (temperature and humidity variations). Examples of secondary emissions are microbial growth on surfaces and the emitted spores (Bluysen, 2009).

With regard to hospital indoor air quality three effects are of particular importance: First, the disproportionately effects of poor indoor air on vulnerable individuals (WHO European Centre for Environment and Health, 2010). Second, the particular effects of poor air quality on sleep. Third, the control and spread of airborne infectious diseases by means of ventilation and air movements.

With regard to hospital indoor air quality three effects are of particular importance: First, the disproportionately effects of poor indoor air on vulnerable individuals (WHO European Centre for Environment and Health, 2010). Second, the particular effects of poor air quality on sleep. Third, the control and spread of airborne infectious diseases by means of ventilation and air movements.

Compared to other building types, the users of hospitals have some special characteristics. The exposure to air pollutants is significantly higher within the hospital as patients are usually indoors, while at the same time patients are usually weaker and more vulnerable. Particularly old as well as particularly young people show an increased vulnerability. As elderly people spend most of their time they are at higher risk of being exposed to indoor air pollutants compared to the rest of the population (Annesi-Maesano et al., 2013; Bentayeb et al., 2013). Within the GERIE study, the most consistent relationship was found between chronic obstructive pulmonary disease (COPD) and environmental tobacco smoke (ETS). Even though, ETS is not an issue within hospitals, the elderly's vulnerability in contrast to the rest of the population is worth noting. (Annesi-Maesano et al., 2013)

An equally increased vulnerability can be seen in children. This sensitivity of children to poor air quality can be explained due to their, relative to body size, smaller airways and higher ventilation rates (Harvard T.H. Chan School of Public Health, 2017).

From a patient's point of view, hospitals are spaces to heal. Therefore, in order to recover physically and mentally, good sleep is essential. The review by Mishra, van Ruitenbeek, Loomans and Kort (2018) summarizes that indoor air quality affects sleep quality in terms of sleep depth and length. They point out that the overall consensus within literature is that lower CO<sub>2</sub> levels improve self-assessed quality of sleep as well as the subjective perception of air, better wakefulness as well as the ability to better concentrate on the day after. (Mishra, van Ruitenbeek, Loomans, & Kort, 2018)

Moreover, similar studies show that lower CO<sub>2</sub> levels implied better sleep depth, sleep efficiency and less awakenings (Mishra et al., 2018; Wargocki, Lan, Lian, & Wyon, 2018).

Wargocki et al. (2018) point out that CO<sub>2</sub> levels can quickly exceed 2,500 ppm, when two people are sharing a room with closed windows and doors during night time. Pollution levels remain particularly high, whenever multi-use bedrooms, such as inpatient rooms, are not aired out before going to bed. A solution for improved sleep can be personal ventilation and in particular, a small current of fresh air to the breathing zone. (Wargocki et al., 2018)

In a time of hospital-acquired infection (HAI), the fact that indoor air movement and ventilation can control or spread the infection in hospitals is of particularly high interest (Khodakarami & Nasrollahi, 2012). As Beggs, Kerr, Noakes, Hathway and Sleight (2008) point out, “ward ventilation could play an important role in controlling the spread of HAI”, such as airborne transmissions of tuberculosis (TB), legionnaire’s disease, and pulmonary aspergillosis. Li et al. (2007) summarize in their literature review that inappropriate airflow patterns contributed for example to the outbreaks of SARS in a ward, smallpox in a hospital, TB in a hospital, measles in a pediatric suite, and chickenpox on a pediatric floor. Tham (2016) references that personalized supply in combination with personalized exhaust could increase the effectiveness of removal of expiratory pollution from a sick person when interacting with another person, such as physicians or nursing staff.

## ACOUSTIC QUALITY

Not all sound is noise. As noise can be defined as unwanted sounds, the classification of sounds as noise depends strongly on the person that’s being considered. The same sound can result in both positive and negative experiences, depending on the user and the overall setting. This is particularly true for users within the context of hospitals. For example, a study by Johansson, Bergbom and Lindahl (2012) on the experience of sound and noise from a patient’s perspective, illustrates that sounds are perceived as positive and alarms are no longer frightening as soon as nurses explain their reasons and provide underlying information. Comparing patients to hospital staff, a distinct difference in the perception of sounds becomes obvious. The different perceptions of the sound environment can be attributed to the degree of emotional familiarity with the environment. While the hospital staff is familiar with the environment and does not experience stress and anxiety, patients are in a stressful situation per se. For patients most sounds turn into noise, because they are unpredictable (Johansson, Bergbom, & Lindahl, 2012). The fact that employees can leave the hospital, while patients remain in the hospital’s noise landscape for a longer period of time, also plays a role. However, not only is there a difference between staff and patients, even among the group of patients, the effects differ. Studies show that patients, who are sickest, are more vulnerable to sound and bad acoustics than the patients that are not in the same vulnerable condition (Johansson, Bergbom, & Lindahl, 2012). While patients are generally very vulnerable, patients in intensive care units are particularly affected. Usually intensive care patients are intubated and sedated. Control cannot be exercised and disorientation in space and time impairs the patient’s well-being.

The World Health Organization (WHO) published a guideline for community noise that consolidated information on the status-quo of noise in built environments as well as evidence on the adverse health effects of community noise (Berglund, Lindvall, & Schwela, 1999). Community noise refers to all noise sources, except noise at industrial workplaces. With regard to hospitals the WHO suggests an average

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**“When sounds and noises occur unexpectedly and beyond the patient’s control, they assault the patient unmercifully and brutally.”**

(Johansson, Bergbom, & Lindahl, 2012)

level of noise of 30 dB(A) during night, with maximum peaks of 40 dB(A) (Berglund et al., 1999). A study by Busch-Vishniac et al. (2005) analyzed objective data on sound pressure levels throughout various hospitals around the world and came to the conclusion that the majority of hospitals does not meet these threshold values set by with the WHO guidelines on community noise. According to their findings, the average equivalent sound levels within hospitals are in the 50–60 dB(A) range for 1 min, 1/2, and 24 h averaging time periods (Busch-Vishniac et al., 2005). The situation is even worse in hospital's intensive care units (ICUs). A review by Johansson, Bergbom, Wayne, Ryherd, & Lindahl (2012) summarizes studies on levels of noise in ICUs and comes to the conclusion that ICUs show mean levels ranging from 55 to 66 dB LAeq, with maximum values of 80 to 101 dB, depending on the study. Moreover, due to little variations from the lowest to highest sound pressure level, the data did not allow for determining the time of day. In other words, the nights at hospitals are just as loud as hospitals during day time. (Busch-Vishniac et al., 2005). Research refers to the multitude of present noises as noise pollution.

That inappropriate sound levels can have adverse effects on human health is commonly recognized evidence (Berglund et al., 1999; Ecophon, 2017; Joseph & Ulrich, 2007; Roger S. Ulrich et al., 2008). With regard to the effects noise has on the user, non-auditive effects and auditive effects need to be distinguished. Auditory effects include hearing loss, communication disorders, speech intelligibility and privacy loss. Examples of non-auditive effects are sleep disorders, cardiovascular disorders within patients as well as reduced performance and concentration and alarm fatigue within staff.

The noise and sound sources in hospital contexts are highly diverse and depend on the hospital's functional area that is being considered. For example, emergency departments, basic inpatient wards as well as ICUs serve highly different purposes, different people are present and different activities take place. Thus, their acoustic landscape is different. In an exemplary study, MacKenzie & Galbrun (2007) examined noise sources in intensive care units and named garbage cans, general activity, conversations, alarms as well as chair scraping, door closing and coughing as main noise sources. These findings, with a strong focus on noises caused by staff as well as medical alarms, are confirmed in a similar manner by Park et al. (2013). According to Park et al., during 24 hours, staff members are audible on average every ~15 seconds and carry out audible activities every ~6 seconds, while alarm signals of medical devices are heard every ~15 seconds.

While the different functional areas result in different acoustic landscapes, they also result in different sound fields. While inpatient rooms are in general rooms with absorbent ceilings, the emergency departments are usually designed as open-plan area and ICUs do not feature noise absorbent materials due to hygiene issues. With regard to sound reflection operating rooms constitute another extrem example. They are usually designed as hard rooms with little sound absorption. In general sound insulation needs to address different scenarios, such as room-to-room sound transmission in order to ensure privacy.

While hearing impairments are of minor relevance in the hospital context, communication disorders, limited speech intelligibility and a lack of privacy in conversations play a major role (Joseph & Ulrich, 2007). In delicate situations, such as surgeries in operating rooms, limited speech intelligibility and the associated communication disorders can have fatal consequences. An analysis by Greenberg et al. (2007) came to the conclusion that 60 out of 444 surgical errors can be traced back to communication breakdowns. In other words, poor acoustical environments can have serious implications for patient safety.

With regard to patient safety, the phenomena of alarm fatigue needs mentioning. Alarm fatigue describes the desensitization of hospital staff due to too many unnecessary alarms from medical devices. This desensitization leads to alarms that are no longer noticed in time, that do not lead to a reaction or that are even deactivated in critical cases. In this way, the safety of the patient is significantly impaired. (Solet & Barach, 2012)

With regard to non-auditive effects, the connection between stress and environmental noise is a well-known phenomenon. Among patients the effects can range from sleep loss, increased pain, prolonged stay and sleep disturbances and cardiovascular responses, such as elevated blood pressure. The effects on sleep have a special lever as they rattail along a multitude of physiological as well as psychological effects. Among staff the effects are slightly different, ranging from emotional exhaustion, burnout to experiencing high work demands, stress and annoyance as well as pressure and strain.

Joseph and Ulrich's (2007) literature review on the impacts of noise on patients provides a comprehensive overview.

## VISUAL AND LIGHTING QUALITY

The visual perceptions of and within an environment depend on lighting. Therefore, visual quality is usually assessed in combination with an environment's lighting quality. The perceived lighting quality of an environment depends on prevailing illuminance levels as well as the available spectrum of light. Both qualities of light depend on the source of light – daylight and/or artificial lighting – as well as on the spatial distribution of the light. According to Bluysen (2009), comfortable light causes neither blinding nor glare, but first of all it features a good color impression and an equal distribution of light throughout the space as well as second, controllability by the user. In terms of performance indicators, visual quality needs to optimize brightness, intensity, spectrum, flicker frequency, contrast, luminous distribution as well as dynamics (Münch et al., 2017).

Overall, lighting levels need to be appropriate for the prevailing performance tasks as well as attuned to the user performing a set of tasks. Besides the light performance indicators, the perception of light is influenced by the characteristics and state of the individual, such as sex, age, medical history, visual ability, prior light history, mood and cultural conditions (Münch et al., 2017). For example, elderly people experience a deterioration of eyesight due to clouding of their lenses. This age-related limitation leads to the need of higher lighting levels than those required by younger people (Dietz, 2018).

Light is necessary for vision and the aspects mentioned above improve an environment's visual quality. However, besides its visual effect, light also has a non-visual effect on humans. Münch et al. (2017) refer to these non-visual effects of light as "(...) brain and body processes that vary with exposure to light and are mediated by the eyes, but are not directly involved in vision." These non-visual effects present themselves in two ways: For one, by means of direct skin absorbance and the synthesis of vitamin D. Secondly, a non-

visual ocular effect on the circadian human system (Fördergemeinschaft Gutes Licht, 2014). The second effect can be referred to as light's melanopic effect that influences the synthesis of melatonin and diurnal release of cortisol (Berson, Dunn, & Takao, 2002). In 2002, Berson, Dunn, & Takao discovered that besides the classical photoreceptor cells located in the outer retina, the inner retina also contains photosensitive retinal ganglion cells (ipRGCs). These special ganglion cells are sensitive to light, but do not promote vision. Instead, they register the brightness of the environment. These ipRGCs contain light-sensitive photopigment melanopsin, with a maximum sensitivity at 480 nm. These non-visual ipRGCs are located in the lower and nasal areas of the retina so that light from the upper half-space must reach the eyes. At the same time, due to saturation behavior, several receptors need to be activated simultaneously, making large-area light sources more suitable than point-shaped ones. (Berson, Dunn, & Takao, 2002)

As light influences the synthesis of melatonin and cortisol, it directly effects the circadian rhythm and thus, light synchronizes human's physiological processes to the 24-hour light-dark/day-night cycle. Depending on the time of exposure to natural light, light can shift the circadian phases. Natural light in the early morning increases the synthesis of cortisol and thus, has a stimulating effect. Studies show that exposure to blue-enriched white light (intensity: 300 lux, color temperature: 5500K) in the early morning increases cognitive processing speed and leads to better concentration performance, compared to less blue-enriched light (intensity: 300 lux, color temperature 3000-3500K). The opposite effect occurs when one is exposed to red-enriched light in the afternoon as this triggers the synthesis of melatonin and thus, starts the natural process of tiring and increases sleep quality. (Harvard T.H. Chan School of Public Health, 2017; Münch et al., 2017)

Consequently, the wrong light at the wrong time needs to be minimized. The exposure to light, its intensity and color, needs to be optimized in terms of 'the right light at the right time'. Light is a central source of information that has the power to stabilize the human circadian rhythm by means of bright days and dark nights (Berson et al., 2002). This effect of stabilization is of particular interest for the elderly (Dietz, 2018; Fördergemeinschaft Gutes Licht, 2014). By means of melanopic light, elderly people can sleep better at night and are more active during the day.

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So light is the means by  
which the interior  
is perceived.

(Bluysen, 2009)

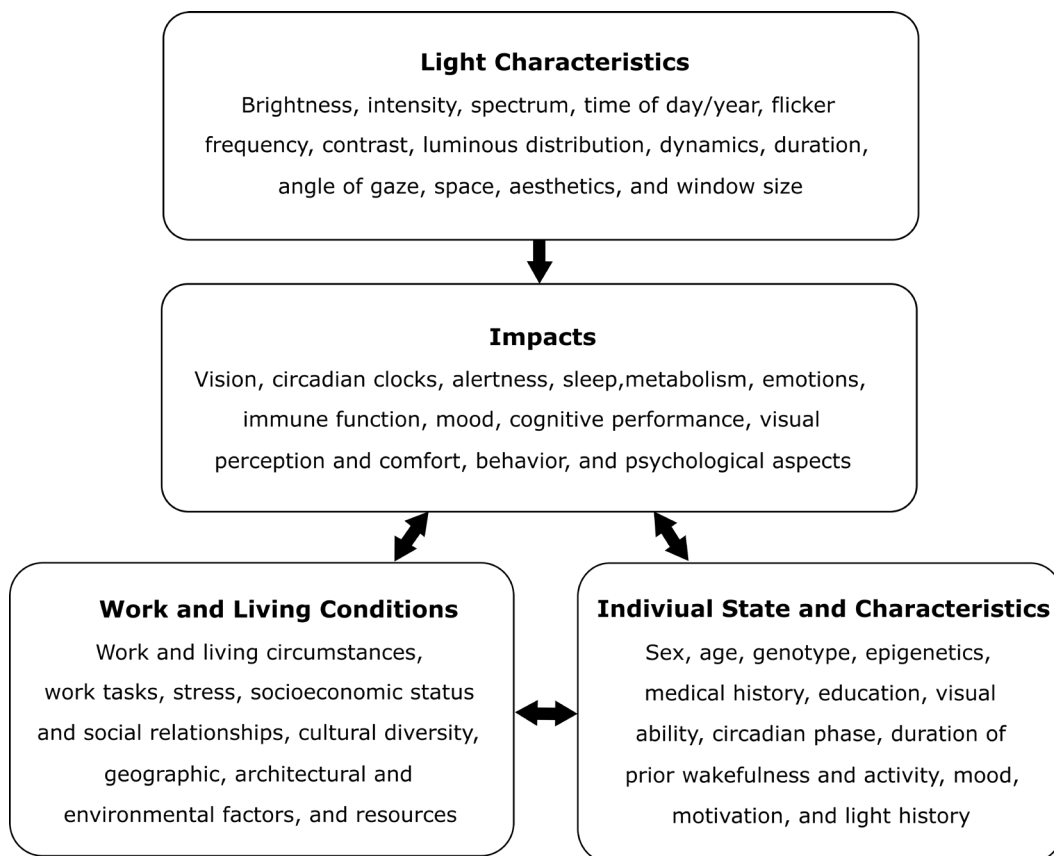
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**“The circadian system plays a key role in regulating many aspects of our physiology, metabolism and behavior including hormone regulation, sleep-wake cycles, alertness, mood and performance patterns, immune function and reproductive function.**

**Disruption of circadian rhythms, for example in shiftworkers, has been associated with multiple negative health outcomes ranging from an increased risk in accidents, chronic diseases such as diabetes and heart disease, and some types of cancer.”**

(Harvard T.H. Chan School of Public Health, 2017)



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Figure B.6 - Effects of light on humans (Münch et al., 2017)

This process of synchronizing light exposure with the circadian rhythm is essential to human health and well-being. A literature review by the Harvard T.H. Chan School of Public Health (2017) summarizes that “the circadian system plays a key role in regulating many aspects of our physiology, metabolism and behavior including hormone regulation, sleep-wake cycles, alertness, mood and performance patterns, immune function and reproductive function.”

Several studies and literature reviews confirm the positive and negative effects of natural as well as artificial light in hospital contexts (Dijkstra, Pieterse, & Pruyn, 2006; Münch et al., 2017; Ulrich et al., 2008; Walch et al., 2005). Consensus among these studies is that appropriate (day) lighting positively affects patients and staff alike. Access to daylight contributes to higher satisfaction in both groups. With regard to patients the following aspects of lighting effects can be summarize: Access to natural light can reduce patient’s perception of pain and thus, decrease the necessary amount of pain medication taken. Second, natural light in form of morning sunlight minimizes the length of stay, leading to a shorter hospital stay of patients suffering from depression. Third, sleep quality can be improved by means of adequate, melanopic lighting. With regard to medical staff evidence exists on the positive effect of light on reducing medical errors by means of improved cognitive performance.

Against this backdrop, lighting quality should be optimized with regard to both, its visual and non-visual effects. Münch et al. (2017) put together the interactions between lighting qualities, impacts on humans, the influence on working and living conditions as well as individual state and characteristics [\(Figure B.6\)](#).

In the context of hospitals, where patients rarely or not at all go outside, and their bed is not always by the window, appropriate daylighting and views of nature as well as circadian artificial lighting are of particular importance. Daylighting and circadian lighting is not only essential to normal care patients. As light is perceived subconsciously, it also promotes the recovery of patients in intensive care units (Finke & Willemeit, 2013).

In addition to daylight entry through windows and transparent areas within the façade, these areas also provide a visual connection between the patient indoors and the outdoors. Besides daylighting, this visual connection to the outdoors is essential to the perceived visual comfort of an environment. With regard to the importance of view, Ulrich (1984) published results on the potential influence of viewing nature on the course of a patient’s hospitalization in terms of length of stay and pain medication intake. Ulrich’s pioneer work laid the foundation for research on nature’s positive distracting effect as well as the restorative effects of visual access to natural environments.

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“Strong studies  
have found that  
exposing patients  
to nature  
lessens stress  
and anxiety.”

(Ulrich et al., 2008)

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# 2 FAÇADE FUNCTIONS AND DESIGN

## 2.1 TRADITIONAL FUNCTIONS

Definitions commonly refer to the façade as the building element that separates the interior environment from the exterior by being wrapped around the building's primary structure. Depending on the underlying structural concept, the façade is either realized as a massive exterior wall and therefore load bearing or as a light-weight construction that is non-load bearing. High-rise buildings are usually constructed by erecting a load bearing skeleton structure (primary structure) and wrapping it with a light-weight envelop (secondary structure).

Taking this general definition as a starting point, the multitude of facades in the built environment shows the variety of possible façade designs and constructions. In order to choose an appropriate façade design, the interconnection between façade design and performance needs to be considered. According to Hartkopf Aziz and Loftness (2012), the façade can be divided into twelve subareas; four vertical divisions – transom, viewing field, kick plate and spandrel – and three horizontal divisions – exterior, integral and interior (Figure B.7). Hartkopf et al. (2012) point out that specific subareas of a façade influence performance targets more than others. For example, the transparent area in the viewing field as well as the transom influence the amount of daylighting as well as the depth with which daylight is transmitted into the room by far more than the kick plate or the spandrel.

Thus, façade design needs to be specified according to these twelve subareas and design decisions need to be made with regard to these areas to assure a certain performance.

Taking this interconnection between design and performance into consideration, the starting point of any façade design process is the identification of key functional requirements that the façade needs to provide. Generally speaking, façade functionalities and façade design derive from functional requirements, which are based on different types of needs. During the design process the functional needs are translated into façade function that then are incorporated into the design.

While design and construction are decisive for a façade's functional scope, the different façade designs share common façade functions. These common functions are referred to as basic functions. In principle, for façade functions two groups can be distinguished: basic and specific functions. There are basic functions arise from universal needs and are satisfied by any properly functioning façade. Moreover, there are more specific functions that arise from specific needs and that are not universally incorporated into façade designs and constructions. While the first are related to issues of habitability (Knaack, Klein, Bilow, & Auer, 2014), the latter are usually rather related to issues of comfort and aesthetics.

With regard to the basic functions a reference to the human-inherent quest of shelter and security as well as the human's strives for stability and consistency can be drawn. As the building's component, which is responsible for separating the interior from the exterior environment, the primary façade functionalities are those of providing shelter and protection. The initial performance goal of any façade is to prevent fluctuation of the indoor conditions that are due to the changing outdoor conditions and ensure consistency of the inner conditions over a period of time. (Knaack & Klein, 2008; Knaack, Klein, & Bilow, 2008) Preventing fluctuation through appropriate façade design refers to optimization goals traditionally pursued within the discipline of building physics, such as heat loss/heat gain control as well as water proofing.

At the same time the functional requirements placed on facades exceed this primary need and necessitate the further expansion and enhancement of performance and façade functions. In comparison to the universal need for shelter, the specific needs are more divers and can be posed by environmental

and climate conditions, legal obligations and specific usage requirements. From a building physics point of view these needs are translated into performance indicators, such as specific minimum of heat-loss, operative temperature levels, humidity rates, illumination levels or air change rates. This secondary set of specific functional requirements matches the traditional optimization goals that are being pursued within the discipline of indoor environmental quality.

Facades that provide shelter and address climate- and usage-specific functional needs in their design reflect the current scope of façade functionality. [Figure B.8](#) summarizes all façade functions that are provided by nowadays façade designs. Within this thesis this combination of needs and corresponding functionalities are referred to as the traditional façade functionalities that are incorporated in nowadays façade design. Examples for such traditional façade functions are heat gain and heat loss control, ventilation and waterproofing.

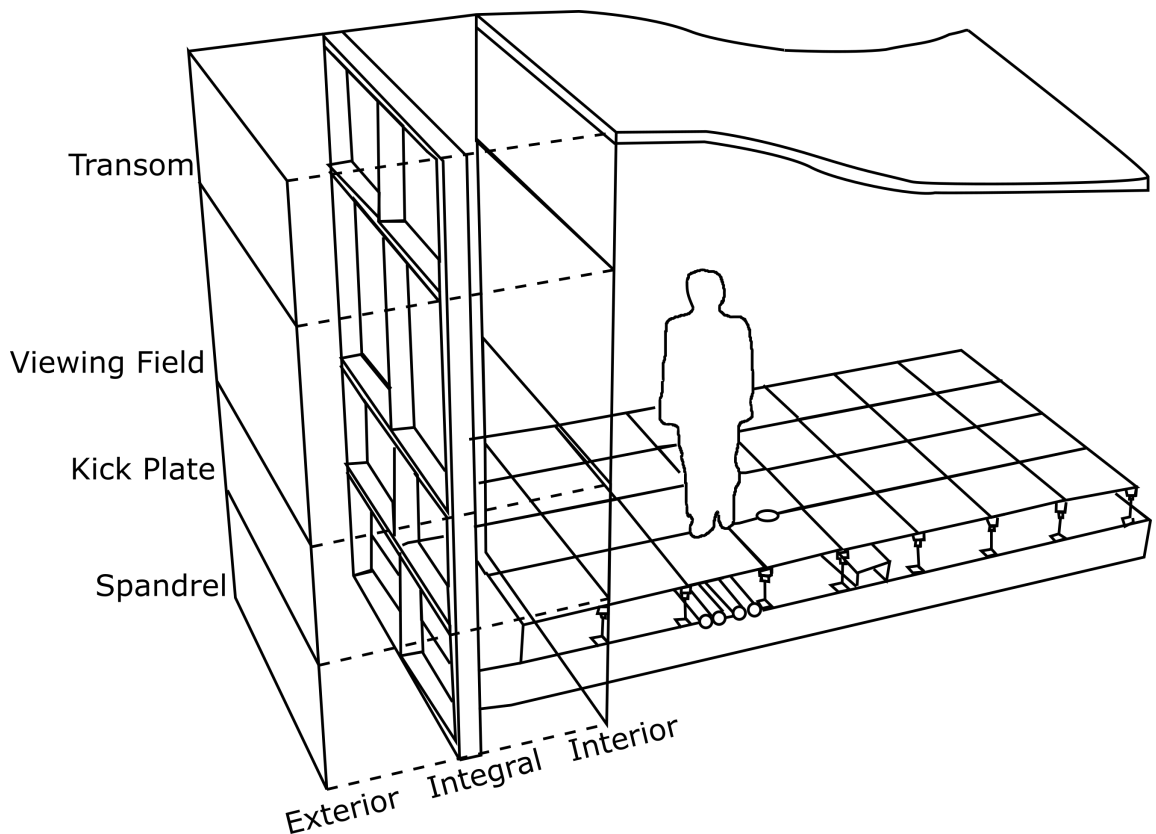


Figure B.7 - Areas of a façade that are critical to various performance requirements (Hartkopf et al., 2012), adjusted colors

For detailed descriptions of the different façade functions and performance indicators, a reference is made to Moro, Rottner, Alihodzic, & Weißbach (2009), Knaack, Klein, Billow & Auer (2014); Knaack & Klein (2008), Lovel (2013), Emmitt (2013), Preiser & Vischer (2005).

According to Emmitt (2013), the set of required functionalities and performances strongly changed and expanded over time. The set of requirements reflects the general challenges that the built environment and the building industry face at a certain time.

While the majority of built facades fulfills this set of functions, one example shall be pointed out in particular. The example emphasizes the clear differences between non-dynamic and dynamic façade

systems and bridges the topics of traditional functions of facades and adaptive façade systems. The low-tech office building '2226' in Lustenau by Baumschlager Eberle Architects, built in 2013 (Baunetz Architekten, 2013). The '2226' can be referred to as an extremely massive, non-dynamic as well as non-technical façade construction (outer wall, load-bearing) (Baunetz Architekten, 2013). Stable temperatures inside the building are not achieved by mechanical components that are adaptable and dynamic, but by large volumes of building materials that serve as thermal mass for energy storage. There is no need for any heating, ventilation or cooling systems. Thermal comfort in the interior is ensured solely through the façade - and that without it being designed as a dynamic and adaptive system. Thus, the façade provides shelter and address climate- and usage-specific functional needs.

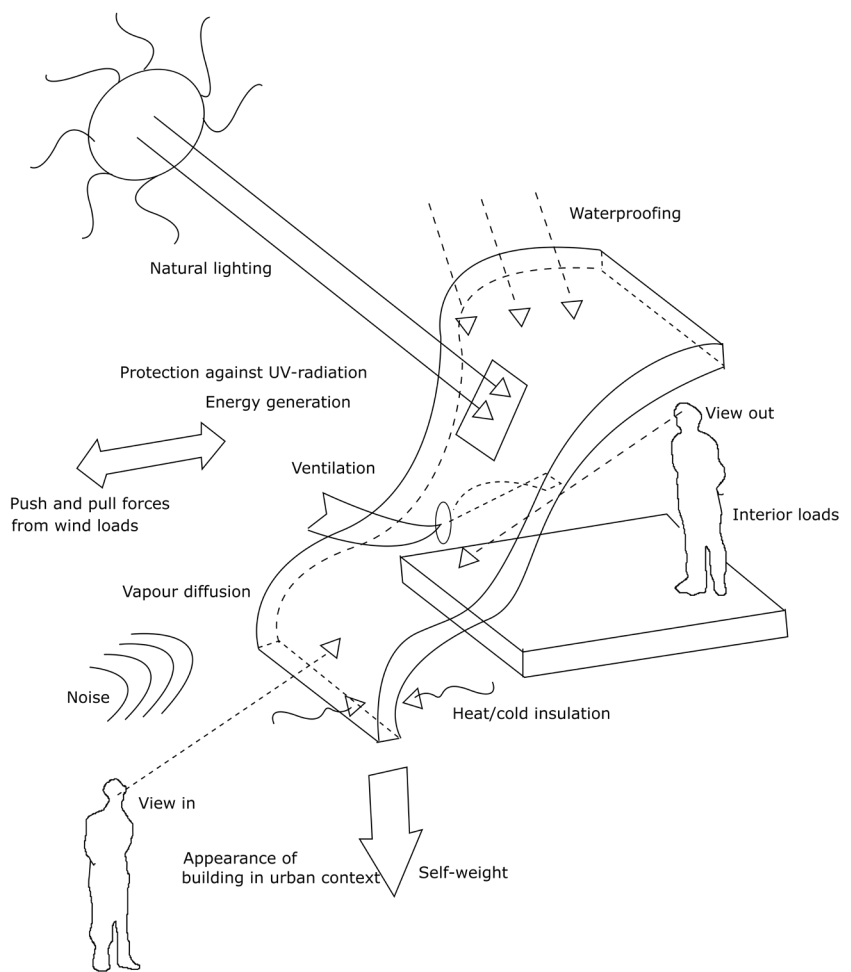


Figure B.8 - Traditional façade functions (Knaack et al., 2014)

## 2.2 ADAPTIVE FAÇADE FUNCTIONALITY

In order to reduce the impairing influence of exterior fluctuations on interior environmental conditions even further, adaptive facades are being developed. An example for such an adaptive façade is the office building ‘Al Bahr Towers’ in Abu Dhabi Island by AHR architects, built in 2012. The ‘Al Bahr Towers’ can be referred to as a dynamic, computational façade. Its foldable lattice shading screens respond to the sun path and thus, improve daylighting as well as reduce glare (AHR Group Limited, 2013).

Loonen et al. (2015) define adaptive facades as “(...) multifunctional and highly adaptive systems, where the physical separator between the interior and exterior environment, i.e. the building envelope, is able to change its functions, features or behavior over time in response to transient performance requirements and boundary conditions, with the aim of improving the overall building performance.” Given the dynamics of environmental conditions, the performance of adaptive facades is no longer static over time, but dynamic within different time periods, i.e. within the range of seconds, minutes, day/night change up to seasons, years or decades. By being adaptive, the thermal, optical, air-flow as well as electrical performance of the façade is being influenced; moisture and acoustic performance are also possible (Loonen, Trčka, Cóstola, & Hensen, 2013). With regard to functionality, the functional scope of adaptive facades is based on the traditional façade functions as stated above. In most cases adaptivity is used to achieve a higher level of indoor environmental quality in the sense of traditional building physics and thus, optimized the already existing functions without adding new ones.

Currently, various conceptual approaches to implement adaptivity into the façade are being pursued in research, e.g. integration of adaptive glazing, phase change materials and shape memory alloys, to name a few technologies. Most of the main principles of adaptive facades are being inspired by nature and represent biophilic or biomimicry approaches.

A distinction can be made with regard to the scale of the adaptation. The adaptation can occur on a macro level, meaning that the façade and its kinetic

elements are moving and adapting its configuration. The adaptation can also take place on micro level, meaning within the materials themselves. (Loonen et al., 2013)

Loonen et al. (2015) suggest a comprehensive matrix for the classification of these different approaches. [Table B.4](#) shows this classification matrix. Following this classification scheme, adaptivity can be distinguished with regard to the improved overall objectives, such as thermal environmental conditions, (overheating, heat loss reductions, etc.), indoor air quality (ventilation, filtration, etc.), visual comfort (view, glare reduction, etc.), acoustic quality (especially airborne sound) or energy performance (loss reduction, energy generation, etc.).

---

Adaptive facades  
are referred to  
by various names:

dynamic facades,  
transformative facades,  
active facades,  
kinetic facades,  
kinematic facades  
or automated facades.

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Generalizing across all conceptual approaches, the overall objective of adaptive facades can be summarized as reducing the impairing influences of (extreme) exterior fluctuations on the interior environmental conditions and ensuring steady indoor environmental conditions. ‘Steady’ should not be misunderstood as ‘static’ conditions, but rather as conditions that do not exceed certain thresholds with respect to frequency and amplitude.

of environmental conditions through behavioral adjustments and psychological adaptation.

Following the adaptive comfort model by de Dear and Brager (1998), the user can adapt to this range

Goal / purpose	Responsive function	Operation	Technologies (materials & systems)	Response time	Spatial scale	Visibility	Degree of adaptability
Thermal comfort	Prevent, Reject, Admit or Modulate (Store, Distribute) <u>solar gains</u> , and conductive, convective and long-wave radiant <u>heat flux</u>	Intrinsic	Shading	Seconds	Building material	No	On-off
		Extrinsic	Insulation	Minutes	Façade element	Low	Gradual
			Switchable glazing	Hours			
			PCM	Day-night	Wall	High	
			Solar tubes	Seasons	Fenestration		
Indoor air quality	Controlled porosity for exchange and filtering of <u>outside air</u>		BIPV and solar thermal systems	Years	Roof		
			Shape memory alloys	Decades	Whole building		
			Façade openings				
Visual performance (illuminance, glare, view)	Prevent, Reject, Admit or Redirect <u>visible light</u>		Kinetic systems				
Acoustic quality	Prevent, Reject, Admit or Redirect <u>sound pressure</u>		Radiant glazing				
Energy generation	Collect and convert <u>wind energy</u> and <u>sunlight</u> into electricity and thermal energy		...				
Personal control	User interaction and adaptation to individual needs						

Table B.4 - Loonen et al.'s matrix of descriptive characterization concepts for façade adaptivity (Loonen et al., 2015)

## 2.3 USER-CENTERED FACADES

Analyzing the traditional façade functions as described by Knaack et al. (2014) and the definition of adaptive facades as well as the classification matrix given by Loonen et al. (2015), the dominant influence of climatic conditions on façade design. Traditional as well as adaptive facades in particular are primarily tailored to environmental influences that are climate-related and provide functions that optimize indoor environmental quality from a traditional building physics point of view. An explicit reference to the user within the building and available forms of interaction are studied in a subordinate manner.

With the definition of adaptive facades in mind, it becomes clear that the concept of “adaptivity” seldom implies the notion of “the façade being attuned to various users”. Nor does the common understanding of adaptivity in façade stands for incorporating users’ different forms of abilities to interact with the façade system. Research on adaptive facades in the majority of cases does not represent façade designs with regard to contextual and user-specific forms of human-façade-interactions. Human-Façade-Interaction – in relation to Human-Machine-Interaction or Human-Computer-Interaction – is not commonly considered, yet. This user-centeredness of façade design with a strong and in-depth focus on users, their abilities and interactions with the building, slowly begins to develop.

For example, the use and research on media facades is slowly shifting from displaying and communicating pre-produced content, like advertisements, towards interactive systems that allow people to interact and engage with the façade and the building (Gehring & Wiethoff, 2014). A different, even better example for depicting this development towards user-centered façade design that is adaptive to individual users and their abilities, is the kinematic façade system “Mood Swing” (Moulton, Rocco, Kider (Jr.), & Fiore, 2018). This interactive façade system attempts to get a better understanding of the user occupying the space within the building and optimizing the façade’s adaptivity accordingly.

The “Mood Swing” façade ‘senses’ and ‘interprets’ the varying moods of the room’s occupants and responds to them by adjusting the daylighting lux level within the room as well as freeing views of nature for building

occupant in an automated manner. In order to sense occupants and their mood, a commodity camera-based system with polarized light is used. Based on the Attention Restoration Theory developed by Kaplan and Kaplan, the underlying notion of this façade system is that by adjusting daylighting and views of nature, the occupants’ emotions can be improved by means of stimulating biological and psychological processes (as in Moulton, Rocco, Kider (Jr.), & Fiore, 2018)

With façade systems, such as the “Mood Swing” by Moulton et al. (2018), adaptive facades get increasingly interwoven with the trend of ubiquitous computation and the discipline of Human-Computer-Interaction, as the building turns into a computational machine (Velasco, Brakke, & Chavarro, 2015).

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# 3 TOWARDS USER-CENTERED DESIGN

## 3.1 PERFORMANCE-BASED DESIGN

The inherent goal of most design processes – including façade design – is to ensure a well-designed product that serves its envisaged purpose, supports the user’s activities and even satisfies additional needs that are set by immediate product users or any intermediate stakeholders. Performance-based design and the underlying performance concept can be understood as an approach to solving this ubiquitous design problem. The performance concept allows for the implementation of such need-centered design approach into buildings (International Council for Building Research Studies and Documentation (CIB), 1982).

Becker and Foliente (2005) define the basic idea of the performance approach as following: “The performance approach is primarily concerned with the description of what a building process, product and/or service are required to achieve (the ‘end’), not about how they should be achieved (the ‘means’).” Therefore, the performance approach forms the contrary to any prescriptive approach, which gives a detailed description of the final product or solution. While prescriptive design approaches predefine technical solutions, performance-based design approaches analyze needs and enable a more precise definition of a product’s intended behavior and performance.

The majority of building codes does not follow the performance concept. Most of the time building codes

guide the code user with particular and prescriptive requirements that lead to certain predefined ways of construction.

The performance concept compares demands and technological possibilities of supplies and embodies an intuitive approach that reflects human manner (Becker, 2008). By applying the performance concept, one focuses on analyzing needs (demand) and subsequently matching these needs with technical solutions (supply). On the demand side, a functional concept, which states all functionalities defined by immediate users and intermediate stakeholder, is requested. Consequently, the demand side is related to the intended use of the building and questions the “Why” and “What” (Spekkink, Jasuja 2005) in terms of functionality and activity. The supply side on the other hand formulates a solution concept. This solution concept relates to the technical possibilities and formulates answers in terms of technical solutions to the question “How” (Spekkink, Jasuja 2005).

The goal of the performance concept is to make the demand and the supply side congruent. For this to happen, the functional needs are translated into performance requirements and the technical solutions into performance specifications. It is possible that one specific need leads to a number of various performance requirements. A common denominator of a product’s design is found, whenever

the performance requirements (demand side) and the performance specification (supply side) are congruent or at best congruent. In order to compare performance requirements (demand side) and performance specification (supply side) performance indicators have to be defined.

Altogether it can be said that the targeted performance-in-use serves as basis for all design decisions made within the design process. The development or selection of a solution concept can be interpreted as a design decision (Ang, Groosman, Scholten 2005). Szigeti and Davis (2005) state "(...) all decisions, choices and tradeoffs start with the required performance-in-use rather than described solutions." By applying a performance-based approach to façade design one ensures that user needs are considered appropriately within the façade design. The performance concept in building design is a method that allows architects and engineers to bring together and co-ordinate (1) intended behavior, (2) design decisions, (3) exterior and interior conditions and (4) actual behavior through a common language – the language of performance requirements and performance indicators.

Performance-based design can be used to implement user-centric façade design. Since user needs are the starting point of the design process, it should be possible to meet user needs. However, there is a potential risk that not all types of needs are identified within a performance-based design process, but only those for which pre-defined performance indicators exist. With regard to building physics, performance indicators are classically defined for IEQ topics and thus represent areas such as temperature, relative humidity, lighting, etc. Aspects of functional and, in particular, psychological comfort, such as control, would not be taken into account. Consequently, performance-based design serves as a starting but, but needs additional refinement in terms of identification and consideration of user needs.



## 3.2 UNIVERSAL DESIGN

The term 'Universal Design' should not be confused with universal principles of design, such as the compilation of design concepts by Lidwell et al. (2010). While the latter provides 125 cross-disciplinary hands-on design methods, the term 'Universal Design' was coined by North Carolina State University's Center for Universal Design in 1997 (Connell et al., 1997).

According to the Center of Universal Design's definition, Universal Design describes a mindset and design framework that focusses on the people, who wish to use a design object, as the fundamental condition of good design (Connell et al., 1997). Universal Design is often referred to as inclusive design – two design frameworks that basically address the same objective and are often used synonymously. Inclusive design emphasizes the necessity to adapt design to the needs of disabled people, while Universal Design does not specify the user group. However, as Story (2011) puts it in the Universal Design Handbook: "Regardless of wording, the goal is profound: we can and should make our human-made world as accessible and usable as possible for as diverse a user population as possible."

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### **UNIVERSAL DESIGN:**

The design of products and environments to be usable by all people, to the greatest extent possible, without adaptation or specialized design.

(Connell et al., 1997)

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This mindset of design is instrumentalized by seven guiding design principles. For a detailed description of each principle see the original publication by the Center for Universal Design (Connell et al., 1997).

Following the definition as well as the seven principles in detail, Universal Design aims for environmental designs that are usable to the greatest extent possible by all people regardless of their age, size, gender, ethnicity, ability or disability. The premise applies that well-designed products serve strongly differing needs and abilities of various user groups simultaneously. Therefore, the objective of Universal Design is not to design as many individual, target group-specific products as possible. On the contrary, while deliberately considering different user groups, Universal Design results in universally applicable products that can be used as satisfactorily as possible by different user groups.

This consideration of different user groups does not only refer to groups of people, who are typically referred to as disabled, but include society as a whole. The diversity of society is decisive here and serves as a starting point for any design consideration. A team of designers at Microsoft covered the subject of inclusive design and stated that disabilities are a result of mismatched interactions and can happen in form of physical, cognitive, and social exclusion. While usually only permanently disabled are included in the design considerations, the team points out that exclusions can also be of temporary and/or situational character. According to the design guidelines, by designing for someone with a permanent disability, someone with a situational or temporary disability or limitation can benefit just the same. In order to pay attention to the broader audience that might be affected by a design solution, the design team at Microsoft introduced the persona spectrum. (Microsoft Design, 2016) ([Figure B.9](#)).

Given these principles by the Center for Universal Design, it becomes clear that the notion of Universal Design exceeds the design and planning recommendations given in the DIN 18040 'Construction of accessible buildings - Design principles' (DIN Deutsches Institut für Normung e.V., 2010). While DIN 18040 focuses on the needs and abilities of physically handicapped

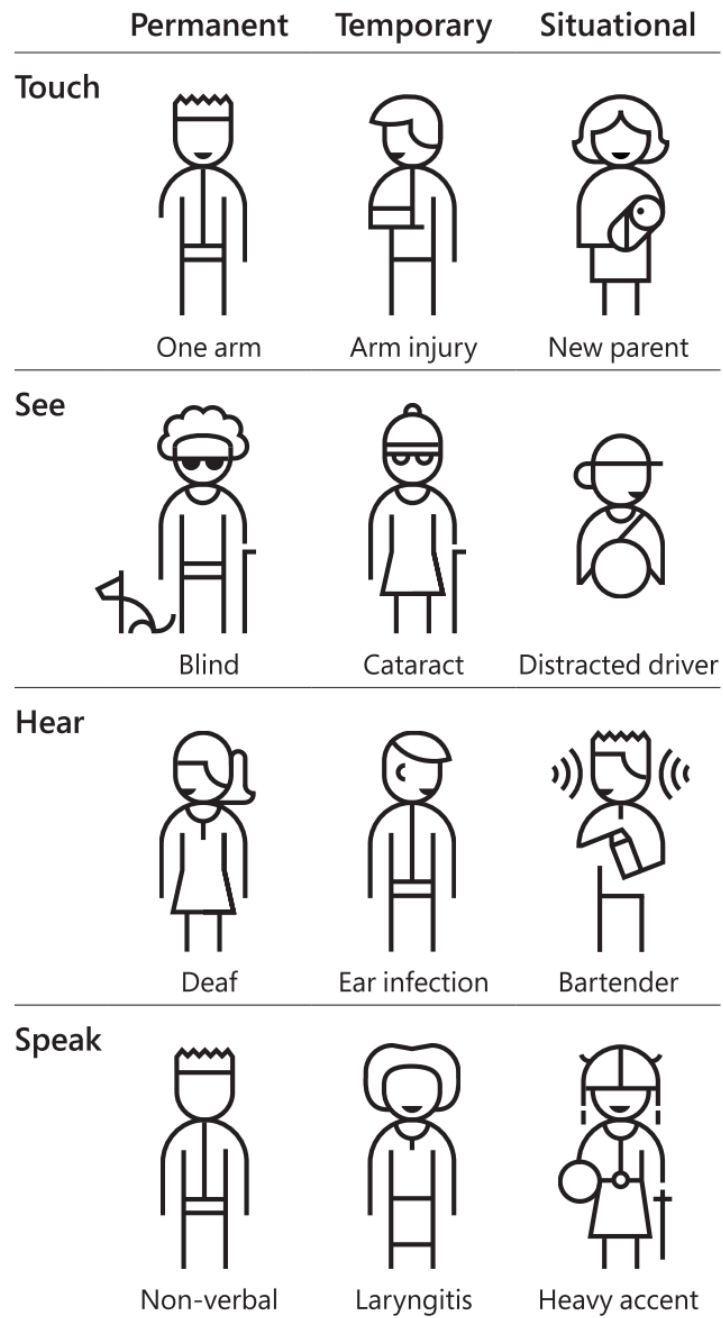


Figure B.9 - Persona spectrum by Microsoft's inclusive design team (Microsoft Design, 2016)

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# Seven Universal Design Principles

(Connell et al., 1997)

## PRINCIPLE 1: EQUITABLE USE

The design is useful and marketable to people with diverse abilities. Guidelines:

- 1a. Provide the same means of use for all users: identical whenever possible; equivalent when not.
- 1b. Avoid segregating or stigmatizing any users.
- 1c. Make provisions for privacy, security, and safety equally available to all users.
- 1d. Make the design appealing to all users.

## PRINCIPLE 2: FLEXIBILITY IN USE

The design accommodates a wide range of individual preferences and abilities. Guidelines:

- 2a. Provide choice in methods of use.
- 2b. Accommodate right- or left-handed access and use.
- 2c. Facilitate the user's accuracy and precision.
- 2d. Provide adaptability to the user's pace.

## PRINCIPLE 3: SIMPLE AND INTUITIVE USE

Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level. Guidelines:

- 3a. Eliminate unnecessary complexity.
- 3b. Be consistent with user expectations and intuition.
- 3c. Accommodate a wide range of literacy and language skills.
- 3d. Arrange information consistent with its importance.
- 3e. Provide effective prompting and feedback during and after task completion.

## PRINCIPLE 4: PERCEPTIBLE INFORMATION

The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities. Guidelines:

- 4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.
- 4b. Maximize "legibility" of essential information.
- 4c. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).
- 4d. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.

## PRINCIPLE 5: TOLERANCE FOR ERROR

The design minimizes hazards and the adverse consequences of accidental or unintended actions. Guidelines:

- 5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.
- 5b. Provide warnings of hazards and errors.
- 5c. Provide fail-safe features.
- 5d. Discourage unconscious action in tasks that require vigilance.

## PRINCIPLE 6: LOW PHYSICAL EFFORT

The design can be used efficiently and comfortably and with a minimum of fatigue. Guidelines:

- 6a. Allow user to maintain a neutral body position.
- 6b. Use reasonable operating forces.
- 6c. Minimize repetitive actions.
- 6d. Minimize sustained physical effort.

## PRINCIPLE 7: SIZE AND SPACE FOR APPROACH AND USE

Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility. Guidelines:

- 7a. Provide a clear line of sight to important elements for any seated or standing user.
- 7b. Make reach to all components comfortable for any seated or standing user.
- 7c. Accommodate variations in hand and grip size.
- 7d. Provide adequate space for the use of assistive devices or personal assistance.

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individuals, Universal Design covers a broader perspective ranging from choice in methods of use beyond providing information to minimizing hazards of unintended actions. The principles of Universal Design as defined by the Center for Universal Design can be used to implement user-centricity into façade design. By applying the principles of universal design any design becomes more attentive to individual differences between user groups and the influence these differences have on interaction. As facades are usually interacted with by a multitude of users with diverse needs and abilities the design could benefit from the application of a Universal Design approach.

Within the context of hospitals, the principles of Universal Design are increasingly being applied and taken into account. By applying Universal Design guidelines to hospital design the needs of medical staff as well as different user groups are being considered. While the use of Universal Design creates added value for many types of use, the added value for hospital and/or healthcare buildings in general is at its greatest. As hospitals bring together a multitude of various users with a high variability in terms of physical attributes, sensory functionality, overall abilities, mental constitution and resulting functional needs, universal design offers an approach to respond adequately.

## 3.3 INTERACTION AND EXPERIENCE DESIGN

In this dissertation, the concept of user experience (UX) design is approached by differentiating the term from related, sometimes even interchangeably used terms, such as ‘Usability’ or ‘Interface Design’. The term UX design is put into the wider perspective of ‘Human Computer Interaction’, ‘Human Building Interaction’ and ‘Interaction Design’ in general.

UX is often thrown in the same pot as the terms ‘Usability’ and ‘User Interface’ (Interaction Design Foundation, 2017), however the terms are not congruent. While ‘Usability’ describes the ease of using a product and ‘User Interface Design’ covers the design of the actual, immediate interface that one interacts with, ‘Interaction Design’ addresses the overall interaction between the user and the immediate product. Despite their differences, all these terms share two fundamental features. First of all, they all focus on people while being embedded in a technology context. Second, as human-centered approaches that address technology, they originate from and are highly interconnected with the field of Human-Computer-Interaction (HCI) – a research field that studies the interaction between humans and computers or computational devices, respectively. Consequently, HCI – as an academic discipline as well as a design discipline – is a highly interdisciplinary field of research that brings together technology, psychology and sociology, ergonomics as well as product design. HCI is a rather young research discipline that started

with examining the interaction between an individual person and their personal computer in the 1980s. Nowadays, as the transition towards ubiquitous computing is unstoppable, HCI research as well as its application in design shifts from a dialog with a single computer towards a dialog with a complex digital world within which computation is not only present in personal computers and devices, such as tablets and smartphones, but increasingly part of everyday devices and appliances. (Dix, 2018)

This shift of ubiquitous computing and the accompanying blurring between physical and digital world, brings to light the need for an even wider scope of consideration. By relating to the overall product life cycle and all elements that need to be considered (Preece, Sharp, & Rogers, 2015) – not only the actual product that’s being sold –, UX design addresses an even wider scope of interaction and incorporates the blending of physical and digital. Usability, user interface design and interaction design can be regarded as one element of UX design, covering different scopes. As each product’s user experience consists of direct interaction between the user and the product, overlap between these disciplines is unavoidable. Preece et al. point (2015) even out that “(...) one cannot design a user experience, only design for a user experience”. By choosing suitable design features and providing utility that users need in the first place, a desired user experience can be evoked.

In order to define these suitable features and utility in terms of functions, which are sensitive to the human experience, UX design needs to understand the users that interact with the product as well as their corresponding abilities and needs. This way the users can benefit from the interaction with the product. The Interaction Design Foundation (2017) defines seven factors that influence user experience and serve as leverage for successful UX Design.

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**The  
Internet  
of Things:  
a shift towards  
ubiquitous  
computing.**

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# Seven Factors of User Experience Design

(Interaction Design Foundation,  
2017)

## **FACTOR 1: USEFUL**

Having purpose and in the eye of the user delivering practical or non-practical benefits, such as fun or aesthetic.

## **FACTOR 2: USABLE**

Enabling the user to achieve an end objective in an effective and efficient manner.

## **FACTOR 3: FINDABLE**

Easy to find; refers to the products themselves as well as the information they contain and deliver.

## **FACTOR 4: CREDIBLE**

Trustworthy, accurate and reliable; refers to the ability of the product to provide the job it is supposed to do as well as the overall life time.

## **FACTOR 5: DESIRABLE**

Preferred over another product by functionality as well as emotional design, branding and aesthetics.

## **FACTOR 6: CREDIBLE**

Accessed by all abilities; refers to inclusive design so that users with hearing, vision, motion or other forms of disabilities are still able to use the product and experience the same kind of experience.

## **FACTOR 7: VALUABLE**

Creating benefit through use.

Comparing the factors of successful UX Design to the principles guiding the notion of Universal Design, the overlap between the two design approaches becomes obvious. Universal Design addresses in detail the aspects of usefulness as well as usability and accessibility within UX design. This trend of ubiquitous computing does not only concern consumer goods, but also spreads to buildings as they are increasingly automated with increasing sensor and actuation capabilities. Examples are smart homes, intelligent heating systems, intelligent access systems, etc. Nembrini and Lalanne (2017) outline the emergence of ‘Human Building Interaction’ (HBI) as a discipline that’s being rooted within the field of HCI and at the same time emphasizes its importance as well as future significance (Figure B.10). The Swiss based smartlivinglab, a center of competence on the built environment of the future, established HBI as a research field and tries to adopt a traditional HCI approach to study the interaction between building and their users. By now, the research focus can be subsumed into two main branches: understand building occupants’ behavior in order to build automatic systems and systems to improve occupants’ awareness of the building by providing information (Lalanne, Alavi, Nembrini, & Verma, 2016).

Nembrini and Lalanne (2017) argue that HCI research up to now neglects building sites, building structures

and building skins, although ubiquitous computing enters into the building sector, shows similarities to HCI, but brings along a special feature: As Nembrini and Lalanne (2017) put it, in contrast to traditional HCI “(...) in which a user interacts with a machine through well-defined and circumscribed modalities, HBI considers users as completely immersed in an interactive object. (...) An important consequence is that the user cannot terminate the interactive session without leaving the space.”

While modern home automation systems tend to favor automatic control that is being attuned to an average user, specific comfort needs that are set by individual user groups are not met. This failure leads to frustration, disappointment and an overall negative user experience with the system. Due to HBIs specialty that the user is constantly immersed, the necessity of implementing satisfying UX design into the design process of future buildings becomes clearer. As UX design originates from the interaction between humans and digital product and services, not all of the seven factors mentioned above are applicable to the built environment on a one-to-one basis. Nevertheless, they can serve as guiding principles in order to enhance the user’s interaction and overall experience when interacting with the built environment, and buildings in particular.

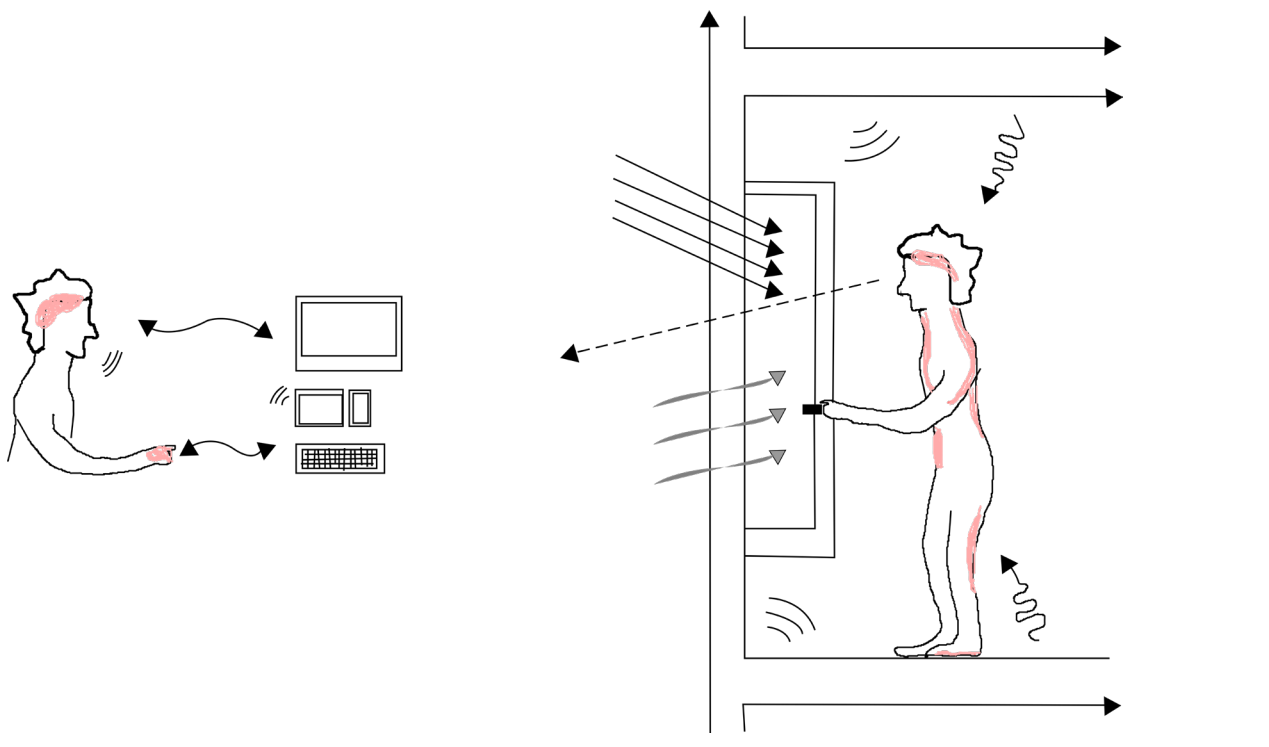


Figure B.10 - Standard HCI (left) compared to human-building interaction (right). Interaction feedback uses multiple sensory channels: Tactile, acoustic, visual, radiative, convective or olfactory (Nembrini & Lalanne, 2017)





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# C METHODOLOGY

The chapter on methodology gives an overview of the methods that were applied within this dissertation, presents their dependencies and shows how the research question, the used methods and the results are related. Before the following subchapters discuss the basic principles of the methodology, the applied methods, and their relation to the final results, the dissertation's underlying research style and the reasoning process are explained.

In order to assign this dissertation a general research style, a distinction between two questions that are addressed within this thesis, must be made: On the one hand, the dissertation addresses the methodological question on finding a suitable method for developing user-centered façade functions. On the other hand, within this dissertation it is tried to answer the operative question on future functions themselves. In other words, in contrast to the actual development of new functions, the dissertation's main research question is to examine the applicability of the Design Thinking methodology when developing new façade functions. Due to its methodical nature, the research question on a suitable methodology provides a framework for the more operative question on actual functions. While the two questions are very

closely linked, the underlying reasoning process is very different.

According to Kolko, creative processes and in particular the design synthesis phase to generate ideas for new product developments can be defined as an "abductive sense making process" (2010). In contrast to deduction and induction - two other forms of logic reasoning - abduction can be used to generate new knowledge as new theories and new solutions. The abductive reasoning process describes the development of a new rule for data or problems for which there is no adequate explanation or solution, yet (Flick, 2014; Flick, Kardorff, & Steinke, 2004). The 'Grounded Theory' methodology, in the original form by Glaser and Strauss (1967), is an example of abductive reasoning (Johansson-Sköldberg, Woodilla, & Çetin-kaya, 2013). As the answer to the question of user-centered functions of the façade requires the generation of new knowledge, it can be considered an abductive reasoning process. This contrasts with the reasoning process that underlies the main research question on a suitable method for developing these new functions of future hospital facades.

The focus is not on generating a completely new approach, but on drawing conclusions in terms of testing and adapting an existing approach. Such a reasoning process is not of abductive nature, but rather can be described as deduction: An existing theory is applied to a particular case or data set (Flick, 2014; Flick et al., 2004). In case that the existing theory requires adjustments and/or further development, this can be done inductively by supplementing the existing theory. According to Eisenhardt and Graebner, inductive and deductive reasoning processes complement each other in the process of theory building (2007). Following a deductive reasoning process, the principles of the Design Thinking methodology are applied in order to generate user-centered façade functions.

Within the framework of the Design Thinking process, various methods are applied, all of which can be assigned to the field of qualitative research. Overall, the dissertation is designed as a snapshot case study, providing for a more detailed reconstruction of specific cases at the time of the research. Thus, this research design can be distinguished from comparative studies, which provide a comprehensive comparison of a large number of cases, as well as longitudinal or retrospective studies, which investigate different points in time. Against the background of the case study, no claim is made to general validity (Flick et al., 2004).

In the following an overview of the Design Thinking methodology and its connection to the abstraction method as well as a description of the individual methods, that make up the methodology, is given.

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**„In fact, inductive and deductive logics are mirrors of one another, with inductive theory building from cases producing new theory from data and deductive theory testing completing the cycle by using data to test theory.“**

(Eisenhardt & Graebner, 2007)

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# 1 ABSTRACTION AND DESIGN THINKING

Products that solve an existing problem in a very innovative and thus novel way usually do not emerge through a systematic and incremental refinement of previously known solutions. While such incremental improvements are an essential part of product development processes, they usually do not result in disruptive product innovations. On the contrary, knowledge about already existing approaches usually prevents the development of innovative solutions.

Innovative product ideas that provide a specific answer to a specific problem can usually not be developed on the spot. In order to develop innovative product ideas, one needs to suppress the knowledge of existing solutions and access one's creative potential. However, 'outside the box'-thinking and creativity are neither spiritual, nor subject to creative individuals, but rather can be made accessible through strategies that structure the design process. Among others, Lindemann summarizes that the method of abstraction can be used as such a strategy (2016).

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Innovation  
requires  
'outside the box'  
thinking.

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The method of abstraction translates a specific problem into an abstract problem, subsequently solves this abstract problem on an abstract level and finally translates it back into a specific solution. In other words, via abstraction one reframes a specific problem into an abstract problem and thus, identifies the core of the design challenge ([Figure C.1](#)).

On the basis of this solution-neutral design challenge, an unbiased understanding of the design problem can be obtained and subsequently translated into a specific design solution. By taking this intermediate step of abstracting the initial problem, a deeper understanding of the initial problem can be obtained and the attachment to existing solutions can be reduced. (Lindemann, 2016) In this manner, a bottom-up approach for problem definition is combined with a top-down approach for solution seeking. This combination allows for a significantly broader, more diverse and innovative development of solutions that address the core of the design challenge. By using the method of abstraction one can ensure that the main problem is addressed and technology is not merely applied.

Human-centered innovation methods, such as Design Thinking, are fundamentally based on the application of abstraction. While design thinking can be defined as a structured process for creative problem solving, two key assumptions of Design Thinking imply the necessity of applying abstraction throughout the design process.

First, a Design Thinking mindset assumes that instead of addressing a problem from technical solvability, the key to innovation and well-designed products is a comprehensive understanding the core of the design

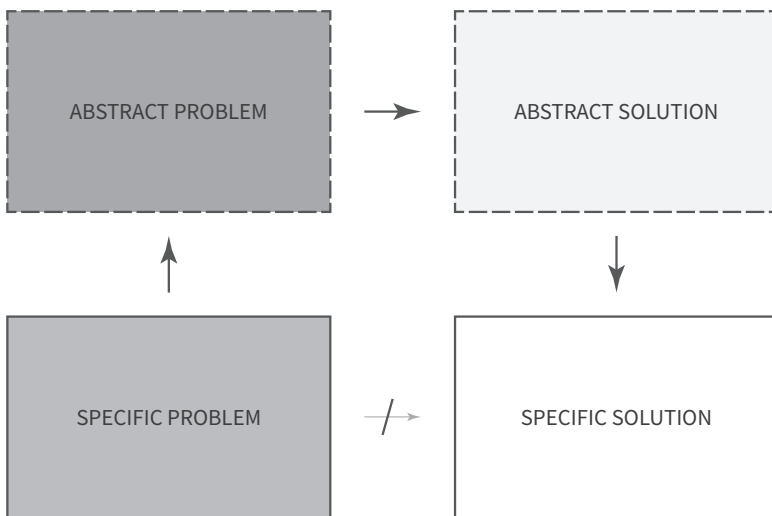


Figure C.1 - Abstraction method: From a specific problem to a specific solution via abstraction

challenge. This means that the core problem is seldom obvious in the beginning, but requires an analysis of explicit as well as in particular implicit user needs (Brown, 2009; Camacho, 2016). Thus, abstracting the initial problem by reframing it according to user needs, is the starting point of any Design Thinking process.

Second, the Design Thinking process is based on the assumption that it is very difficult to come up with an innovative solution to a specific problem right off the bat. A Design Thinking mindset is rather occupied with getting past obvious solutions and expanding the solution space by means of abstraction. Abstracting the design problem as well as the solution space helps to question the assumed design challenge, dig deeper into the design problem and free one's mind from already existing solutions.

Consequently, Design Thinking and other abstraction-based design methods assume, that in order to

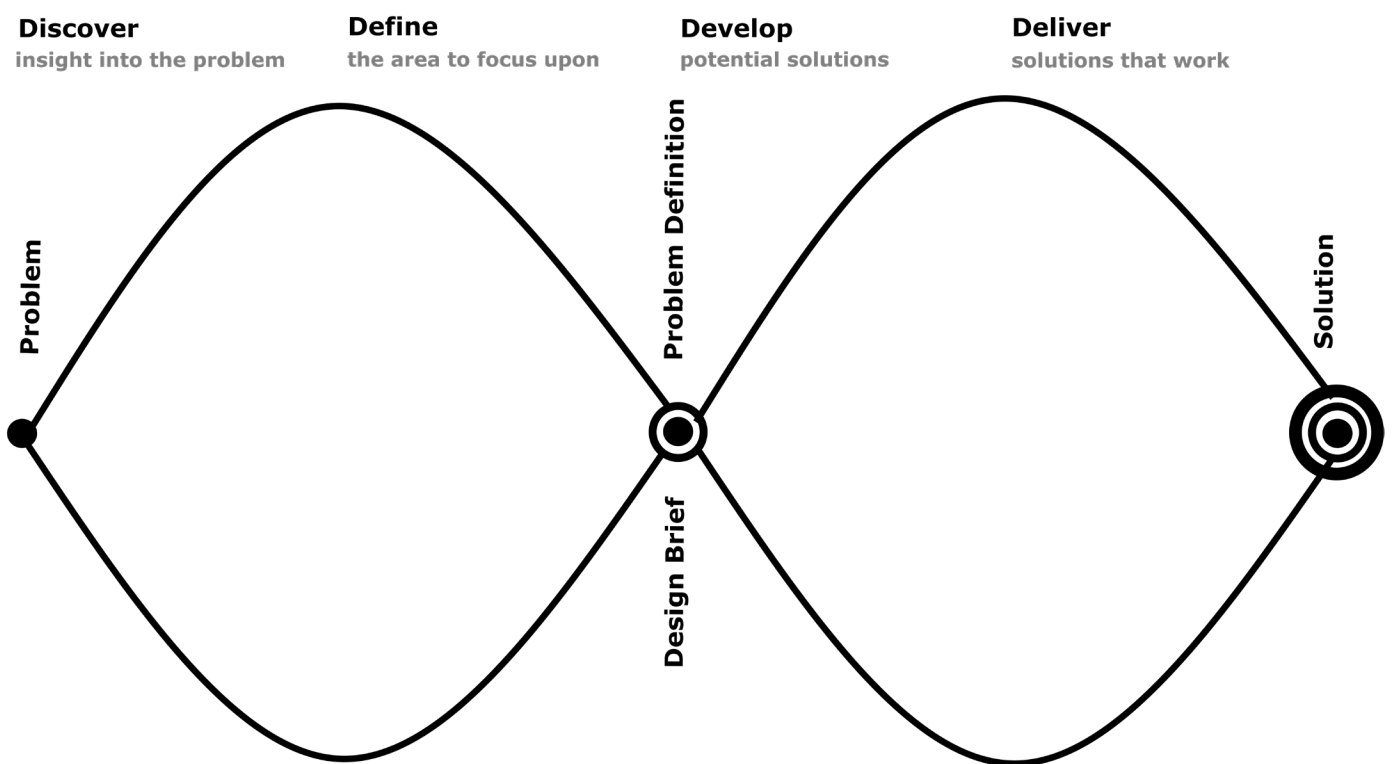
confirm the problem definition as well as to create a suitable solution, reframing and abstraction is needed. (Brown, 2009; Camacho, 2016; Doorley, Holcomb, Klebahn, Segovia, & Utley, 2018)

In order to meet these two key assumptions, design processes, such as Design Thinking, follow alternating phases of divergent and convergent thinking. The Double Diamond model by the Design Council (2018) illustrated the idea of divergent and convergent thinking. The Double Diamond analogy is the Design Council's graphical visualization of a design process that states that the problem as well as the solution spaces must first be deliberately expanded (divergent thinking) before narrowing it down to the best idea solution (convergent thinking) (Figure C.2).

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**Design Thinking can be defined as a human-centered and structured process for creative problem solving that brings together what is desirable from a human point of view with what is technologically feasible and economically viable.**

(Hasso-Plattner-Institut, 2018)



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Figure C.2 - Double diamond process by Design Council (Design Council, 2018)

The Design Thinking process as taught at the Hasso Plattner Institute of Design at Stanford University (d.school) comprises five modes: EMPATHIZE, DEFINE, IDEATE, PROTOTYPE and TEST (Figure C.3) (Doorley et al., 2018). The phases alternate between divergent and convergent thinking – expanding the solution space before narrowing it down.

Within each phase different methods (in the sense of tools that help to design) can be chosen and applied in order to fulfill the mode’s objective. While the individual modes are usually undergone one after another, the order of precedence is not strictly specified. Usually, iterations between the phases are needed.

The methodological design of this dissertation was inspired by the presented Design Thinking process as taught at the Hasso Plattner Institute of Design at Stanford University (d.school). In all phases, a mix of methods has been used. The methods applied within the individual phases of EMPATHIZE, DEFINE and IDEATE are explained in detail in the following subchapters.

The iterative phases of the Design Thinking process were aligned with the conventional phases of academic research projects, such as literature review, definition of research design, data collection, data analysis. Given the research’s focus on the identification of environmental misfits and the derivation of functions of facades, not all five phases

of the Design Thinking process were conducted within the scope of the dissertation. During the dissertation the first three phases of the Design Thinking process were carried out and the results delivered to the project partner. The remaining phases are not part of this dissertation as these Design Thinking phases are conducted by the research partner.

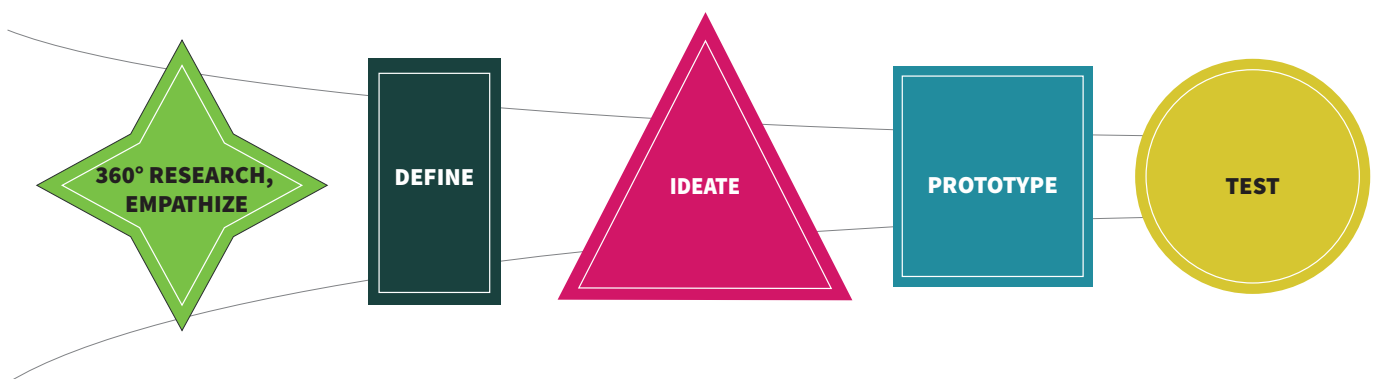


Figure C.3 - Design Thinking process by Hasso Plattner Institute of Design at Stanford University (own illustration)

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# Five Modes of Design Thinking



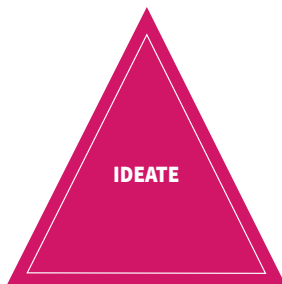
## EMPATHIZE

Any Design Thinking process starts by building empathy for the user one is designing for. First of all, the goal of the empathy mode is to identify the right user. Subsequently, one needs to get to know this user by observing, engaging and at best immersing oneself into the user's experiences. By empathizing with the user, explicit as well as in particular implicit needs come to light. The empathy mode is characterized by divergent thinking: Instead of solving a problem into the blue, Design Thinking starts by expanding the problem space to grasps its complexity.



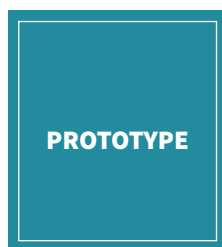
## DEFINE

Given the insights of the empathy mode, the define mode seeks to determine an actionable design challenge on the basis of the users and their environment. In order to define this design challenge, empathy findings are analyzed in terms of user needs, abilities and design limitations. The define mode is characterized by convergent thinking. Instead of getting lost in the multitude of possible problems to conquer, Design Thinking narrows down and identifies the key problem to solve.



## IDEATE

The objective of the ideate mode is 'going wide' and generate a high quantity of highly diverse ideas. While idea generation is about quantity, the evaluation and selection of ideas is about quality and narrowing it down. Therefore, the ideate mode is mainly defined by divergent thinking. Instead of drilling one solution concept into the last detail, Design Thinking generates a multitude of ideas – from obvious ones to 'out of the box' to crazy wild. However, in order to complete the ideation and shift to prototyping, a conclusive phase of convergent thinking is needed.



## PROTOTYPE

By selecting the best and most promising ideas the prototype phase starts. The goal of any prototype is to get your ideas out of one's head and into a physical form one can interact. Prototypes can be anything – 'walls of post-its' characteristic to Design Thinking, (paper) objects, stories. By using (low-resolution) prototypes one does not primarily test functionality, but gets a deeper inside into user needs and input to refine the initial design.



## TEST

While neither ideation, nor prototyping are the times to drill detail, the test mode is. By testing your prototype with users, feedback can be gathered. The testing mode should be used to test the prototype and the underlying idea, but also to indemnify the problem definition one designed for.

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# 2 EMPATHIZE FOR DATA COLLECTION

The goal of the EMPATHIZE phase is to identify the right user in order to subsequently define the right design challenge. Thus, understanding the users and the environment that they are surrounded by and interact with is key. Within this dissertation the EMPATHIZE mode was used for data collection via literature research, observation and expert interviews.

The process of data collection started with a 360° research in order to understand hospitals in terms of their functional structure, building typology and key users. This 360° research started as a desk research by conducting a broad literature research. [Figure C.4](#) summarizes the topics covered by the literature research. As illustrated, the literature research covered three main subject areas: first the German health care system and German hospitals in general, second the specifics of hospitals in terms of procedural structures, functional areas as well as descriptive requirements in building codes and standards, and third the various users within hospitals. The three areas are mutually dependent and serve as basic input for the subsequent interviews.

Besides consulting hospital-specific building codes, such as DIN 13080 (DIN Deutsches Institut für Normung e.V., 2016) and DIN 5035-3 (DIN Deutsches Institut für Normung e.V., 2006), the literature research covered federal reports and statistical analysis by the Federal Statistical Office, key publications by representatives of traditional health care services, such as the German Hospital Federation and the German Hospital Institute, as well as publications and reports of think-tanks and consulting agencies, such as McKinsey&Company on the German health care system, health care's digital future or future hospitals ([Figure C.4](#)). While the building codes and statistical reports by federal agencies rather covered the status-quo, the additional literature was future-oriented and focused strongly

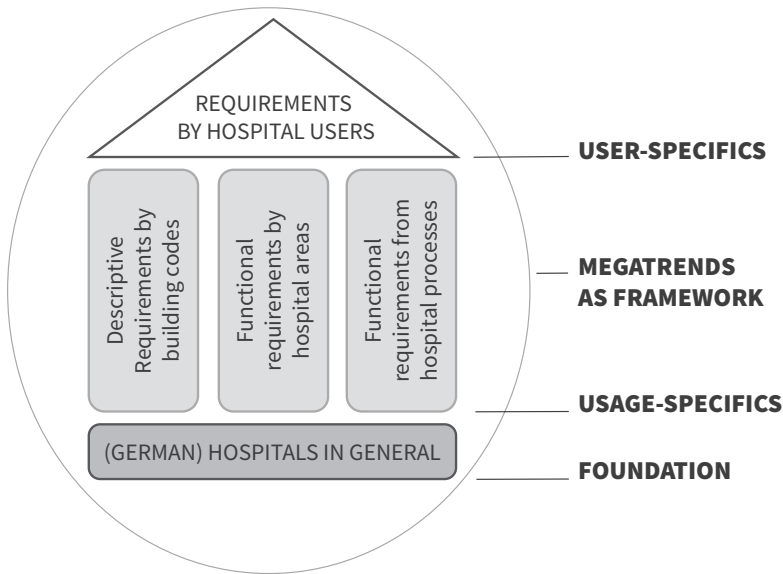
on the development and influence of megatrends as drivers within the health care and hospital context. The statistical analysis was complemented by rather strategic reports and analysis. While the literature research provided for a basic understanding of the hospital context, including its structural, organizational and functional as well as regulatory framework, from a Design Thinking point of view desk research could not provide sufficient user-centered insights. Neither the identification of key users, nor knowledge of their abilities, limitations or needs could be gathered in this manner. Especially, the identification of explicit as well as in particular implicit user needs required an additional, more user-centric approach.

As a user-centered design process, the Design Thinking toolbox provides a multitude of methods to build empathy with the user (Doorley et al., 2018). The majority of these methods that are applied to empathize with the user, are qualitative methods lent from social science disciplines, such as sociology, psychology and behavioral studies. Among others, the range of methods includes focus groups, (expert) interviews, field observations as well as the analysis of photography and video or audio sequences (Flick, 2014; Flick, Kardorff, & Steinke, 2004; Mayring, 2016).

Within the scope of this dissertation, essential data were collected throughout qualitative interviews as well as a four-week period of in-situ field observations. This combination of methods was chosen to gain insight into various user groups and to build empathy. While the field observations allowed for the identification of implicit user needs and environmental misfits, the interviews were used to communicate with hospitals' key stakeholders - directly affected and third parties involved.



Figure C.4 - Structure of subject areas covered during the 360° literature research on German hospitals



## FIELD OBSERVATIONS

Since the scope of this thesis did not allow to conduct field observation in all potential hospital types, two complementary strategies were pursued to still be able to estimate as far as possible the entire spectrum of hospital types.

On the one hand, in-situ field observations were conducted in two very different types of hospitals. The two hospitals differed with regard to their level of care, their number of beds and inpatient treatments, the treatment's complexity as well as location and profit-orientation. Both multiple-day stays were

organized by the hospitals and covered special hospital services, such as laboratory, supply and stock, specific departments, such as emergency, general surgery and diagnostic imaging and inpatient units, such as neurology, stroke, intensive care, palliative care, geriatric care, obstetrics, gynecology, and the emergency room. While one out of the two hospital is organized as a non-profit community and teaching hospital, providing 350 inpatient beds and a medium level of care ('regular and priority care supplier') to a rural area, the second hospital is organized as a for-profit community, but non-teaching hospital, providing 1'000 inpatient beds and a maximum level of care ('maximum care supplier') to a suburban area.

The extended hospital stays of several days were complemented by short-term visits of several hours, which were not officially organized. While in the course of the officially organized stays publicly as well as non-publicly accessible areas were subject to examination, in the course of the additional short-term visits only the publicly accessible areas were eligible for examination.

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Building  
empathy via  
field observations  
and interviews

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# INTERVIEWS

In addition to the field observations, the data sets of this dissertation were extended by interviews. The interviews were conducted in two chronologically separated sets framing the field observation. While both sets of interviews can be categorized as explorative interviews (Bogner, Littig, & Menz, 2014), they were conducted with very different groups of interview partners and served different purposes. While the first set of interviews took place before the hospital stays and was used to explore the research framework as well as choosing the necessary level of abstraction, the second set of interviews was conducted during as well as subsequently to the field observations and served the purpose of building empathy and collecting additional information on the various user groups that can be found in hospitals.

For the first set of interviews, interview partners with diverse backgrounds were identified. The selected interview partners were not exclusively employed in hospitals, but rather have their background in neighboring or (distantly) related fields. Interviews were conducted with representatives from the fields of digital health, assistance systems, augmented reality, user experience design, the Association of Research-

Based Pharmaceutical Companies, etc. The first set of expert interviews was used as a complementary sources of information (Bogner et al., 2014) on the German health care system (Figure C.5). The interviews lasted about an hour and used an interview guide, which did not specify any particular questions, but rather served as a topic guide. (Bogner et al., 2014; Kruse, 2015)

The second set of interviews was conducted with stakeholders that are either directly associated with everyday hospital life or involved in the design of hospital buildings. The experts directly associated with hospitals included caregivers, medical professionals, service and support staff as well as administrative professionals. (Figure C.5) Within these interviews, the experts served to identify explicit user needs. The insights were complemented by interviews with architects and designers that focus on design recommendations and future developments in the field of hospital real estate. The second set of interviews was conducted as semi-structured expert interviews, lasting about an hour and being recorded. (Bogner et al., 2014; Kruse, 2015)

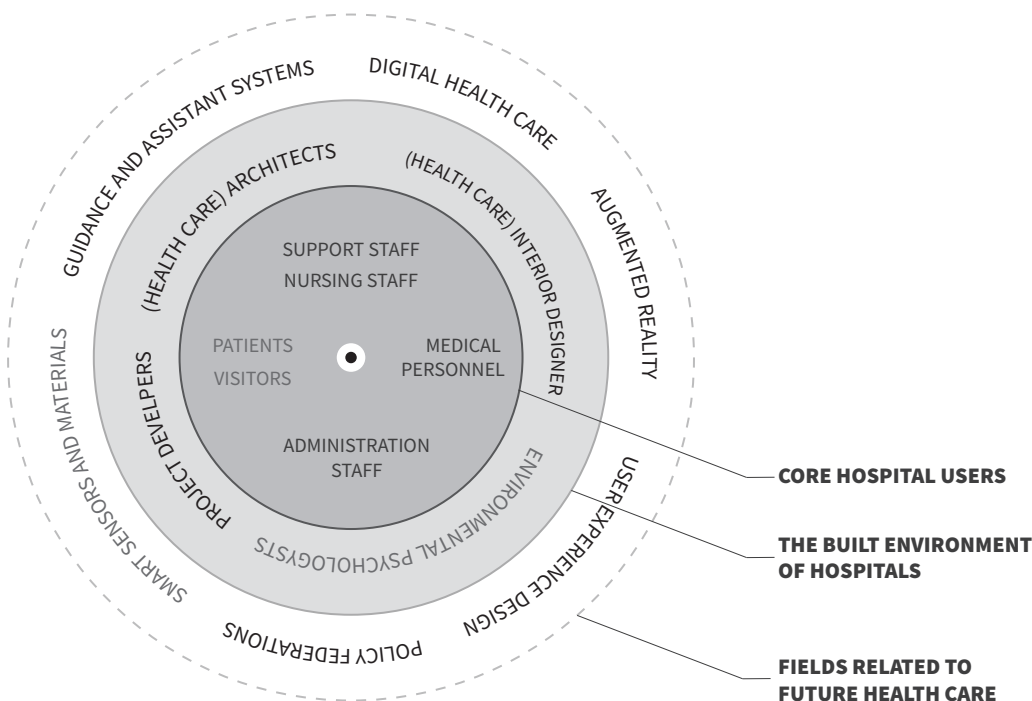


Figure C.5 - Structure of expert interviews

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# 3 DEFINE FOR DATA ANALYSIS

The DEFINE phase of the Design Thinking process was used for data processing and data analysis. The Design Thinking methodology describes the DEFINE phase as the phase „(...) when you unpack your empathy findings into needs and insights and scope a meaningful challenge.“ (Doorley et al., 2018). Therefore, the aim of the data analysis is to consolidate and structure the collected data and, based on this data, develop a problem statement that can be solved within the bounds of the IDEATE phase. During the DEFINE phase, the output of the EMPATHIZE phase is further processed so that it can be used as input for the IDEATE phase. The DEFINE phase is the step within any Design Thinking process where reframing of the design problem takes place. There are many different formats for the results of the data analysis; ranging from Personas to Journey Maps to general Design Guidelines, etc.

The data that were collected during the hospitations and interviews, were evaluated during the DEFINE phase. The combination of these two different and independent data types - verbal data of the interviews and visual as well as haptic data of the hospitations

- served to triangulate the data. After Flick, data sets from different data sources as well as from different times, places or people can be combined by means of data triangulation (Flick et al., 2004, p. 196 ff). The visual data, especially in form of photographs, as well as the own experiences that were made during the field of observations, complement the verbal data of the interviews. In the dissertation, the aim of this data triangulation was not to validate the interview data, but rather to use a second data source to obtain additional information.

The data evaluation was carried out primarily for informative purposes, i.e. not explicitly for theory generation - as described in Bogner, Littig, & Menz, (2014). For the evaluation of the interview data as well as the observations, content structuring analyses - based on Mayring (2016) - were carried out (Kuckartz, 2016). As the memo culture of the Grounded Theory methodology aligns with the typical Design Thinking approach, memos in the form of post-it notes were written in order to analyze the data. Memos were created for the analysis of the observation data, i.e. photos and observation protocols, as well as for the interviews. Data analysis within the context of Design Thinking does not necessarily meet the quality criteria that are normally set for qualitative data analysis in scientific practice. Usually no complete transcription of interviews is done, only selected text passages are transcribed. Due to the informative nature of speaking to users during observations, not all interviews were completely transcribed.

Following Mayring (2016), the data sets that consisted of the transcriptions and the data memos, were structured by assigning categories. These categories were created in a series of steps. The categories were constructed on the basis of a deductively formed set of

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DEFINING  
bridges the gap  
between  
EMPATHIZING and  
IDEATING.

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categories. These a-priori categories were derived from the research question, the hypotheses as well as based on the literature on the comfort model according to Vischer (Figure C.6). The categories were clustered in main and subordinate categories. The resulting a-priori categories were tested and successively extended to a finer category system during the data analysis. Subsequently, a category-based data analysis was carried out using a topics matrix. The entries in the matrix represented paraphrases of content that were further processed by means of generalization and reduction (Mayring, 2016).

The aim of the data analysis was twofold: On the one hand, it was intended to identify the key users, who can be found in the hospital context and majorly influence the development of new façade functions. On the other hand, it was also intended to identify the needs of these users and the environmental misfits according to Vischer that are of relevance to these key user groups. Based on these different objectives, different result formats were chosen for the representation of the analysis results. For example, exemplary personas were developed for key users of the hospital. The environmental misfits encountered by these personas were collected in the form of comprehensive lists, and then generalized to problem groups. In the case of environmental misfits, a differentiation was made between environmental misfits that result from facades and such that result from other factors and therefore are independent of facades.

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**Personas**  
are fictitious representatives of a user group and contain information on the background of the user, outline characteristics and daily experiences, including special needs, scope of abilities and mobility.

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(Doorley et al., 2018)

On the basis of the two kinds of results - key personas to be designed for and their central environmental problems - it was then possible to move on to the idea generation phase. In the IDEATION phase, the environmental misfits and corresponding user needs were addressed in relation to the personas.

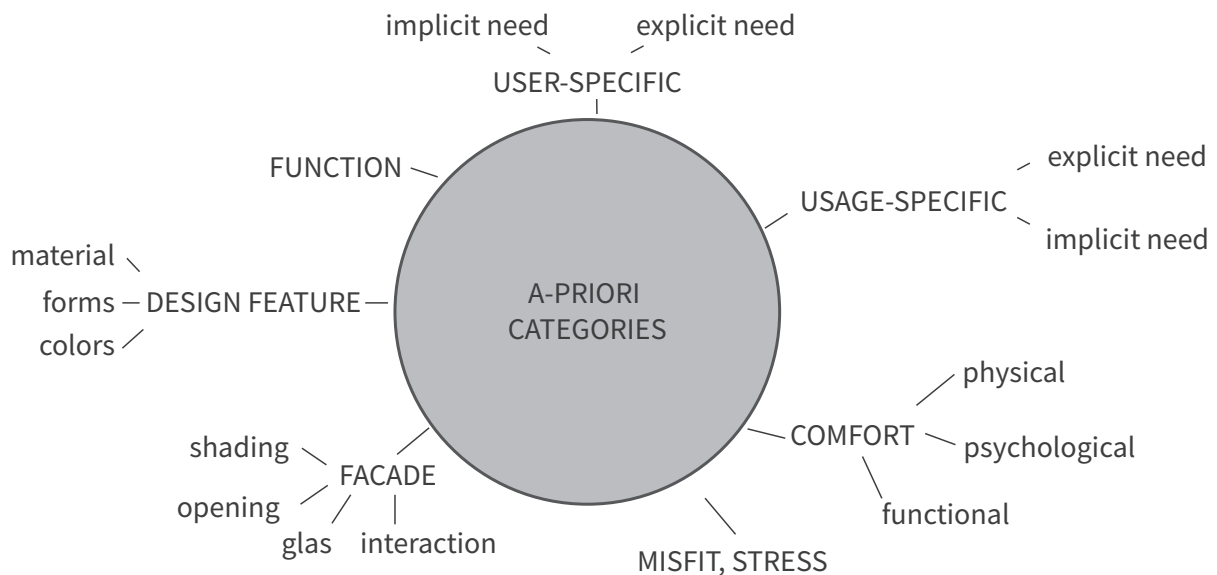


Figure C.6 - A-Priori categories for coding the observation and interview data

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# 4 IDEATE FOR CONCEPTS OF IDEAS

The IDEATE phase was used for the conceptualization of future façade functions and design features. In order to depict new functions as well as sub-functions, the method of user-centered function modeling was applied.

According to the Design Thinking process, the IDEATION phase is to generate ideas that address the identified problem statement and offer a first set of solutions. While this phase is not about details, a multitude of diverse ideas should be generated. Thus, the IDEATE phase was used to derive new functionalities and design features.

As the DEFINE phase resulted in a set of key personas as well as associated environmental misfits, the IDEATE phase was built on this structure, taking up the personas, their misfits and allocates suitable façade functions and design features. In order to derive new functionalities and design features that address one or more problems identified, two ideation methods from the Design Thinking toolbox were used: ‘Power of Ten’ and ‘How might we ...?’ (Doorley et al., 2018; Usability.gov, 2017). Both methods foster divergent thinking and help broadening the solution space. The ‘Power of

Ten’ is a method that is based on adding constraints to a design problem. By adding constraints, the solution space is either limited or expanded and new design solutions, here functionalities and design features, can be identified. The additional constraints serve as impulse and inspiration to generate new ideas. The method ‘How might we...?’ does not add constraints, but poses short questions that help launching the process of ideation. ‘How might we ...?’ (HMW) questions can focus on one particular aspect of the design problem, explore the opposite, or explore the transferability of an analogous context. Both methods were executed in combination with brainstorming techniques.

Given the desired interdisciplinary approach of any Design Thinking process, an “ideation get-together” with interdisciplinary participants was facilitated. By using these two methods and additionally executing them in an interdisciplinary setting, a diverse range of solutions to the user-specific design challenges, which was stated in terms of environmental misfits, could be identified.

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**“ ‘How might we (HMW) questions’ are short questions that launch ideation. They’re broad enough to include a wide range of solutions but narrow enough to impose helpful boundaries.”**

(Doorley et al., 2018)

The results of the IDEATE phase can be regarded as deliverables between need finding and implementation in terms of technology. Given the research question on the identification of user-centric functionalities on the basis of user-specific abilities and needs in terms of environmental misfits, a matching with specific technologies was not intended. Yet, it is inevitable that technologies that are available on the market or under development inspire and influence this derivation of functionalities. However, a firm matching of needs, derived functionalities and technologies was not undertaken. Moreover, the resulting sets of functional requirements and design features were used to express future visions of facades, rather than technical realizations. The results are comparable to concept cars used in the product development process of automotive industry.



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# D RESULTS

## 1 GERMAN HOSPITALS

In the following chapter, hospital-specific facts are described and thus, a background of the hospital context is given. This contextualization is followed by an overview of key hospital users and a detailed description of selected users. For exemplary users, characteristic features are presented, the environmental misfits they encounter are described and derived façade functions are sketched. In addition to these user-specific functionalities, hospital-specific frameworks and requirements for product development, which have resulted from the interviews with architects and hospital planners, are presented.

In Germany in 2016 there were 1,956 hospitals, ranging from basic to maximum care facilities, providing 499,351 beds for inpatient treatment, treating 19.2 million patients per year and employing 1.8 million employees, of which 17.8% are in medical services (Statistisches Bundesamt, 2017). Within the German health care system, hospitals are responsible for providing inpatient care. According to §107 of Germany's social security law (Sozialgesetzbuch (SGB V) Fünftes Buch Gesetzliche Krankenversicherung, 2017):

“Hospitals

1. provide hospital treatment or obstetric care,
2. operate under constant medical supervision by a physician, have adequate diagnostic and therapeutic facilities in accordance with their level of care and apply scientific methods,
3. with the help of medical, nursing, functional and medical-technical personnel available at all times, are prepared to diagnose, cure, prevent the deterioration of illnesses of patients, alleviate their symptoms or provide obstetric care, and in which
4. the patients can be accommodated and cared for.”

German hospitals can be categorized as general hospitals and other hospitals that are specialized with psychiatric, psychotherapeutic or neurological wards. In addition, hospitals can be categorized according to carrier, legal form, number of beds, care levels or number of specialist departments. Over the last decade, a decrease in the number of hospitals can be observed. While 2,242 hospitals were operated in 2000, a total number of 1,956 hospitals provided medical services and



treatment in Germany in 2016. Of these, 577 hospitals were operated by public carriers, 679 hospitals by non-profit organizations and 700 hospitals by private ownership. In absolute numbers, more than one-third of all hospitals are privately owned, and about one-third are publicly owned. (Statistisches Bundesamt, 2017) A trend can be observed, changing from mostly public sponsorships in 2002 to mostly private sponsorships in 2013. Comparing hospitals by number of beds, puts this trend in another light. Nearly every second bed (47.9 %) remains in public hospitals, a good third of the hospital beds (33.5 %) are in non-profit hospitals and only just under one sixth (18.7 %) are in private hospitals. As private hospitals with an average of 132 beds rank among the small hospitals, public hospitals with an average of 419 beds, however, are more than three times as large. While every third hospital is privately operated, only every sixth hospital bed is in private hands. Public hospitals are usually larger, meaning they have more beds than smaller privately-owned hospitals. (Statistisches Bundesamt, 2017) While a shift towards privately owned hospitals can be observed, the German hospital landscape will not be totally privatized. According to a comprehensive study on the future of German hospitals in 2020, it can be assumed that hospitals of maximum level of care, which often constitute teaching hospitals, will remain publicly operated. (Penter, Arnold, Friedrich, & Eichhorst, 2014) With regard to the level of care that a hospital provides, four different types of hospitals can be distinguished. The level of care is highly interconnected with the number of beds available and the degree of specialization. While some differences exist among the 16 federal states, the hospital landscape can basically be divided into three levels of care: (1) small-sized hospitals providing a minimum level of medical care with fewer than 200 beds, (2) medium-sized general services hospitals providing a medium level of medical care with 200 to 500 beds and (3) large-sized hospitals providing a maximum level of medical care with more than 500 beds. While medium-sized hospitals usually serve as specialty hospitals, large-sized hospitals usually constitute teaching hospitals, which does not mean that they can't be just as specialized in certain medical specialties.

Until 2004 hospital treatments were paid for on the basis of cost structures individually set by the hospitals. In 2004 a general cost structure – Diagnosis Related Groups (DRG) – was obligatory introduced on a federal level, setting the same cost structure across hospitals. In Germany, the DRG system is used as a billing system between almost 2,000 hospitals and over 200 health insurance companies. The idea of the DRG system was to introduce performance-based remuneration of hospital costs. The DRGs enabled a federal, homogenous price level. Depending on diagnosis and patient-specific parameters, such as age, sex, ventilation hours, weight, etc., flat rates for each treatment case were defined. The flat rates cover

all costs necessary for inpatient treatment, including staff, material and infrastructure costs. Moreover, for each diagnosis, a specific length of treatment or stay is calculated. Over- or underruns of the length of stay are taken into account via additional compensation or reductions.

In principle, public hospital planning is supervised by public authorities. The federal administration sets out the legal framework while at the same time funding investments. However, detailed hospital planning with financing of investment costs is the responsibility of the states. The core of this is the Hospital Financing Act (German: Krankenhausfinanzierungsgesetz), which serves the purpose of securing the economic viability of hospitals. The Hospital Financing Act obliges the federal states to develop hospital plans in order to ensure that the population is supplied with efficient hospitals that operate independently, but in line with public needs. Within this planning process hospital capacities are addressed by means of number of beds, departments and hospital location. The required number of beds as well as the degree of care are determined for each department. Within this framework, the federal authorities make funds available for investments covering in particular the costs of construction, such as new construction, reconstruction and extension of existing buildings. (Roth, Dombrowski, & Fisch, 2015) However, in practice no complete financing of investment projects is secured by federal financing. Since 1991 a continuous decline in subsidies under the Hospital Financing Act has been observed, although with strong regional differences. (Deutsche Krankenhaus Gesellschaft - Dezernat II - Krankenhausfinanzierung und -planung, 2015) This context has also been confirmed in the expert interviews.

A study by McKinsey on future hospitals comes to the conclusion that the German hospital landscape will change fundamentally. As a result, centers of excellence will be created with the clustering of medical expertise instead of full-service hospitals. Dynamic and flexible network structures will develop between these centers of excellence, leading to optimal care. In such a scenario, acute hospitals only offer primary outpatient and inpatient services. Patients are stabilized as outpatients and then moved to the appropriate treatment center. This scenario has implications for the built environment. A decline in inpatient treatment leads to a change in the structure of the built environment, meaning fewer inpatient wards and more outpatient facilities. In addition, the formation of chains and provider networks, such as Helios or Asklepios, comes along with centralized construction specifications to increase the recognisability of the facilities. (Eichhorst, Jenkins, & Stern, 2016)

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# 2 KEY HOSPITAL USER GROUPS

## 2.1 OVERVIEW OF MAIN USER GROUPS

Hospitals can correctly be compared to small cities. Just like small cities, hospitals can be characterized by their immense complexity that increases with the hospital's level of care. Small-sized hospitals usually only provide general medical care and thus, only consist of few departments, such as internal medicine, surgery and anesthesiology. In contrast, large-sized hospitals of maximum level of medical care usually provide for a variety of different medical services.

Across hospitals there are common areas and zones that are correlated with certain modes of use and certain user groups. In accordance with the terminology and classification of DIN 13080 (DIN Deutsches Institut für Normung e.V., 2016), most important functional zones and units are listed in [Table D.1](#).

The list of functional zones and units shows that hospital buildings are subject to mixed use mode, combining workplaces, diagnosis, therapy and nursing spaces as well as hospitality and accommodation. This mixed-use mode results in a large number of diverse users. Within each of these functional zones and subordinated functional units, representatives of the four main user groups – patients, health care providers, medical as well as operational services – are present. Depending on the functional unit, special subgroups of users are present ([Figure D.1](#)).

This user diversity among the main groups as well as among the subgroups is evident in different functional requirements. While patients spend their day mostly in bed, in their inpatient room, physicians as well as nurses and allied health professionals move around the ward and the hospital. Patients set high requirements with regard to indoor quality and atmosphere. Differences do not only occur between the main users, but especially within one user group as users are highly diverse. The functional requirements are highly interconnected with the daily routine of the user. Comparing surgeons to general physicians

shows differences with regard to their functional requirements in relation to their daily activities.

However, besides differences with regard to functional requirements, the differences among user groups manifest in differing initial conditions under which users encounter the building. While physicians and nursing professionals regularly enter the hospital as their workplace, patients are usually only there for a couple of days. According to Germany's Federal Statistical Office, a hospital's stay last on average 7.3 days in 2016. This means that the length of stay has almost halved since 1991. However, this average value of the duration of stay is not very meaningful, considering the strong variations depending on the medical departments. While treatment in the psychotherapeutic medicine or psychosomatics department lasts 42.7 days on average, ophthalmological patients can leave the hospital after 2.9 days on average. (Statistisches Bundesamt 2016). These different circumstances result in different levels of familiarity with the environment and are often accompanied by stress for the patient.

<b>FUNCTIONAL ZONES</b>	<b>FUNCTIONAL UNITS</b>
DIAGNOSTICS AND THERAPY	EMERGENCY ROOM LABORATORY OPERATING ROOM DIAGNOSTIC IMAGING
CARE	DELIVERY ROOM GENERAL CARE MATERNITY AND NEONATAL CARE INFANT AND PEDIATRIC CARE INTENSIVE CARE GERIATRIC CARE PALLIATIVE CARE
GENERAL SERVICES	CAFETERIA CHANGING ROOM ON-CALL SERVICE
OTHER FACILITIES	INTEGRATED OUTPATIENT FACILITIES

Table D.1 - Hospital's relevant functional zones and units, in accordance with DIN 13080

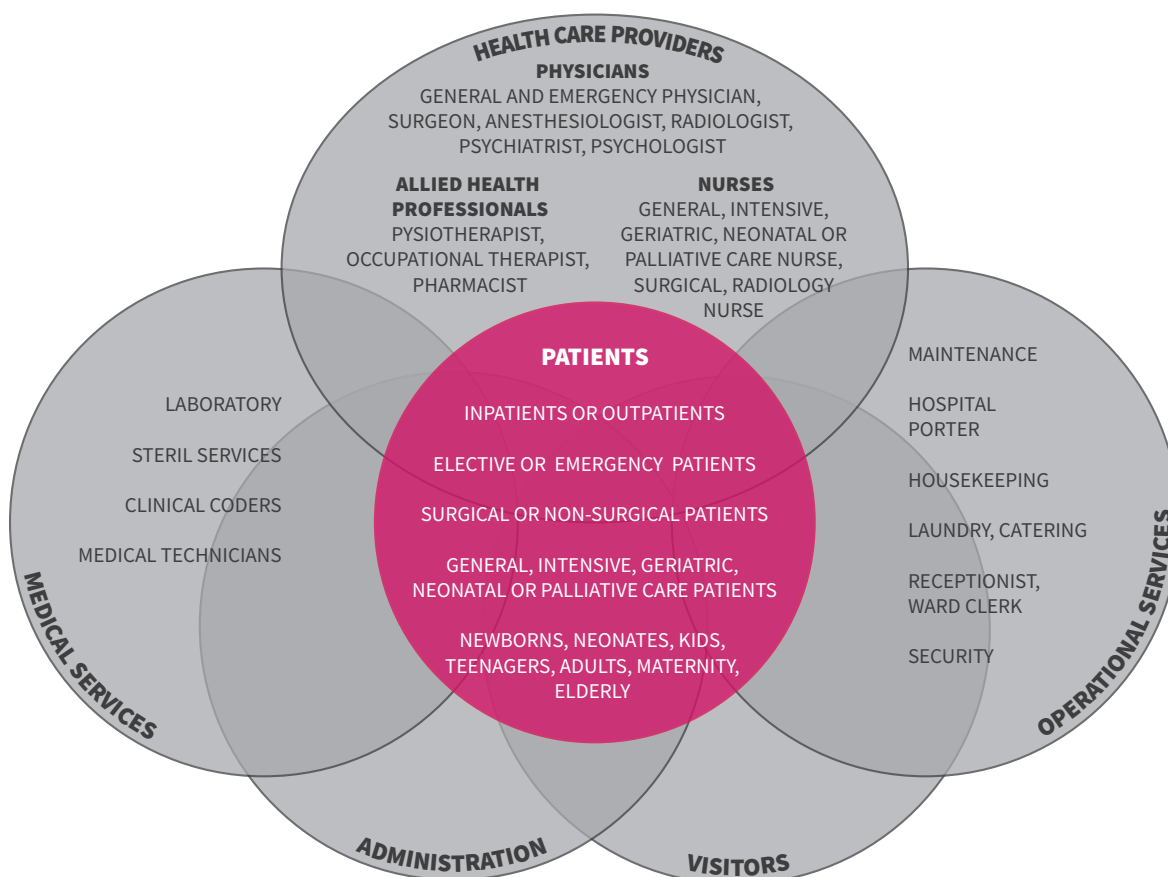


Figure D.1 - Key user groups within hospitals

## PATIENTS

When thinking about hospitals, the first user group that comes in mind are patients. Everyone was a patient once or at least visited someone in a hospital. So empathizing with the patient's view is pretty intuitive. However, among patients a multitude of different users exist. A closer analysis of available data reveals this diversity. The analysis of main diagnoses can serve as a starting point of an in-depth user analysis. In hospital statistics, the main diagnosis is coded according to the International Statistical Classification of Diseases and Related Health Problems (ICD). The 10th revision (ICD-10) of this classification system was published by the World Health Organization (WHO) (2016).

Despite differences in size and the associated differences of departments, generally speaking, there are usually three main departments - surgery, internal medicine and gynecology -, which treat about two thirds of patients and diseases. In 2016, 54.6% of the 20.1 million hospitalized patients were treated in surgery, 34.7% in internal medicine and 11.5% in gynecology or obstetrics. So it is not surprising that heart failure and childbirth were the two most common diagnoses and treatment causes for hospitalization in 2016. Basically, the primary diagnosis of hospitalization was similar for men (49% of patients) and women. The average age of patients was 55 years, with men at 54.6 years and women at 54.8 years. However, the distribution of age groups varies depending on the main diagnosis. Patients diagnosed with heart failure were on average 81 years old, while patients who had gallstones removed were significantly younger at 58 years and expectant mothers again were significantly younger. (Statistisches Bundesamt 2016).

The generation debate, which introduced a distinction between baby boomers, Generation X, Generation Y and Generation Z, can also be applied to the hospital context and the different age groups of patients. Trends that are observed outside the hospital can also be observed in the hospital. Digitalization and the use of digital media as well as devices play a greater role for younger patients and also pose fewer obstacles for them in terms of operation. While older patients tend to have greater problems with technology. Here, megatrends can also be used as a framework for future developments.

However, patients can not only be distinguished by sex, age and department they are medically treated by. The observation and interviews showed that patients need to be differentiated whether or not they stay in the hospital overnight and therefore are considered inpatients or not, and count in as outpatients. Furthermore, elective patients need to be distinguished from emergency patients. While the latter do not actively decide on a certain hospital, they are usually rushed to the closest one that can provide initial and primary treatment. Elective patients on the other hand schedule their appointment, such as a surgery, and chose a certain hospital. Thus, selection criteria are different, leading to a hospital selection that is much more conscious and differentiated.

Besides elective vs. emergency, patients can be surgical or non-surgical patients. Whether operative or non-operative has a decisive impact on the functional areas that a patient frequents during his hospital stay and what experiences are made. For surgical patients, the surgery itself is of key importance; especially the time before the operation, the transfer to the operating room, the initiation and subsequent discharge by the

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### Additional Information

As explained in the introduction, megatrends have a trend-setting character and can be used as indicators showing necessary changes. For hospitals, the megatrends of health, individualization and digitization are of key importance. Digital hospital initiatives are increasingly being launched, although at very different levels – ranging from Wi-Fi to digital patient books to virtual operation procedures via telemedicine. As in other industries, the effects of increasing digitization are already apparent at the level of the individuals. Our healthcare system is becoming a mirror of our modern network society, both in terms of information exchange and the use of technology (Huber et al., 2015). According to Huber et al., it is already becoming apparent that patients wish to use digital information sources and communication channels for the most part. In order to apply a user-centered design approach, it is in particular the interaction of these three megatrends that plays a decisive role in the hospital context and requires consideration. The Philips Health Study sees the interaction of these megatrends as a multidimensional paradigm shift that creates a new holistic health care culture (Huber, Kirig, Rauch, & Ehret, 2015). Huber et al. postulate health as a megatrend that will change our future significantly. Health is increasingly being stylized as a status symbol, an expression of an avant-garde lifestyle and almost a citizens' duty. Increasing digitalization and the trend towards individualization serve as a catalyst for health responsibility and change the service demands. In this way, the patient's self-conception changes: from a mere patient who goes to the physician or hospital with symptoms, to a mature health consumer, who is already in touch with his physician when he is still healthy. As a health consumer, the patient brings a lot of personal responsibility.

anesthesiologist as well as waking up in the recovery room after the operation. Postoperative states of confusion do not play a role for non-surgical patients, but they are particularly dangerous for older surgical patients. Communicating with patients is particularly important in the specialty of surgery, because patients often have to be recommended surgical intervention and the patient has a particularly high need for information, as this is an invasive measure that is initially perceived as a threat. In addition to the differentiating characteristics already presented, patients can also be differentiated according to the level of care they require. In a first step, a basic distinction is made between general care and intensive care.

While general care takes place in the regular hospital wards, intensive care is carried out in the intensive care unit of the hospital. Intensive care patients can be characterized as being in a significantly more vulnerable basic constitution than general care patients. In principle, intensive care units treat patients who have serious and life-threatening illnesses or have undergone treatment and therefore require continuous monitoring and care. Extended and continuous care through medication and machines, such as ventilators, serves to ensure normal bodily functions. The care of patients by hospital staff, such as nurses and physicians, is much more intensive. As a rule, one nurse cares for about two intensive care patients. Mobility is a crucial factor in intensive care units. Generally, patients are not mobile, frequently sedated and intubated for ventilatory purposes. A central moment for intensive care patients is waking up and coming round. For many patients, this moment or period is associated with confusion, lack of orientation, anxiety and even hallucinations. Often feelings of dependency and being out of control are also associated. The contrast to intensive care patients is formed by general care patients. While intensive care patients ultimately have little or no mobility and require continuous care, general care patients can be characterized by an increased degree of mobility and independence. Patients in normal wards are not monitored and are not intubated.

Within intensive care and geriatric care, it is further differentiated according to particular age groups and the associated medical challenges. Usually, neonatal care and geriatric care are differentiated. Both age groups - neonatal and geriatric care - pose particular difficulties. While incubators are often indispensable for neonates, space and care for geriatric patients often have to be optimized for multimorbidity and dementia-related restrictions in terms of mobility and orientation.

## **HEALTH CARE PROVIDERS**

Health care providers include physicians, nurses and allied health professionals. While physicians assess and manage the patient's medical diagnosis and treatment, nurses provide ongoing care and collect continuous information, while interacting with the patient. Allied health professionals bring another addition to this duo of physicians and nurses, helping with diagnosis and treatments. Just as patients, the user group of physicians and nurses is rather broad and includes different user types. With regard to physicians, general physicians, surgeons and anesthesiologists, as well as radiologists need to be distinguished. While general physicians spend most of their time on ward, surgeons and anesthesiologists are mostly located in the operating room (OR). The daily routine of a general physician on ward consist of visiting patients, ordering examinations, assessing examination results and completing paperwork. General physicians interact highly with patients. In contrast, surgeons and anesthesiologists spend their time operating and observing vital signs of surgical patients. However, within an OR, the activities of surgeons differ strongly from an anesthesiologist's activities. Surgeons are highly active, while anesthesiologists usually observe the action and only become active, whenever needed. The anesthesiologist accompanies the patient into the induction and discharge room and ensures that the patient gradually falls asleep under anesthesia and wakes up again. With regard to nurses, the same differentiation between general care and intensive care as well as geriatric care, neonatal care and palliative care applies. For each specialty, nurses are specially trained. Nurses are present on ward 24/7. Usually, hospitals operate in three-shift operation – night shift, first shift and late shift rhythms. Depending on the nurse's qualification, the nurse participates not only in the physical care of the patient, such as bedding and washing, but can perform tasks such as taking blood, administering medication, etc. The main tasks in a nurse's daily routine include checking on the patient, visiting the patients with the physicians, measuring vital parameters, providing medication and overall documentation.

## **MEDICAL & OPERATIONAL SERVICE TEAMS**

The medical and operational service teams within hospitals include a variety of different user groups. Generally speaking, members of the medical and operational service team work to support the day-to-day running of the hospital. In order to keep the hospital running, sterile services and medical technicians, such as maintenance staff, hospital porters bringing patients from one place to another within the hospital and housekeeping need to be highlighted.

## 2.2 PERSONAS OF EXEMPLARY USERS

Personas are used to illustrate the differences between different users in the hospital. As already described in the chapter on methods, personas do not represent a real person one-to-one, but rather combine characteristic features of real persons to a fictitious person. Thus, the following personas compile main characteristics for exemplary user groups. By selecting the different personas and the associated differences, awareness of user-related product specifications shall be raised.

For one, the personas are selected on the basis of statistical data on patient numbers. Second, the personas are intended to highlight significant differences between patient groups and are selected accordingly. Thus, the chosen personas differ clearly in their characteristics and product requirements. The aim is to highlight differences within a user group (such as ‚patients‘) as well as differences between user groups (such as ‚patients‘ and ‚physicians‘). So, two different patient groups are selected to represent differences within a user group. These are supplemented by a persona from the medical service.

Comparable types of information are covered in the description of the personas so that comparisons can be drawn between the personas. The composition of the personas is based the results of the interviews with physicians and patients as well as the results of the observations on site.

### **PERSONA: GERIATRIC INPATIENT ‘ANN SMITH’**

Driven by the demographic change in Germany and an aging society, the patient clientele in hospitals is also getting older, too. The exemplary persona of a geriatric patient should meet this fact of the ageing hospital clientele. Geriatric units in hospitals are growing increasingly and bring with them special challenges. At the same time, there is a considerable overlap between geriatric hospital wards and nursing homes for long-term care. With the increasing age of the patients and the severity of the illnesses, the border between geriatrics and palliative medicine blurs.

Geriatric patients are characterized especially by multimorbidity and are therefore usually not only cared for by one discipline, but require interdisciplinary cooperation between departments. Compared to other patient groups, geriatric patients usually have limited abilities and restricted mobility. These limited abilities, limited mobility and disturbed circadian rhythms, which lead to sleep problems, lead to an increased need for care and thus to higher workload for the personnel. ([Figure D.4](#), [Figure D.5](#))

Conditions that are natural to other patient groups and do not cause any problems, can be challenging for geriatric patients. For example, in dementia patients, a dark coloring of the floor can lead to irritation, as this can be misinterpreted as an opening in the floor. If geriatric patients are treated surgically, waking up after the operation and the time afterwards constitutes a key moment. Geriatric patients show Delir symptoms after surgery more often than other patient groups. They suffer from acute confusion and cannot orient themselves in space and time. An attempt is made to provide orientation by means of watches and date displays, but these are often not perceived by the patients. Apart from patients suffering from Delir, it was observed that patients are usually easily confused by too much technology surrounding them. The control panel at the bedside to control lighting or a touchpad that serves as a multimedia entertainment device was not operated intuitively. Nevertheless, radio and television play a central role in the everyday hospital life of these patients.

Limited mobility, which can range from using a walker to being bedridden, leads to limited participation in everyday life. Thus, it can be observed that geriatric patients sit in the same place for hours and do not interact with their surroundings. Permanently closed curtains in patient rooms are not uncommon. Neither are poor indoor air conditions and dark rooms or inadequate lighting. Most geriatric patients come to terms with even poor environmental conditions as soon as they have limited mobility. It has often been observed that nursing staff and/or the medical service first retracted curtains and opened windows after entering a room. ([Figure D.2](#), [Figure D.3](#))

In principle, therapists strive to increase the mobility of patients by moving them - either by walking around the house or by passive movement in bed. Patients who actively move around the house have stated that design incentives in hospitals would have a positive effect. Patients are often taken to recreation rooms to leave their own room and get some distraction. (Figure D.6) If patients are relatively mobile, e.g. by using a walker, they are willing to leave their own room. (Figure D.7) They often stroll along the hospital corridors and take a rest at suitable points, e.g. by sitting down. It has been observed that patients in the geriatric ward were unable to find their way around and therefore needed more care as soon as they were mobile. Typically, the room doors of the geriatric patients were decorated with little images to help the patients find their way around. The risk of falling also increases with reduced mobility. The declared aim of the nursing staff is to prevent geriatric patients from falling or injuring themselves in the course of independent mobilization.

Conversations showed that patients from this patient group usually do not know what and when their next treatment will take place. Frequently, relatives are present to talk to the physicians during rounds. If they cannot be present during rounds, it has been observed that as soon as they arrive at the ward, they obtain information from the responsible nurse. If an examination is due, the patients are usually picked

up unexpectedly from their room by the hospital transport service and taken to the examination room.

The following pictures (Figure D.2 to Figure D.8) give an impression of geriatric inpatients in a geriatric hospital ward. The description of a geriatric inpatient persona summarizes the findings.



Figure D.2 - Closed curtains in an inpatient room, view from bed



Figure D.3 - Closed curtains in an inpatient room and obstruction by an wrongly placed chair, view from door

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Figure D.4 - Geriatric inpatient and physiotherapist, walking around the hospital hallways



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Figure D.5 - Geriatric inpatient being mobilized within bed by a physiotherapist







Figure D.6 - Geriatric inpatient with limited mobility, sitting in a wheelchair and spending times in the common areas of the hospital



Figure D.7 - Geriatric inpatient with limited mobility walking around the hospital with walker



Figure D.8 - Geriatric inpatient with limited mobility, walking around the hospital with a walker and enjoying the views of the outdoors

# ANN SMITH

## CLINICAL PICTURE

Emergency patient | surgical patient | geriatric inpatient ward, multimorbid with an acute fracture of the femur, accompanied with first signs of dementia

## ANN'S STORY

Despite her walker Ann can only walk with difficulties. At home, she fell and fractured her femur that had to be surgically operated on. She was admitted to the hospital for initial treatment as an emergency patient and needs to stay for further monitoring as an inpatient.

Due to the seriousness of the operation, Ann had to spend some time in the intensive care unit of the hospital. Postoperatively, Ann suffered from Delir, meaning acute confusion. After the surgery and as the anesthesia has already worn off, Ann had problems orienting herself and perceives her surroundings differently due to visual and hearing impairments. The situation was and still is intensified by disruptions to their circadian rhythm, which lead to sleep disturbances and continuous sleep deprivation. While she is grateful for being at the general care unit, she is still sensitive to elevated noise levels at night.

## ABILITIES, LIMITATIONS

As a multimorbid patient, Ann is only partially mobile and active. Due to increased instability, Ann suffers a greater risk of falling than before. Her visual perception is limited. At dusk she can only make out details with difficulty and she shows a higher sensitivity to glare. She can no longer carry out her daily routines fully, needs to rest more frequently and requires assistance in everyday life. Smart devices can not be used intuitively by her.

## HOSPITAL CHALLENGES

Ann gets frustrated within the hospital, because she is highly dependent on other people. Whenever Ann needs assistance, she has to call for help and wait her turn. Her dependency results in her not being able to leave her room and/or the ward by herself. Due to her limited mobility and limitations, she withdraws herself and is frightened to leave her known surroundings. Thus, she has not been outside and experienced the natural elements. She feels isolated. Moreover, she gets frustrated, because she lacks information on her daily schedule, the procedures that are planned and the diagnoses that were made. Ann feels like she is out of control and not included in the loop of information. Not knowing what happens next frustrates her. While Ann lacks company, she is annoyed by her room mate's loud snoring and screaming during nighttime. Conflicts arise due to different perceptions of room temperatures and noise levels in particular.

## PERSONAL INFORMATION

81 years old, widowed, but highly connected to her remaining family

## DAILY SCHEDULE

7 am	Examination and check of vital parameters, medication intake
8 am	Breakfast
9 am	Rounds
12 pm	Lunch
6 pm	Dinner
7 pm	Vital parameters, medication
10 pm	Bed time

*in the morning and the afternoon: physiotherapy, examinations, bandages, vital monitoring*

## DAILY ACTIVITIES

After her surgery, Ann is highly confused as she suffers from Delir and does not perform any daily activities. Her acute confusion gets better, Ann's activities during a day in the hospital are dominated by waiting in her inpatient room. She is not fully mobile and can not move around by herself. Thus, she is waiting that breakfast is being served, that it is her turn during rounds, that porters are transport her to the examination rooms, etc. In the meantime she receives visitors or snoozes. Sometimes she spends time in the public areas and watches television.

## DESIRED EXPERIENCE

Ann is looking for company and the nurses attention. She wants the nurses, therapists and physicians to take their time and explain everything in a way she can understand and process the provided information. With this predominance of waiting, she would appreciate some distraction and access to nature and the outdoors, despite her lack of mobility.

# GERIATRIC INPATIENT



Designed by Freepik

## **PERSONA: PEDIATRIC INPATIENT AND ACCOMPANYING PARENT ‘LEO AND HIS MOTHER SARAH DAVIS’**

Compared to geriatric patients, pediatric patients represent a completely different group of patients. Most pediatric wards treat infants. Infants present different challenges compared to adults. For example, the treatment of toddlers requires more time and, if necessary, the use of equipment. As a rule, pediatric patients are admitted to the hospital with an accompanying person. The accompanying person has two functions. First of all, they look after the child and ensure that the child is continuously supervised. In this way, the accompanying person supervises the child during examinations and ensures the child's cooperation. The accompanying persons play a central role on the pediatric ward and take over essential functions, such as the administration of medication. On the other hand, many of the little patients are not yet able to articulate themselves in order to describe

symptoms and pain. Thus, the accompanying person informs the physicians about relevant information or changes in the child's condition. However, this indirect description of symptoms and conditions entails difficulties. The information is always from third parties and must be evaluated accordingly. This can only happen by means of an extensive exchange of information. In principle, the accompanying persons ask for plenty of information and want to be informed accordingly. The situation in the hospital is a stressful situation for the parents, sometimes even more stressful than for the infant.

As a rule, accompanying persons and children are not informed in advance on the precise time window of certain examinations. Therefore, they have to wait in the patient's room and be ready for the examination. Due to this lack of information, the patients have to stay in the room and wait. Children, especially toddlers, usually find it more difficult to occupy themselves independently. In particular, if they have to stay longer in the hospital, boredom can develop in addition to homesickness. Boredom is particularly prevalent among small children, if they are recovering. Usually they want to discover the surroundings of their room. A proven way to keep the smaller, but also the



Figure D.9 - Pediatric inpatient room, view from door

bigger children busy is the television.

But also for the accompanying persons it can become boring and exhausting over time. They spend most of the day in the patient's room. The feeling of being „locked up“ was expressed. Especially in rooms with more than one patient, i.e. with more than one accompanying person, conflicts of interest can arise due to different perceptions. Different temperature requirements are common. Poor indoor air conditions are usually not perceived, resulting in stuffy rooms.

The fact that sleeping in the ward cannot be compared to a night in one's own home. It is another burden on the patients and their accompanying person. Due to unfamiliar surroundings and nightly checks by the nurses, children frequently scream, especially at night. This leads to a restlessness that affects both the children and the accompanying person. In particular, the bright light at night impairs everyone's sleep.

Usually the children's wards are designed and furnished similar to the adult wards. So in a room that sleeps two patients, the two beds are the essential furniture. Often, however, this leads to the

problem that in addition to the actual patients, the accompanying persons who also need a place to sleep are present too. Folding beds are provided, but they do not have to be rebuilt every night and demounted in the morning. There are no explicit resting areas for the accompanying person.

The pictures ([Figure D.9](#), [Figure D.10](#)) give an impression of a pediatric inpatient room. The description of the pediatric persona summarizes the findings on pediatric patients and their accompanying person.



Figure D.10 - Pediatric inpatient room including folding bed of an accompanying person

# LEO & SARAH DAVIS

## CLINICAL PICTURE

Emergency patient | pediatric patient | pediatric inpatient ward, intracranial injury, concussion accompanied by nausea and vomiting as well as sensitivity to light and noise, accompanied by his mother

## LEO AND SARAH'S STORY

Leo played catch with his older brother in the living room. The two jumped over the coffee table to the couch. Leo missed the couch and hit his head on the table. He was unconscious for a few minutes. His mother, Sarah, reported persistent crying and uncoordinated apathetic behavior. At home as well as in the hospital, Leo threw up and has been very restless and crying ever since. To rule out cerebral hemorrhage Leo is being intensively monitored during the 24 hours after the accident. During this time, Leo's state of consciousness and reaction to external stimuli (light, touch) are assessed regularly. To ensure that the concussion does not cause permanent damage, Leo was forced to bed rest. His mother Sarah spends the night with him in the hospital. She was provided with a folding bed that has to be cleaned up the next day before the first examination.

## ABILITIES, LIMITATIONS

Basically Leo is a very agile little boy. He is very interested and curious. He finds it difficult to sit down quietly and rest. Due to his age, Leo is not able to express himself comprehensively yet, so the doctors are dependent on his mother. At the hospital his behavior is characterized by crying and restlessness. During the physical and neurological examinations, Leo is very restless and hard to calm down. The presence of his mother is essential. She either holds him in her arms or sits next to him in the bed.

## HOSPITAL CHALLENGES

It is a challenge to keep Leo busy. He is bored and wants to explore the surroundings. Sarah is busy entertaining and watching Leo to ensure he stays in bed. Whenever Leo is awake, it is difficult for her to leave the bed. Leo wants to spend time outside, so does Sarah. The small room and the missing access to nature frustrate Sarah. They share the room with another toddler and the accompanying parent. Sarah is tired due to an uncomfortable and restless night. The noisy environment and the bright lights that the nurses need to turn on during the night for checks make it difficult to fall asleep. At the same time, the first check in the morning wakes her up brutally. Sarah lacks sufficient information on the scheduled examinations and has difficulty finding the way to the examination rooms.

She is worried about her son and the hospital's unfamiliar atmosphere intensifies her anxiety. She won't let him out of sight and wonders if she receives all important information. Whenever she approaches the nurses, she gets the feeling that they are busy and do not have time to sit down and talk with her.

## PEDIATRIC INPATIENT AND ACCOMPANYING MOTHER

## PERSONAL INFORMATION

3 years old boy, 32 years old mother  
Sarah is married, Leo's mother and has an older son

## DAILY SCHEDULE

7 am	Examination and check of vital parameters
8 am	Breakfast
9 am	Patient rounds
12 pm	Lunch
6 pm	Dinner
7 pm	Bed time

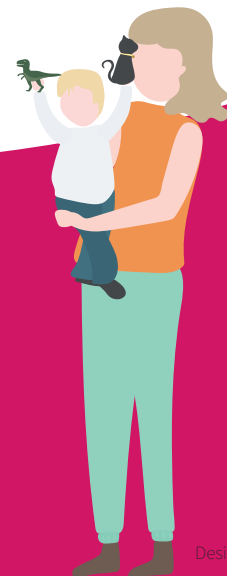
*In the morning and the afternoon: examinations, medical imaging and vital monitoring; during night time: hourly checks on Leo's health conditions by the nurses*

## DAILY ACTIVITIES

Due to Leo's bed rest, Sarah is responsible for keeping Leo calm and entertain him in bed. The two spend most of the day within Leo's hospital bed, reading stories out loud or watching kids shows on television. Whenever Leo is awake, the two do not leave the room. Also Sarah does not leave the room, whenever Leo is asleep.

## DESIRED EXPERIENCE

Sarah would like to stay in a room by herself and Leo to make herself comfortable despite the stressful situation. She is thankful for the continuous monitoring of her son's conditions and the fact that she can spend the night with him, although she would like this to be better planned. A room designed for children and their accompanying parent would make a big difference to Sarah. However, providing continuous information would make an even bigger difference.



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## **PERSONA: PHYSICIAN IN RESIDENCE, NEUROLOGY, STROKE UNIT ‘MARY JAMES’**

The day spent by physicians in hospital is very different to a patient's day spend in the hospital. While patients usually have to wait, physicians are constantly busy and on the move. The physicians' sphere is not only limited to the ward, but extends over the hospital. Thus, the inpatient areas, examination areas, treatment rooms and e.g. radiology theatres are frequented by the hospital physicians. Depending on the hospital, shifts start at different times and the shift lengths can also vary. Nevertheless, it could be observed that the activities within a day are very varied and consist of different components. The work on and in direct contact with the patient, however, does not make up the largest part. Interaction with the patient takes place most intensively during rounds in the morning.

Rounds are essential during a physician's hospital day. The patient visit gives the physician an overview of the inpatients and their conditions. It has been observed that essential information is provided to the physician through the nurses, as they spend most time with the patient. During rounds the physician spends only a few minutes, 5 - 20 minutes, with the patient and is dependent on receiving all central information in advance or during the conversation. Before the patient visits, the physician is informed of the patient's current condition by other physicians, nurses as well as therapists. It has been observed that the patient's file ('Curve') plays a central role in the physicians' work process and at the same time brings with it a number of challenges. In the patient chart (German: Kurve), all vital parameters, medication as well as ordered examinations and therapies are documented by the nursing staff. The fact that patient information is still documented in paper form means that information can only be documented and passed on with delay. The fact that two parties wanted to document or review information at a patient's chart at the same time could be observed in many cases. On a stroke unit as well as other monitoring stations, further information has to be evaluated in addition to the patient's chart. For example, patients are intensively monitored, among other things via camera recordings, in order to be able to register emergencies in the patient's room early.

Following the visit, the ordered examinations are processed, some of which are attended by physicians who carry them out. The actual work for the physician, however, is usually the evaluation of the examination results and thus the diagnosis as well as the

prescription of further examinations and treatments. For neurologists, the examination via medical imaging plays a central role in obtaining information. Patients who have been assigned for medical imaging are discussed during a meeting with the radiologist. The radiology meeting (German: Röntgenschau) during which the radiologist presents the assessment of the patient images and states diagnoses, takes place every day, in a darkened room.

In addition to the direct interactions with patients themselves, for example in form of rounds and examinations, the physicians have to carry out administrative tasks. For example, writing medical reports. For these administrative tasks a normal office space is necessary. Usually a physician's room, which represents a place of do paper work as well as rest and sleep, is provided.

As wards generally treat inpatient as well as outpatients, there is always a high workload at the ward. One interviewee stated that it happens that "often in the evening you don't know why it's already evening - the time goes by that way". Physicians on night shifts or 24-hour weekend shifts have a particularly high workload. Basically a feeling of being rushed can be perceived. The telephone, which serves as a central information medium, rings at regular intervals. Brief telephone calls are used to ask questions, obtain status information or even exchange central information about a patient.

The following pictures ([Figure D.11](#) to [Figure D.16](#)) give an impression of a physician's activities during a day in the hospital. The description of the physician's persona summarizes the findings on physicians, especially within the discipline of neurology.



Figure D.11 - Physicians work station, physicians gathering information on a patient



Figure D.12 - Physicians reviewing a patient's chart, limited space, window sill is being used as storage space



Figure D.13 - Patient examination within the inpatient room, examination at the bedside

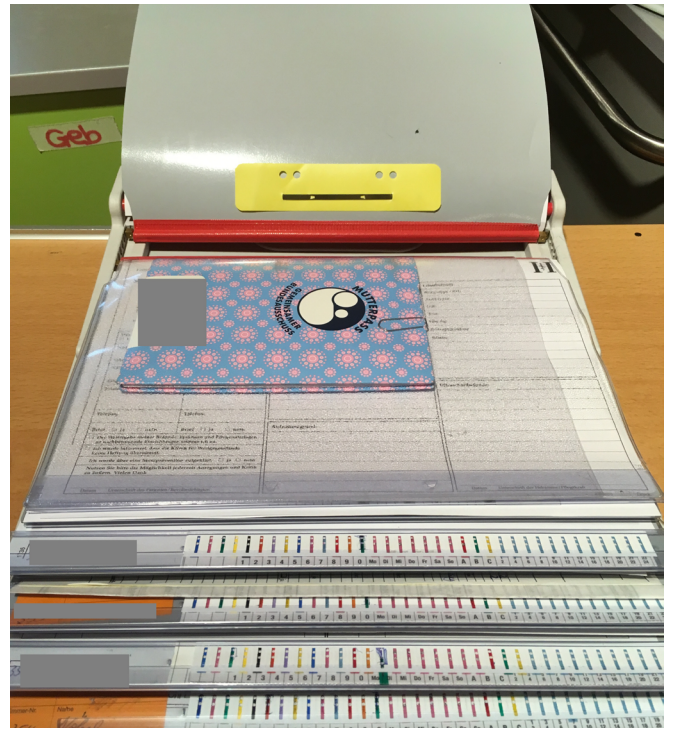


Figure D.14 - Exemplary patient's charts ('Fieberkurve')



Figure D.15 - Physician's workspace combined with an examination room

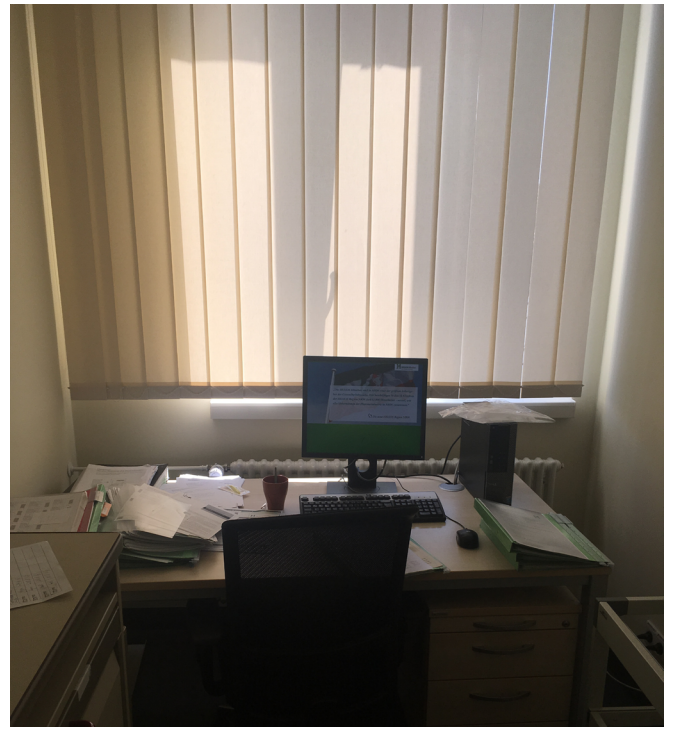


Figure D.16 - Physician's workspace for desk work



# MARY JAMES

## JOB AND CLINICAL PROFESSION

Graduated medical school, resident in the department of neurology, works under the supervision of an attending physician, responsible for patients at a stroke unit

## MARY'S STORY

Mary is a resident at the hospital, in the department of neurology. She always wanted to become a neurologist and help patients with major health disorders. The brain has fascinated her since she was a little girl and motivated her all throughout medical school. So, she graduated medical school and is now training in the discipline of neurology. As an ongoing neurologist, Mary does not perform surgery, but studies and treats disorders of the nervous system. As a resident she provide care for patients in a teaching hospital, but is supervised by an attending physician who must approve her decisions. At the moment she is assigned to the hospital's stroke unit. The stroke unit is a certified interdisciplinary unit within the hospital that treats stoke patients by means of neurology, internal medicine, surgery and allied health professionals, such as physio therapists. Due to her residency, Mary works a lot of hours, covering night shifts and 24h-shift on weekends. It is hard for her to keep track of her natural daily rhythm and sometime she does not even know what time of the day it is whenever she leaves the hospital.

## HOSPITAL CHALLENGES

Mary is frustrated that – despite digitalization throughout her personal life – key information on patients are still only collected on paper. Due to this fact, only one person can use the patient chart at a time, leading to ineffective delays of providing information. Moreover, the ward is packed and not enough storage space is available. So, window sills are used as shelf space and equipment, such as wheelchairs and walkers limit the walking space in the hall ways. Due to limited space available, the hospital does not provide a suitable office spaces to physicians. Mary works a lot of hours in the hospital, covering night shifts and 24h-shift on weekends. It is hard for her to keep track of the natural rhythm of a day and sometime she does not even know what time of the day it is. Her sleep rhythm gets particularly disrupted, whenever she covers the night shift or the 24h shifts on weekends. The fact that neurological patients are highly vulnerable, frightened and their deceases are often non-curable, is not always easy on Mary. Besides her regular responsibilities, she has only barely time to deal with the emotional challenges that neurological patients face. She sometimes questions whether she is responsive enough to the patients from a psychological point of view.

## DESIRED EXPERIENCE

Mary wishes for more time for patients and all follow-up work. A smoother exchange of information between physicians, nurses as well as allied health professionals would make Mary's everyday life easier. Moreover, being able to view patient information independent of the patients' paper chart, would be desirable to Mary.

## PHYSICIAN IN RESIDENT NEUROLOGIST, STROKE UNIT

## PERSONAL INFORMATION

28 years old,  
highly motivated and well-trained,  
in a relationship

## DAILY SCHEDULE

7.30 am Analyzing monitoring data  
8.15 am Neurology physician meeting  
9.30 am Patient sounds and  
examinations  
11 am Patient's follow-up work  
12 pm Radiology theater meeting  
14.30pm Up-date meeting, shift change  
10.30pm Up-date meeting, shift change

*In the afternoon: analyzing examination data and ordering additional tests or forms of therapy*

## DAILY ACTIVITIES

In the morning, Mary starts her day by analyzing the patient data the bedside monitors collected over night. Afterwards, a meeting of the ward's physicians takes place. Due to shift change, the attending physician, fellows, residents as well as students of two shifts attend this meeting. The meeting provides an update on patients, including information on latest health conditions, diagnoses as well as necessary examinations to physicians. Next up are patient rounds. Mary spends the first half of her working day seeing patients during rounds. As soon as rounds are completed, follow-up work follows: tests, medical imaging or physio therapy need to be ordered. In between the follow-ups, is is time for a theater meeting with the radiologists. In the dark radiology theater, the radiologists show medical images of patients and state their diagnoses. Whenever time is available, Mary needs to complete administrative paper work, such as medical reports or patient dismissals.



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# 3 ENVIRONMENTAL MISFITS

## 3.1 CLASSIFICATION OF ENVIRONMENTAL MISFITS

### **Different types of misfits**

The results confirm that a distinction can be made between different types of environmental misfits. Moreover, the influence of the façade on these misfits differs. There are two different types of environmental misfits in the hospital: The first group of misfits represents a result of the façade and/or an interaction with it. The façade directly causes the misfit or is indirectly contributing to these misfits. These environmental misfits are referred to as façade-dependent misfits. The second group of misfits have no relation to the façade at all and result due to other factors. These environmental misfits are referred to as façade-independent misfits.

### **Environmental misfits directly caused by the façade**

Hospital users of different key user groups were asked to name misfits that are directly caused by the façade. This question was not answered, as the users could not name any or were not aware of any misfits. Usually this question about façade-induced environmental misfits was met with irritation and misunderstanding. In most cases it was necessary to explain what is considered to be the façade and to what extent the user is affected by it or interacts with it. In general, it can be said for the interviewed users that there was no sensitivity for the effect of the façade on the room. The façade was not perceived as an active element that influences the room. Rather, the façade was considered appropriate, not further questioned and no object to pose requirements at. Thus, directly façade-induced environmental misfits could not or only very sparsely be named.

### **Environmental misfits as poor indoor environmental conditions**

The indirect façade-induced misfits were approached by questions concerning the environmental conditions in general. When the interviewed hospital users were asked about problems that arise due to the room and its ambient conditions, environmental misfits referring to temperature and air quality were mentioned. For example, it was repeatedly noted that the temperatures are poor and often significantly too warm during summer. Poor air quality was not mentioned by the patients, but by the nurses and physicians as they entered the room. Daylighting was usually not addressed by the interviewees. Against this background, however, it is worth noting that patients usually did not notice that their curtains were closed throughout the day, but opening them by another person was considered very pleasant and positive. In addition, the fact that there is a visual connection to the outdoors, as well as the view of nature, was described by some users as beneficial and enriching.

### **Façade-independent environmental misfits**

If users are furthermore asked about any kind of misfit, independent of the façade, the spectrum of answers is much wider and more diverse. Depending on the user group, the answers given address different issues. Thus, medical and nursing staff usually complained about high workload and limited storage space. However, these topics were not important for the patients or were seemingly not perceived. For patients, on the other hand, information aspects and their limited range of mobility played a central role.

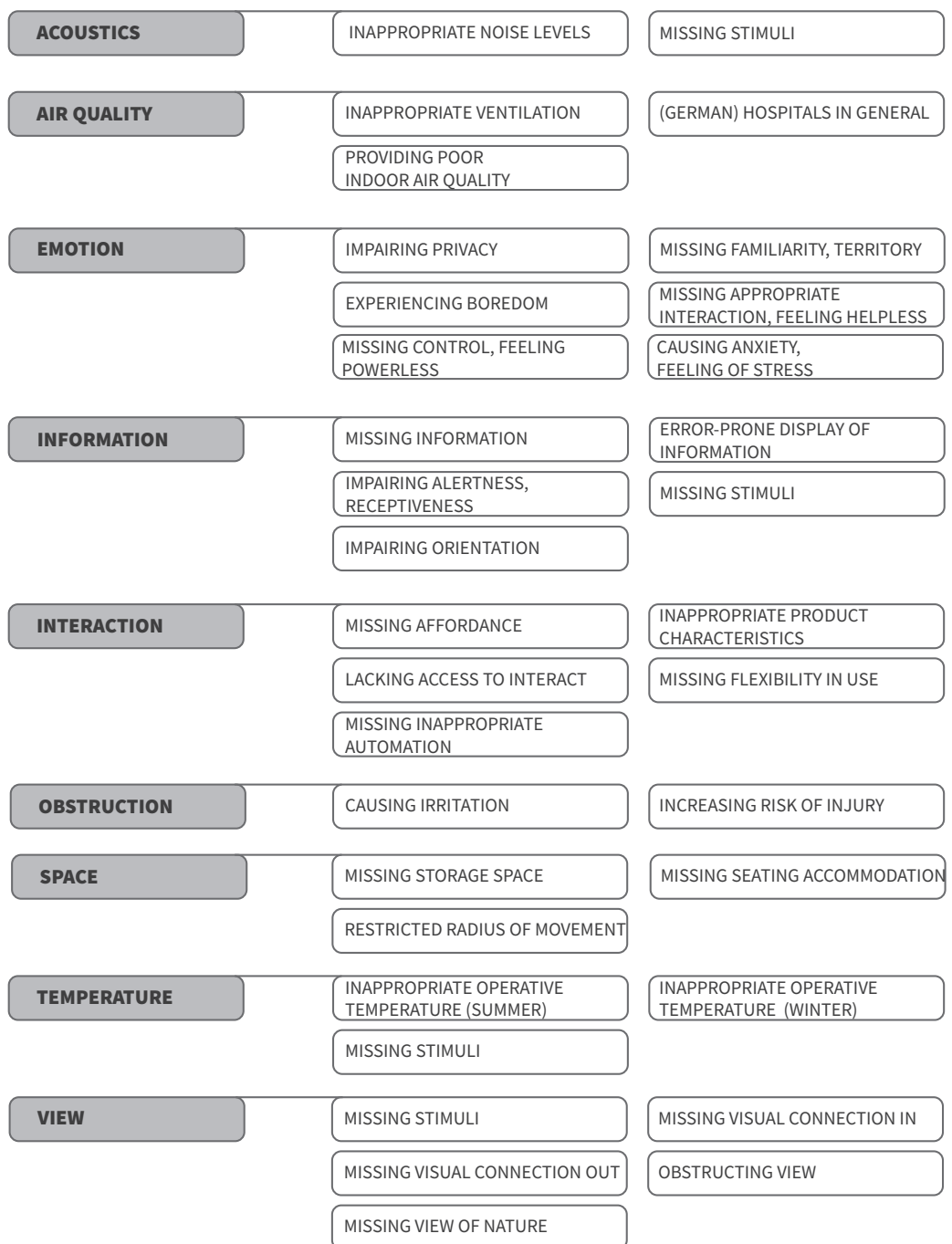
### **Classification of Environmental Misfits**

In order to structure the observed environmental misfits, ten main categories were defined. The main

categories cover a broad perspective and are therefore labeled in a generic way. As within each main category different types of misfits can occur, the main categories are complemented by more specific subcategories. The subcategories are more diverse and therefore,

more numerous. [Figure D.17](#) summarizes the main categories as well as the subordinated subcategories. The categories and subcategories were used as codes to structure the observed environmental misfits.

Figure D.17 - Main categories of environmental misfits and associated sub-categories



## 3.2 ENVIRONMENTAL MISFITS BY PERSONA

The individual subcategories were used to code the list of environmental misfits, but the frequency of which the individual codes were used varied. While the main categories ‘Acoustics’ and ‘Air quality’ were used less frequently to code environmental misfits, the categories of ‘Emotion’, ‘Information’ and ‘Interaction’ were used as codes more often. However, this generalization is not particularly useful as user-specific differences appear.

The environmental misfits that different hospital personas encounter are summarized. The summary relates to the personas presented in Section D.2 and thus, a distinction is made between misfits for geriatric inpatients, pediatric inpatients and their accompanying adults as well as physicians on normal and monitoring care wards of neurology. Each misfit is briefly described. In addition, an indication, whether this misfit applies to more than one persona (2nd column, indication \*) is given and a main category is assigned.

Furthermore, the assessment covers whether the misfit results from the façade’s specifications or an interaction with the façade (façade-dependent), or whether the misfit is caused independently of the façade (façade-independent). The misfits are grouped together in terms of similarity to the introduced main misfit-categories.

The compilations does not claim exhaustiveness, but

rather presents the results of the in-situ observations and interviews. In addition, the misfits are illustrated in photographs taken during the in-situ field observations.

### General care geriatric inpatient

The environmental misfits of a geriatric inpatient are summarized in [Table D.2](#). [Figures D.18](#) to [Figure D.23](#) illustrate these misfits.

Geriatric inpatients show environmental misfits that are mostly associated with the categories of ‘Information’, ‘Interaction’ and additionally, ‘Lighting’. Analyzing the misfits with regard to the assigned subcategories shows that with this subgroup of users, the subcategories of ‘Information: Missing information’ as well as ‘Lighting: Inappropriate Daylighting’ and ‘Lighting: Inappropriate Artificial Lighting’ are of particularly importance.

Table D.2 - Environmental misfits of a geriatric inpatient

#	Description of the Misfit	Main Category	Resulting from façade	Independent of façade
1	* Insufficient window ventilation leads to poor indoor air quality, feeling of stuffy air and basis for the spread of infection.	Air Quality	x	(x)
2	Geriatric and especially palliative patients suffer from being bedsore (decubitus), which carry an unpleasant odor.	Air Quality		x

Table D.2 - Environmental misfits of a geriatric inpatient, continued

#	Description of the Misfit	Main Category	Resulting from façade	Independent of façade
3	* Due to longer hospital stays, boredom increases with time.	Emotion		x
4	* Patients experience a lack of familiarity with the room and lack individual design options that create a homely feeling.	Emotion		x
5	* Waiting and feeling on hold, increases feeling of being in control and being at the mercy of others.	Emotion		x
6	Closed doors of inpatient rooms increase the feeling of being out of control and only passively active. The impression of being cut off from the outside is the result.	Emotion		x
7	Closed curtains and no connection to the exterior make orientation in time more difficult. The assessment of times of day, but also seasons, is becoming increasingly difficult for the patient and can lead to sleep deprivation.	Information	x	
8	Patients show an impaired day and night rhythm, which is additionally worsened by poor lighting conditions and background noise.	Information	x	
9	* Orientation in the hospital, especially when transferring from inpatient wards to therapy and examination rooms, presents a challenge and often leads to patients getting lost.	Information		x
10	* Signs of orientation are not provided in a suitable manner; orientation is lost and patients feel out of control. Mobile patients get lost at the ward and cannot find their way back to their room.	Information		x
11	Information is displayed in a way that is not suitable to elderly people. Displays with time and date indications are too small or not recognized as such. Door signs are error-prone and too small.	Information		x
12	Whenever a mobile patient is taking a walk around the hospital ward, stimuli are missing.	Information		x
13	* No information on daily activities and schedules is provided, which requires waiting and bears a moment of surprise.	Information		x
14	* The lack of mobility up to being bedridden prevents access to the façade.	Interaction	x	
15	The lack of mobility up to being bedridden prevents active interaction with the façade, such as opening windows or drawing the curtains.	Interaction	x	
16	Due to the use of assistive equipment, such as walkers, hands are not free to grip window handles. Free hands are accompanied by a moment of insecurity and loss of stability.	Interaction	x	

Table D.2 - Environmental misfits of a geriatric inpatient, continued

#	Description of the Misfit	Main Category	Resulting from façade	Independent of façade
17	Window handles are not recognized as such by dementia patients, i.e. they lack affordance and result in windows that can-not be operated by patients.	Interaction	x	
18	Window handles that are places too high up the window and require a stretch by normal-sized people and therefore result in windows that cannot be operated appropriately.	Interaction	x	
19	The lack of mobility that results in limited access and control over the interior conditions increases the feeling of independency and being at the mercy of others. Help by nurses is required.	Interaction		x
20	* The lack of mobility up to being bedridden prevents access to nature and the outdoors.	Interaction		x
21	At night and in the dark, reflections of light in floor-deep glazing can cause irritation, especially in patients with dementia.	Lighting	x	
22	Patients have the feeling that it is too dark in the room more quickly. Levels of illumination are perceived as too low.	Lighting	x	x
23	Strong variations in brightness in the immediate proximity to the façade and deeper in the room cause difficulties in orientation and movement. A hard edge of light is particularly disturbing.	Lighting	x	
24	Patients are sensitive to glare and even small degrees of glare can cause discomfort.	Lighting	x	x
25	* In multi-bed rooms high illumination levels directly at the window and lower levels deeper in the room lead to a disadvantage of those patients who are accommodated further away from the façade.	Lighting	x	
26	* Walking around most hospital's hallway does not provide for natural lighting.	Lighting	(x)	x
27	* Sleep is interrupted by the nurses' nightly checks and due to bright/non-dimmed lights, falling asleep is hampered.	Lighting		x
28	* Bright lights in the morning lead to a sudden awakening.	Lighting		x
29	* Open windows can cause risk of injury, due to collisions, especially whenever they are positioned close to public areas that are highly frequented.	Obstruction	x	
30	Shadows thrown by the shading system lead to irritating patterns on the floor that obstruct movement and prevent one from walking.	Obstruction	x	
31	* Whenever a mobile patient is taking a walk around the hospital ward, places to sit are missing.	Space		x
32	* Too high of temperatures in combination with a lack of ventilation lead to dry room air, i.e. low relative humidity.	Temperature	x	(x)

Table D.2 - Environmental misfits of a geriatric inpatient, continued

#	Description of the Misfit	Main Category	Resulting from façade	Independent of façade
33	* High solar radiation through the glazing leads to high temperatures, especially when the windows cannot be opened independently.	Temperature	x	
34	* Patients sitting or lying in bed cannot see directly outwards because the window's sill is too high or horizontal beams are blocking the view.	View	x	
35	* Walking around most hospital's hallway does not provide for a visual connection to the outdoors.	View	(x)	x
36	* Due to horizontal orientation within the patient bed, the view is directed at the ceiling, where little stimuli can be found.	View		x
37	* Whenever a mobile patient is taking a walk around the hospital ward, places with nice views are missing.	View		x

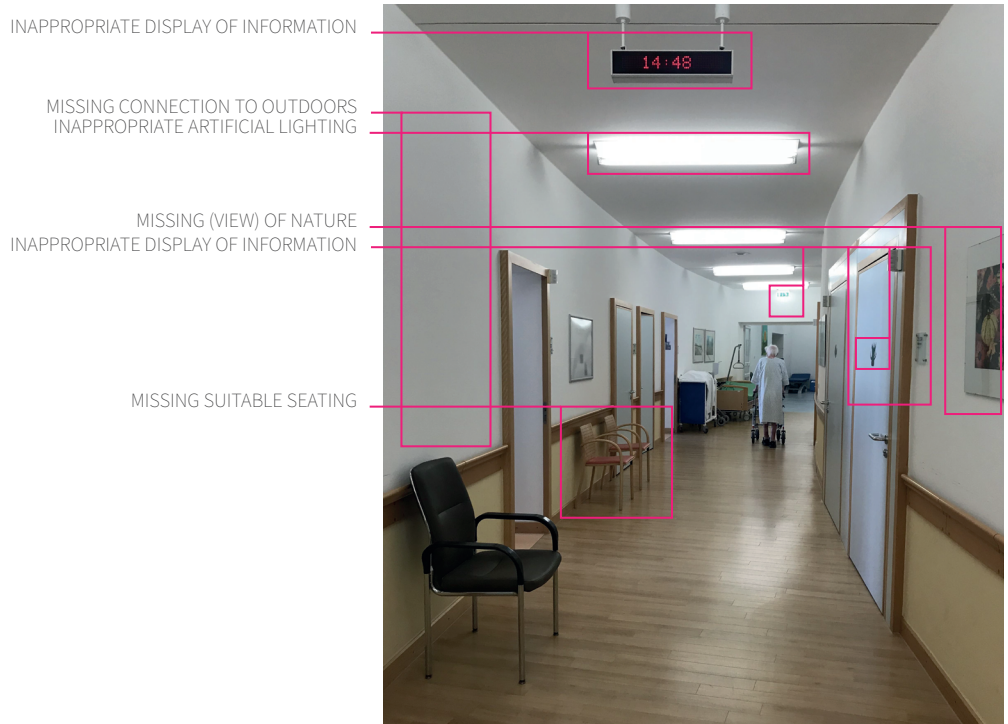


Figure D.18 - Environmental misfits of a geriatric inpatient with limited mobility walking around the hospital with walker

INAPPROPRIATE INTERACTION | MISSING CONTROL  
POOR AIR QUALITY | MISSING VENTILATION

INAPPROPRIATE DISPLAY OF INFORMATION

MISSING TEMPERATURE REGULATION



Figure D.19 - Environmental misfits of a geriatric inpatient while being mobilized within bed by a physiotherapist

MISSING STIMULI

INAPPROPRIATE INTERACTION | MISSING CONTROL  
INAPPROPRIATE DISPLAY OF INFORMATION

OBSTRUCTING VIEW  
MISSING SUITABLE SEATING

INAPPROPRIATE REFLECTION

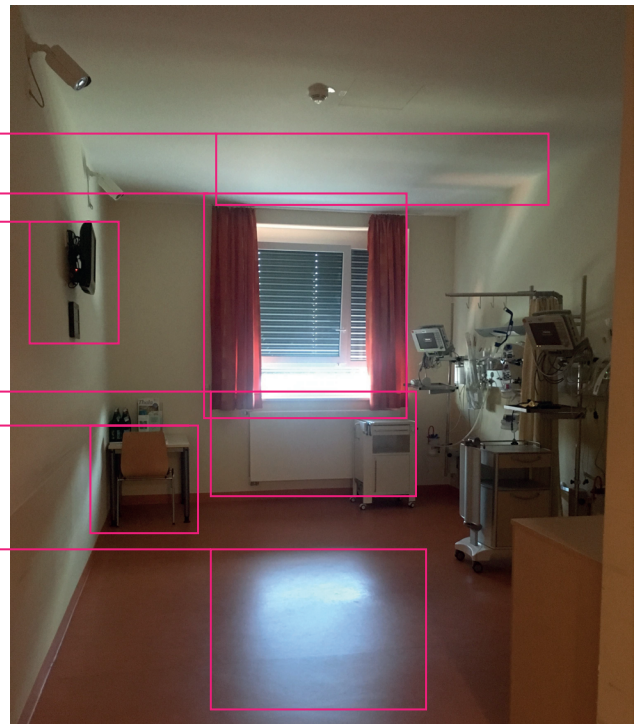


Figure D.20 - Environmental misfits in an inpatient room with monitoring devices



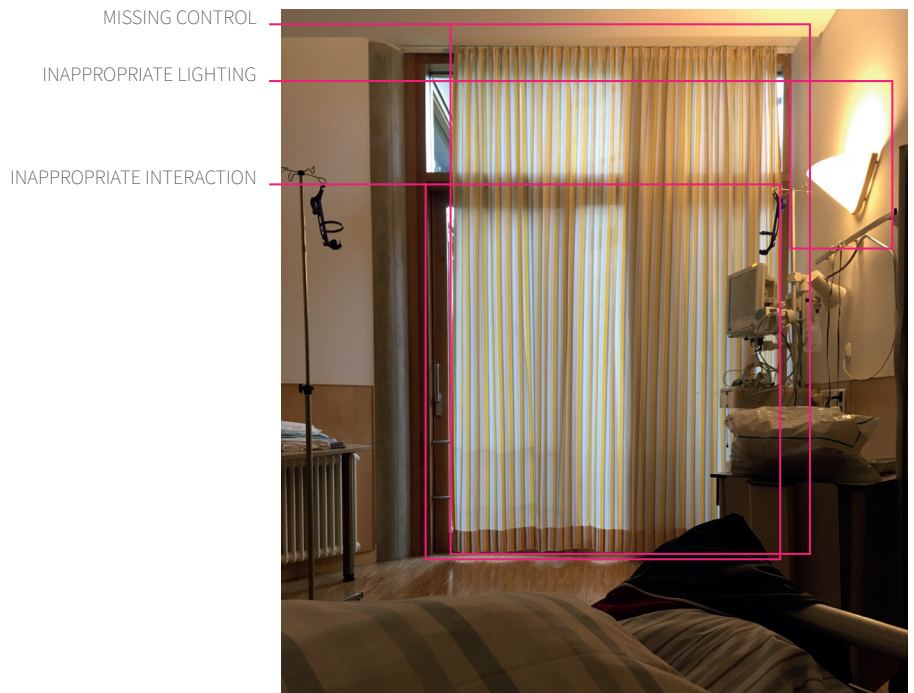


Figure D.21 - Environmental misfits caused by closed curtains in an inpatient room



Figure D.22 - Environmental misfits of geriatric inpatient with limited mobility, walking around the hospital with a walker and enjoying the views of the outdoors

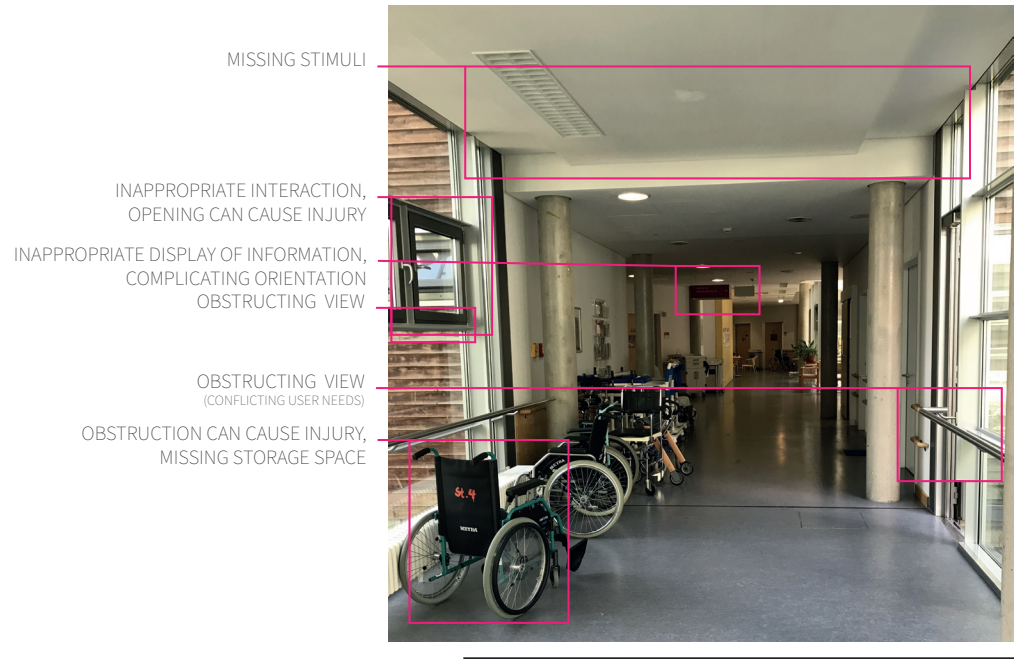


Figure D.23 - Environmental misfits in a hospital hallway, in parts caused by obstructing elements

### General care pediatric inpatient and accompanying person

The environmental misfits of a pediatric inpatient and their accompanying person are summarized in [Table D.3](#). [Figures D.24](#) to [Figure D.25](#) illustrate these misfits.

Pediatric inpatients and their accompanying person show environmental misfits that are mostly associated with the categories of ‘Emotion’, ‘Lighting’ and ‘Space’. Analyzing their misfits with regard to the assigned subcategories shows that the subcategory of ‘Space: Missing (appropriate) seating accommodation’ is of particularly importance.

Table D.3 - Environmental misfits of a pediatric inpatient and accompanying person

#	Description of the Misfit	Main Category	Resulting from façade	Independent of façade
1	Pediatric inpatient wards tend to be noisy wards (crying patients, more people, etc.). Relatively high noise levels disrupt sleep and rest.	Acoustics		x
2	* Young patients are particular sensitive to unknown equipment and distracting sounds.	Acoustics		x
3	Insufficient window ventilation leads to poor indoor air quality, feeling of stuffy air and the basis for the spread of an infection.	Air Quality	x	(x)
4	Sharing the room with another pediatric patient and the accompanying person is challenging as it brings along different needs with regard to ventilation.	Air Quality	x	x
5	* Young patients are particularly sensitive to unknown surroundings.	Emotion		x
6	Due to longer hospital stays, among patients (as they are recovering) as well as the accompanying person boredom increases over time.	Emotion		x
7	* Closed doors of inpatient rooms increase the impression of being cut off from the outside.	Emotion		x
8	* Patients experience a lack of familiarity with the room and lack individual design options that create a homely feeling.	Emotion		x
9	* Waiting and feeling on hold, increases feeling of being in control and being at the mercy of others.	Emotion		x
10	* Orientation in the hospital, especially when transferring from in-patient wards to therapy and examination rooms, presents a challenge and often leads to getting lost.	Information		x
11	* Whenever a mobile patient is taking a walk around the hospital ward, stimuli are missing.	Information		x
12	No information on daily activities and schedules is provided, which requires waiting and bears a moment of surprise.	Information		x
13	* Situational, the arms of the accompanying person are handicapped by carrying the child and complicate the opening of windows and doors.	Interaction	x	
14	* The lack of mobility up to being bedridden prevents access to nature and the outdoors.	Interaction		x

Table D.3 - Environmental misfits of a pediatric inpatient and accompanying person, continued

#	Description of the Misfit	Main Category	Resulting from façade	Independent of façade
15	* In multi-bed rooms high illumination levels directly at the window and lower levels deeper in the room lead to a disadvantage of those patients who are accommodated further away from the façade.	Lighting	x	
16	* Walking around most hospital's hallway does not provide for natural lighting.	Lighting	(x)	x
17	* Sleep is interrupted by the nurses' nightly checks and due to bright/non-dimmed lights, falling asleep is hampered.	Lighting		x
18	* Bright lights in the morning lead to a sud-den awakening.	Lighting		x
19	* Open windows can cause risk of injury, especially whenever they are positioned close to public areas that are highly frequented.	Obstruction	x	
20	Whenever a mobile patient is taking a walk around the hospital ward, places to sit are missing.	Space		x
21	Due to the fact that pediatric wardrooms are equipped like normal patient rooms, there is little space available if the accompanying persons are also present. Additional furniture, such as rollaway beds, need to be put away every morning.	Space		x
22	* For the accompanying person, private spaces to sit down and relax are limited.	Space		x
23	* Due to limited storage space, empty horizontal surfaces are used as storage areas.	Space		x
24	* Too high of temperatures in combination with a lack of ventilation lead to dry room air, i.e. low relative humidity.	Temperature	x	(x)
25	High solar radiation through the glazing leads to high temperatures, especially when the windows cannot be opened independently.	Temperature	x	
26	* Sharing the room with another pediatric patient and the accompanying person is challenging as it brings along different needs with regard to temperature.	Temperature	x	x
27	* Patients sitting or lying in bed cannot see directly outwards because the window's sill is too high or horizontal beams are blocking the view.	View	x	
28	* Walking around most hospital's hallway does not provide for a visual connection to the outdoors.	View	(x)	x
29	* Whenever a mobile patient is taking a walk around the hospital ward, places with nice views are missing.	View		x
30	* Due to horizontal orientation within the patient bed, the view is directed at the ceiling, where little stimuli can be found.	View		x

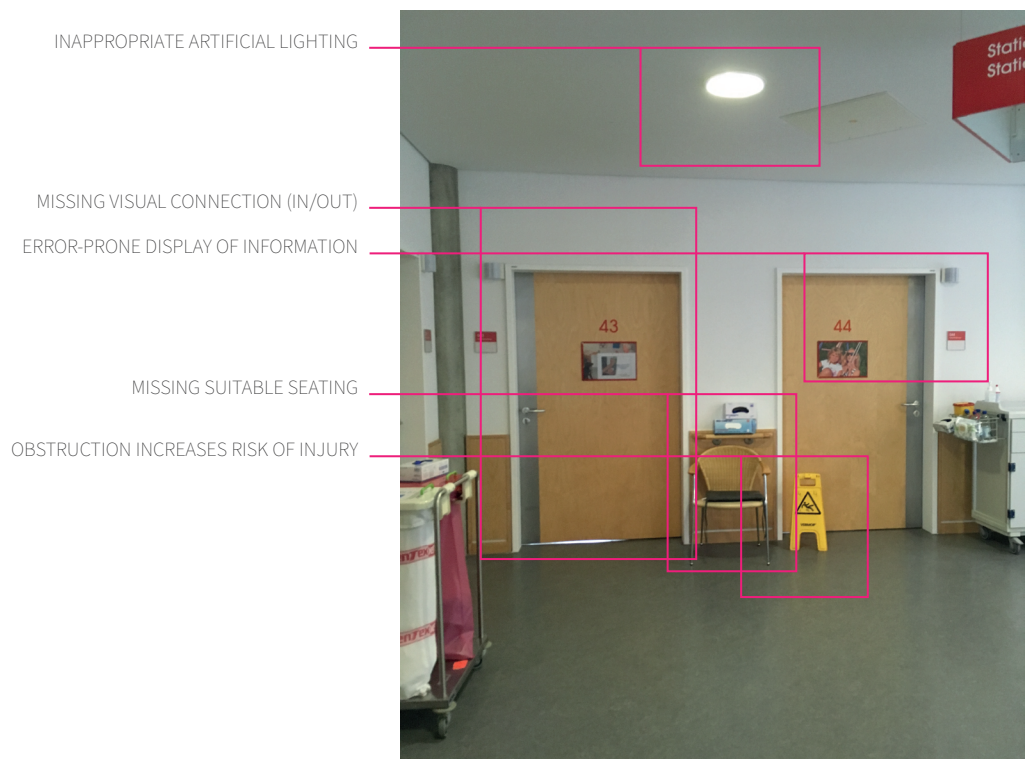


Figure D.24 - Environmental misfits in a hallway of a pediatric ward

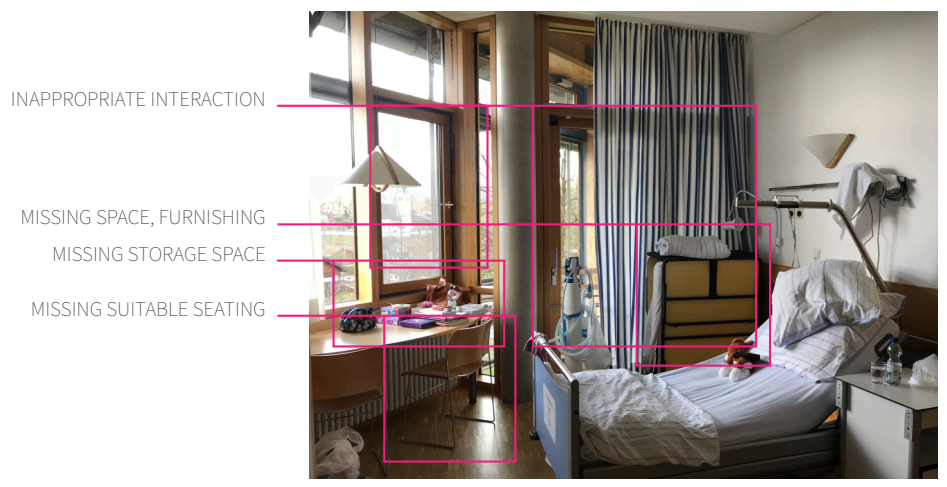


Figure D.25 - Environmental misfits of a pediatric inpatient room including folding bed of an accompanying person

**Physician specialized within the discipline of neurology at a general care /monitoring care ward**

The environmental misfits of a pediatric inpatient and their accompanying person are summarized in [Table D.4](#). [Figures D.26](#) to [Figure D.29](#) illustrate these misfits.

Physicians in the department of neurology working at a stroke unit show environmental misfits that are with considerable frequency associated with the category

of ‘Information’. Here, the subcategory of ‘Information: Missing information’ is particularly strong.

Table D.4 - Environmental misfits of a physician in the department of neurology, general care / monitoring care ward

#	Description of the Misfit	Main Category	Resulting from façade	Independent of façade
1	* Insufficient window ventilation leads to poor indoor air quality, feeling of stuffy air and the basis for the spread of an infection.	Air Quality	x	(x)
2	A high workload must be mastered; leading to a feeling of stress and being overwhelming.	Emotion		x
3	Due to long days in the hospital and missing connection to the outdoors, the natural sense of time is impaired, making it hard to orient in time.	Information	x	
4	Information on a patient's health status and ordered examinations are gathered within the patient's chart. This chart is available in paper form. Due to the paper, the chart is only available to one person at a time. Simultaneous access to the data is not provided for. Furthermore, the location of the chart is not always known. The fact that the patient charts are in paper form leads to delayed exchange and documentation of information.	Information		x
5	During 24-hour shifts the personal sleep rhythm gets distracted as one is constantly on standby.	Information		x
6	Frequent alarm sounds lower personal alertness and increases the risk of missing an alarm.	Information		x
7	In case of a patient alarm, one needs to check in with the nurses' station first to get information on which patient is impacted and where he/she is located. It costs precious time.	Information		x
8	Information on patients is provided by means of the patient's chart. During rounds, the patient's chart is studied intensively and information are not compiled clearly and well-structured at a glance.	Information		x
9	Doors to inpatient rooms are usually closed in order to ensure patient's privacy throughout the day. Information on the patients within the room as well as their current conditions would be helpful.	Information		x

Table D.4 - Environmental misfits of a physician in the department of neurology, general care / monitoring care ward, continued

#	Description of the Misfit	Main Category	Resulting from façade	Independent of façade
10	In order to make a correct diagnosis, it is necessary to receive all relevant information. One depends on the fact that the patient communicates all important information during rounds and that these are completed by information from the nursing staff.	Information		x
11	During rounds, patients are informed about their current diagnoses, next steps and details on medical procedures as well as examinations are provided. However, often this information is not sufficient and sustainable as the patient is too stressed and not receptive.	Information		x
12	Digitalization has not broadly entered the hospital world, yet. Digital tools are not used comprehensively.	Interaction		x
13	Office spaces are integrated into the hospital floor plan and are usually separated by closed doors. These office structures do not foster co-working and exchange of information (open office spaces, German: Bürolandschaften).	Interaction		x
14	Some examinations, such as ultrasounds, can take place in the inpatient rooms. Inappropriate daylighting or artificial lighting can result in glare that hampers work with the display.	Lighting	x	x
15	* Walking around most hospitals' hallways does not provide for natural lighting.	Lighting	(x)	x
16	* Due to limited storage space, available empty surfaces and areas are used as storage areas. This leads to obstructions that can increase the risk of injuries, such as falling.	Space		x
17	Break rooms to rest and recover are not sufficiently provided. Usually the physician rooms combine office and rest space.	Space		x
18	Workstations with computer work spaces are provided, but rarely set up in specially designated workspaces and rather part of the general physicians' room that also provides a bed for rest and sleep during night shifts.	Space		
19	* Too high of temperatures in combination with a lack of ventilation lead to dry room air, i.e. low relative humidity.	Temperature	x	(x)
20	* High solar radiation through the glazing leads to high temperatures, especially when the windows cannot be opened independently.	Temperature	x	
21	* Walking around most hospital's hallway does not provide for a visual connection to the outdoors.	View	(x)	x

INAPPROPRIATE DISPLAY OF INFORMATION  
ERROR-PRONE DISPLAY OF INFORMATION

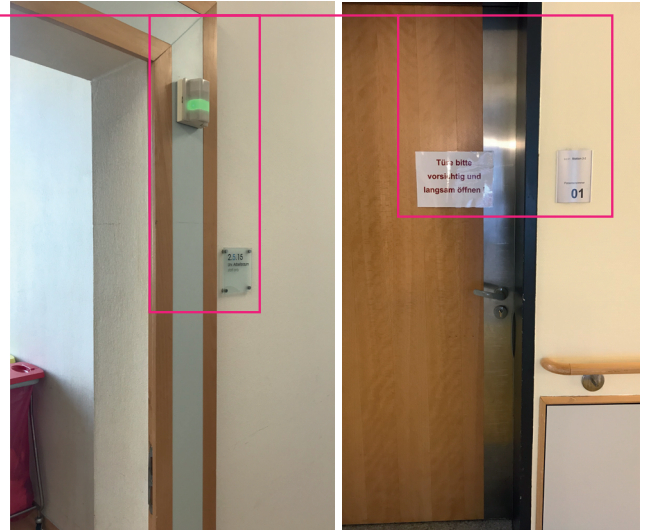


Figure D.26 - Environmental misfits with regard to display of information and signaling at doors

MISSING CONNECTION TO OUTDOORS  
MISSING STIMULI

MISSING STORAGE SPACE



Figure D.27 - Environmental misfits of physicians rooms with limited working and storage space



INAPPROPRIATE LIGHTING

INAPPROPRIATE LIGHTING

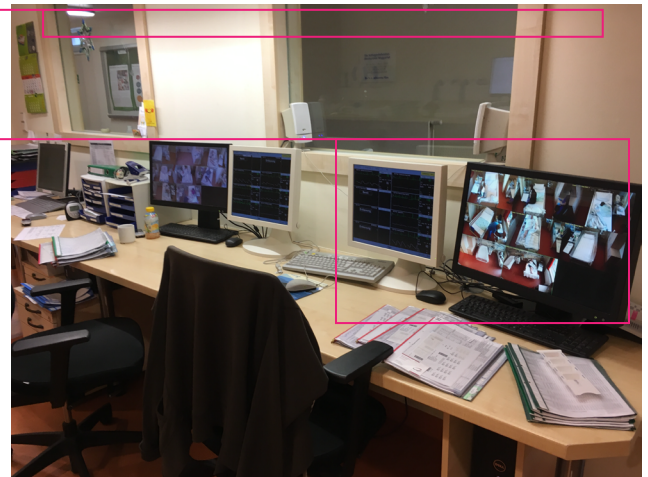


Figure D.28 - Environmental misfits in a physician and nursing work station of a monitoring ward

INAPPROPRIATE DISPLAY OF INFORMATION

INAPPROPRIATE INTERACTION

ERROR-PRONE INFORMATION



Figure D.29 - Environmental misfits in a physician and nursing office; exemplary patient's chart

# 3.3 UNIVERSAL ENVIRONMENTAL MISFITS ACROSS PERSONAS

In addition to user-specific misfits, there are also some common misfits that apply equally to all or several user groups at the same time. Common misfits can be understood as universal misfits that affect more than one user group. Universal misfits can be found in particular where many user groups share the same space and carry out similar activities.

Corridors, for example, are such shared areas and similar as well as overlapping needs are posed at them. Hospital corridors typically are within the building and surrounded by interior walls. Thus, hospital corridors do not provide a visual connection to the outside, they do not provide access to nature or stimuli by nature and they are usually equipped with non-circadian artificial lighting. (Figure D.30) This does not only have a negative effect on a geriatric patient, but also does

not provide any stimuli or orientation for the medical staff.

With regard to the assigned subcategories of environmental misfits, the following subcategories are of universal character and were assigned to misfits of both geriatric and pediatric inpatients as well as the physician's persona. (Table D.5)



Figure D.30 - Universal environmental misfits in a hospital hallway

Table D.5 - Common environmental misfits among geriatric inpatients, pediatric inpatients and their accompanying person as well as physicians

MAIN CATEGORY	DESCRIPTION OF THE MISFIT
VIEW: MISSING VISUAL CONNECTION TO OUTDOORS	Walking around most hospital's hallway does not provide for a visual connection to the outdoors.
AIR QUALITY: PROVIDING POOR INDOOR AIR QUALITY, ODORS	Insufficient window ventilation leads to poor indoor air quality, feeling of stuffy air and basis for the spread of infection.
EMOTION: MISSING CONTROL, FEELING POWERLESS	Closed doors of inpatient rooms increase the feeling of being out of control and only passively active. The impression of being cut off from the outside is the result.
LIGHTING: INAPPROPRIATE DAYLIGHTING	Walking around most hospital's hallway does not provide for natural lighting.
TEMPERATURE: INAPPROPRIATE OPERATIVE TEMPERATURE (SUMMER)	High solar radiation through the glazing leads to high temperatures, especially when the windows cannot be opened independently.

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# 4 USER-CENTRIC FAÇADE FUNCTIONS

On the basis of the collections of user-specific as well as universal environmental misfits, functional improvements or new façade functions as well as design features can be derived. By using the environmental misfits as indications, user-centricity finds consideration. The derived functions and design features represent a fix to the environmental misfits presented earlier and aim for providing better utility and an increased quality of space to the user.

Given the sets of environmental misfits, several façade functions and design features can be derived. As examples, eight different façade functions and design features that address the environmental misfits of different hospital user groups are given. The façade functions were provided with headings that give a first impression of the functionality and the associated misfit.

- Information/Interaction: “Façade serves as a room guard”
- Information: “Façade provides information”
- Interaction: “Façade provides multi-way interaction”
- Lighting: “Façade provides and redirects light into a space”
- Space: “Façade provides storage space”
- Space: “Façade provides a place to sit and rest”
- View: “Façade provides views”
- View/Interaction: “Façade providing nature in space”

The list of functions does not claim completeness, but rather aims for illustrating how, by applying a user-centered design approach, environmental misfits can be translated into new functions and design features.

Thus, while the derived functions are based on environmental misfits, the description of the functions and design features illustrates how the information

on user-centered design and findings from the field of environmental psychology, presented in the State of the Art, can be applied and translated into façade design. The collection includes a description of the functionality concept, but does not provide a detailed description of the function or its technical implementation. Due to overlaps, the functions are not presented separately for each user, but the function description refers to the different user groups and their requirements.

[Table D.6](#) to [Table D.10](#) summarize conceivable façade functions and design features.

For three out of the eight functions a more detailed description is given: Room Guard, Multi-way of Interaction and Providing Information. These functions are chosen for two reasons. First, the functions address the most frequently used codes of environmental misfits and therefore try to minimize the most urgent misfits. Second, these functions illustrate façade functions that not only enhance existing functions, such as provision of daylight, but enlarge the traditional scope of façade functionality. As this is the main objective of the dissertation, the selection is made accordingly.

In advance, it should be pointed out that the façade in its initial definition represents the boundary of a room towards the outside. However, some of the functions presented in the following relate to an enlarged understanding of the façade: The facades as any space-forming element that forms a room’s boundary towards the outside or within the building itself, such as interior walls.

Table D.6 - New façade functionality and design features with regard to lighting: Façade provides and redirects light into a space

<b>Specification of Façade Function and Design Feature</b>	<b>Geriatric</b>	<b>Pediatric</b>	<b>Physician</b>
By accessing information on current outdoor lighting conditions, adjusting the lighting levels within and thus, enabling a suitable circadian lighting. by adjusting day lighting and solar radiation entry. by adjusting artificial lighting.	x	(x)	x
By accessing information on current outdoor lighting conditions, adjusting façade properties accordingly. during night time, hindering glare and inappropriate reflections in the façade due to interior lighting.	x		
during day time, minimize glare while ensuring appropriate lighting levels for office and computer activities.	(x)		x
during day time, ensuring that solar shading devices and the shadows drawn by them do not cause obstruction.	x		
Redirecting light into the depth of the room in order to provide daylighting to all users within an inpatient room.	x	x	
Redirecting light into interior hallways.	x	x	x

Table D.7 - New façade functionality and design features with regard to space: Façade provides storage space

<b>Specification of Façade Function and Design Feature</b>	<b>Geriatric</b>	<b>Pediatric</b>	<b>Physician</b>
Horizontal storage: By increasing the depth of the façade and designing horizontal surfaces, storage area, similar to windows sills are provided. Ideally, these are adjustable in terms of height.	(x)	x	x
Vertical storage: By increasing the depth of the façade, the façade turns into a built-in cupboard that provides vertical storage space. Equipment can be stored without presenting an obstruction. Storage space is provided in places where opaque surfaces were already planned. Thus transparent areas are not minimized.	(x)	x	x

Table D.8 - New façade functionality and design features with regard to space: Façade provides a place to sit and rest

<b>Specification of Façade Function and Design Feature</b>	<b>Geriatric</b>	<b>Pediatric</b>	<b>Physician</b>
By increasing the depth of the façade, providing a space to sit and rest or sleep			
... in the hallways.	x	(x)	
... in the inpatient rooms.	x	x	
... in the inpatient rooms as additional bed for an accompanying person.		x	

Table D.9 - New façade functionality and design features with regard to view: Façade providing views

<b>Specification of Façade Function and Design Feature</b>	<b>Geriatric</b>	<b>Pediatric</b>	<b>Physician</b>
Enabling an unobstructed visual connection to the outdoors by choosing appropriate product characteristics.	x	x	x
Non-obstruction of view in an horizontal position, such as lying in a hospital bed	x	x	x
Non-obstruction of view in a setting position (chair or wheelchair)	x	x	x
Especially in hallways, where no direct visual connection on eye levels is possible by means of light bands in the upper third of the inner walls	x	x	x
Enabling an unobstructed visual connection form outside the room to hallways and other interior hospital areas in order to be able to attract attention, if necessary.	x	x	
Adjusting transparent façade areas by turning them into semi-transparent or opaque elements in order to...			
... ensure privacy within inpatient rooms. Especially, whenever a patient is changing from a horizontal position in bed into a vertical standing position.	x	x	
... enable flexibility with regard to daylight entry and view out.	x	x	x
Whenever visual connection to the outside is not possible, the (inner) facades can serve as interesting viewpoints by providing visual stimuli.	x	x	x

Table D.10 - New façade functionality and design features with regard to view/interaction: Façade providing nature in space

<b>Specification of Façade Function and Design Feature</b>	<b>Geriatric</b>	<b>Pediatric</b>	<b>Physician</b>
Providing access to nature, either within the room and space itself or by access to (a protected) outdoors.	x	x	x
Providing a sensory feeling of nature by means of ...	x	x	x
... direct interaction by haptic (touch), visual (view), acoustic (hearing) and olfactory (smell) of nature itself (such as plants).	x	x	x
... using natural materials.	x	x	x
... providing access to nature by integrating dynamics into the room. For example, in terms of variable/non-rhythmic ventilation and airflow.	x	x	x

## 4.1 INFORMATION/INTERACTION: FAÇADE SERVES AS A ROOM GUARD

Given a typical hospital floor plan within an inpatient room, the façade ‘oversees’ the room. Usually, the room units are sized in such a way that the façade as such “has an eye” on the room. This characteristic of hospital architecture could be used as an advantage and the façade could be turned into an element that overlooks the room, both figuratively and literally. This is not a matter of control, but an effort to increase the patient’s safety and well-being.

In the figurative sense the façade could be understood as a monitoring instrument. Thus, central information that is essential for the room quality and the perception of the room merges at the façade. At the same time, the façade can serve as a measuring unit to the inside and outside. Parameters that are typically used to determine indoor environmental quality could be addressed in the interior. These parameters do not necessarily have to be measured directly by the façade itself, but they need to converge with information about the external conditions that are collected via the façade. The combination of a room-based measurement concept with façade measurements is conceivable. Particularly those parameters are of interest, for which the room occupants lose sensitivity over time, such as olfactory habituation effects, or for which the user has no perception at all, such as CO<sub>2</sub> concentrations. The idea of measuring environmental conditions continuously is of particular interest for users that lack mobility or suffer from limited cognitive abilities. In this context, the façade as a rooms guard can provide information and enhance human sensory assessments.

In addition to measuring classical indoor environmental quality parameters, the façade could also detect the presence and absence of users. Attendances and absences could be detected by movements similar to a motion detector. In this way, input could be generated for higher-level systems such as lighting systems. A further aspect that would contribute to safety in the hospital and relieve the hospital staff would be to use the façade for the detection of falls. Geriatric patients in particular, who are only mobile to a limited extent, suffer from the consequences of falls. Often the fall of a patient is not immediately noticed by the staff in the

hospital. The façade could have an abstracting view of the room and, similar to already available fall mats, provide essential information about the patient’s condition and call for help in case of an emergency.

Turning the façade into a room guard element would benefit the patients, especially those who need higher care and attention by the nursing staff, such as geriatric inpatients. While pediatric inpatients are usually accompanied by a person, they are already provided with higher levels of care and attention. By using the façade as a measuring and observation element, another step towards higher patient security and care can be taken. The idea of putting the façade in charge of keeping a watch on irregularities in terms of movements and emergencies, might even help with lightening the workload of the nursing as well as medical staff.

[Table D.11](#) summarizes conceivable façade functions and design features that directly relate to the presented façade function.

Table D.11 - New façade functionality and design features with regard to information/interaction: Façade serves as a room guard

<b>Specification of Façade Function and Design Feature</b>	<b>Geriatric</b>	<b>Pediatric</b>	<b>Physician</b>
Façade as monitoring instrument that measures parameters of the indoor environment in order to assess the quality of the indoor environment (IEQ).	x	x	x
Measuring CO2 levels	x	x	x
Measuring VOC levels	x	x	x
Measuring operative temperature levels	x	x	x
Measuring lighting levels	x	x	x
Measuring noise and acoustic levels	x	x	x
Façade as monitoring instrument that assesses the presence of users and their patterns of movement.			
Recognizing presence and absence of users.	x	x	x
Recognizing users and their requirements	x	x	x
Recognizing falls and setting of alarm signal	x		(x)
Façade as monitoring instrument that assesses the possibilities of obstructions and increased risks of injury caused by the façade, such as open windows in public hallways.	x	x	x
Façade as mitigate between inside and outside. By measuring indoor environmental quality parameters and relating them to outdoor environmental conditions, com-plex interactions with different degrees of automation can be proposed and executed.	x	x	x
Feedback information on outside lighting levels and light temperature/color to the lighting system, in order to implement circadian (day) lighting qualities.	x	x	x



# 4.2 INTERACTION: FAÇADE PROVIDES MULTIPLE INTERACTION

Multi-way interaction specifies the interactions that can take place with regard to facades. Basically, three different perspectives can be subsumed under the concept of a façade with multiple ways of interaction. First of all, multi-way interaction refers to different ways that enable an interaction between humans and a façade. Second, multi-way interaction specifies that it is not necessarily only a human, who interacts with the façade, but rather a multitude of participants can constitute to an interaction. Third, multi-ways of interaction address the multitude of consequences an interaction can have.

[Table D.12](#) summarizes conceivable façade functions and design features that directly relate to the presented façade function.

## **Ways of interaction**

The first aspect ‘ways of interaction’ addresses the issue of interaction between human and façade. If one compares this kind of interaction with the frequently discussed topic of human-machine interaction, parallels emerge. The façade becomes a machine in this context and an interaction with the human being is to be ensured. Thus, facades and humans are regarded as interaction partners. The analysis of misfits has shown that all user groups and in particular the patients interact with the façade. Depending on the user, this interaction takes place under different conditions, such as user-specific physiological limitations, different cognitive abilities and technology affinity. In addition to the different prerequisites, different demands are also placed upon the interaction. Hence, misfits resulting from interacting with the façade depend on various factors.

Conventional interaction between a user and the façade take place, whenever the user stands directly in front of the façade and can interact with it haptic by means of touch. With regard to geriatric inpatients the frequency of interaction-related misfits was particularly high and this affected in particular the conventional way of interaction with facades. As shown in the misfits of geriatric patients, they often suffer from impaired mobility, such as bed-riddenness and need of using

walkers. Thus, conventional ways of interaction are limited by restrictions, such as holding on to a walker, and therefore lead to the presented environmental misfits. Interaction via a window handle illustrates an example of an impaired way of interaction. This way, Universal Design is not implemented.

A first step is to create a fitting environment for the interaction elements, such as for example window handles, by using suitable product characteristics such as size, height, dimensions and color design. While, for example, the flexible installation of the interaction elements (here for example the window handles), especially with regard to the mounting height, provides an advantage for various users that are directly in front of the façade, users who are denied access to the façade are still impaired. In order to increase the universal character of the façade interaction and thus ensure its ‘equitable use’ and ‘flexibility in use’, however, different types of interaction must be possible at the same time.

Multi-Way interaction in the sense of ‘ways of interaction’ describes a façade functionality that allows to interact with the façade via different ways. Thus, in addition to the conventional haptic interaction it is necessary to provide further types of interaction in order to address the observed misfits holistically.

Against the background of a geriatric patient and possible bed-riddenness or limited mobility, the requirement arises that the interaction with the façade is also guaranteed over distance or without direct haptic touch. For example, another form of interaction could take place via voice commands or gesture control. With suitable sensors, such as Soli, LeapMotion, Kinect, RealSense etc., even smallest gestures could be recognized and transformed into interactions. Not only geriatric or less mobile users will benefit from this type of interaction, but whenever the haptic interaction is permanently, temporarily or situatively restricted. Simultaneously, it provides benefits, if haptic interaction is to be prevented - for hygienic reasons and the spread of infection, for example.

Table D.12 - New façade functionality and design features with regard to interaction: Façade provides multi-way interaction

<b>Specification of Façade Function and Design Feature</b>	<b>Geriatric</b>	<b>Pediatric</b>	<b>Physician</b>
Choosing appropriate product characteristics that allow for a certain degree of flexibility in regard of the haptic interacting user, such as adjustable height of window handles, etc.	x	x	x
Besides haptic interaction via direct touch, provide multiple ways of interaction in order to interact with the façade across a certain distance and not only in close proximity to the façade.	x	x	x
Interaction via gestures	x	x	x
Interaction via speech and voice control	x	x	x
Different degrees of automation, ranging from fully automated via user-specific automation to non-automated	x	x	x
Allowing for interaction between humans and facades, but equally interaction between surrounding elements and the façade, such as the patient bed.	x	x	(x)
Enabling interaction of multiple consequences, such as interaction with the operable façade elements, sun shading devices, glare control devices, ventilation, etc.	x	x	(x)
Providing information by means of color codings.			x
Façade providing orientation.			
Providing instructions on orientation in case of an evacuation scenario.	x	x	x
Providing instructions in terms of wayfinding around the hospital. However, not only by displaying information, but rather by guiding the user to the desired destination.	x	x	
Providing instructions terms of wayfinding and orientation in terms of a patient emergency. Signposting the emergency location and guiding the user to the location.			x

### Participants of interaction

Following human-machine interaction, the aspects just described refer to an interaction between humans and façades as machines. Against the backdrop of increasing intelligence of everyday objects and increasing connectivity, interaction is not limited to humans and façades, but can include everyday objects. This extended scope of participants in interaction with the façade represents a further aspect of multi-way interaction. Thus, the façade can interact not only with the human as such, but also with the immediate environment and its elements. For example, the hospital bed is a central element in every hospital room as well as in the hospital as a system. Hospital beds are used to collect and evaluate information about a hospital. As an interaction partner, the hospital bed could communicate central information about the room as well as the user assigned to the bed, his or her presence and room requirements to the façade. However, the interaction is not limited to the patient bed only, but can potentially involve all elements of the room. [Figure D.31](#) schematically shows a patient room, its elements and their interaction with the façade.

### Consequences of an interaction

The third dimension of the multi-way interaction functionality of the façade specifies the activities that can be performed as a result of the interaction. Thus, it is conceivable that in addition to the simple opening and closing of the window, other activities can also be integrated. These can take place within the façade itself, such as collecting data on maintenance intervals. But can in particular initiate actions that influence the room and its environment as such. Today, it is already easily possible to interact with the external sun shading system. However, additional actions such as dynamic control of the ventilation and glare protection inside would also be conceivable.

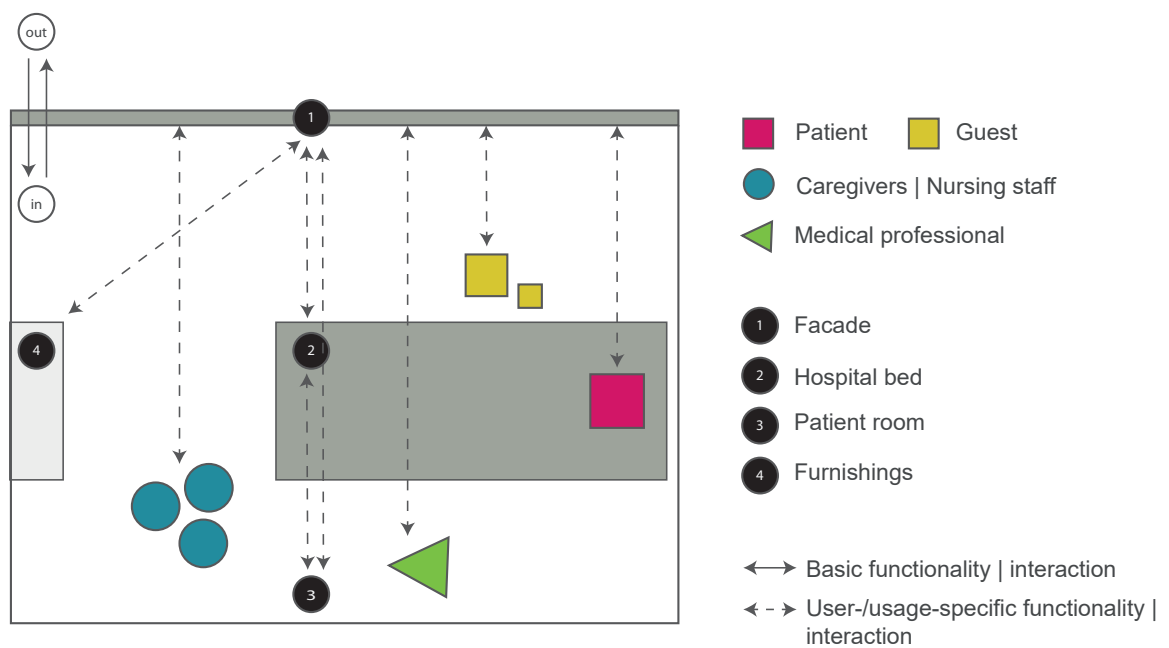


Figure D.31 - Multiple interactions between façade, users and objects

## 4.3 INFORMATION: FAÇADE PROVIDES INFORMATION

Many of the misfits identified in the analysis address information. For various user groups, the provision of information plays a central role. The exact nature of the content varies from user group to user group, but the need for information is universal. Considering the misfits that can be assigned to the category (missing) information, it becomes clear that the façade can be used in different ways for the purpose of providing information.

Basically, the façade makes up a large percentage of the building skin. By taking interior walls that enclose the room inwards into consideration, an even larger surface area of walls results. Currently, this area can be composed of transparent and/or opaque elements. While the transparent parts ensure a visual connection to the outside and also enable ventilation in the case of operable windows, opaque surfaces generally do not fulfil any specific function. The basic idea behind the idea of 'Display of Information' as a façade function is to use these previously unused areas to display information and thus, to minimize environmental misfits prone to information. This makes the façade comparable to today's common display, but larger and seamlessly integrated. As a result, the façade becomes a projection surface and a provider of information. This function can be used both for the definition of the façade as a boundary to the outside space and for the elements forming a boundary to the inside.

The information provided by the façade can be both user-specific or general, such as information on orientation in the building or in case of an emergency evacuation. Depending on the user specification, information can either be permanently visible to everyone or only be visible to entitled users with the aid of specific devices. Linking Augmented Reality (AR) technology to the façade enables the use of previously unused areas to provide information in a filtered manner. Examples for AR applications in the façade are providing information during rounds to the physician or to the maintenance staff, when assessing the conditions of a façade.

In principle, various applications are theoretically imaginable for the provision and accessibility of the information provided via the façade. On the one hand, the information can be made available directly to the users of the room. This can be done for various reasons, such as orientation, entertainment, etc. The basic idea, however, is that the information is intended for and addressed to the user of the room - patient room, examination room, corridor, etc. If one considers the patient-specific environmental misfits, the information provided can serve to distract, remind or educate about examinations and therapies. Especially geriatric patients showed that repetitive information is of positive benefit, e.g. reminding patients of sufficient fluid intake. Information can be provided as insight into one's own patient file. Or also stimuli of other kind can be created, such as pictures of moving nature.

Regardless of the patient's room, information can be helpful for orientation, especially in more public areas, such as corridors, lounges and entrance halls. In addition to the mere provision of information, it is also conceivable with regard to orientation aspects that the façade guides the disoriented user through the hospital with the aid of visual signals. With this function, the distinction between information display and interactive interface becomes blurred. The façade as an orientation aid is conceivable not only for those cases in which one wants to proceed from point A to point B in the hospital or to indicate escape ways, but also in the event of a patient emergency. In case of an emergency, to avoid the physician having to ask for the patient's room first and not being able to hurry directly to the patient, the room-side and corridor-forming boundary walls could serve as signposting that directs the physician to the patient's location.

However, the misfits described do not only refer to missing information, but also to the provision of information at the wrong time, in the wrong place, in an inappropriate manner. In this context, different examples can be given for different user groups. For hospital staff, the phenomenon of alarm fatigue and the associated impaired alertness and receptiveness should be mentioned. Patient emergencies are usually alerted by means of alarm signals. However, with increasing exposure to these signals, the receptivity decreases and alarm fatigue occurs. As a result, alarms are no longer perceived sufficiently. In this

way, another type of information channel could be provided via the façade.

Beyond these common use cases of ‘Providing information’ and ‘Appropriate information’, the next scenario addresses in particular the hospital-specific needs of the medical and nursing staff. Here, the information provided serves as a mediator between the interior and exterior of a room. The nursing staff is particularly interested in being able to access information on the inside of a patient’s room without having to open a door and thus, restrict the privacy of the patients. For example, information-giving elements could be integrated into the interior walls. This is of particular interest for wards with a general degree of care. In this way, the nursing and medical staff could receive information about the patient’s current condition, requests, necessary medication, etc. without having to disturb the patient in the room. The interior façade could serve as a line of sight that at the same time provides additional information.

While in the first case the information is provided for the user of the room, in the second case the information serves a user outside the room, who is dependent on the information from the inside and would otherwise receive it by entering the room. The basic principle is that information is provided in a universal manner that complies with the principles of Universal and Experience Design. The façade that displays the information should therefore be able to recognize which user is standing in front of it and interact, so that information can be adapted accordingly. For example, in terms of Universal Design, the information presented could be adapted in terms of size and content.

The display of information, whether purely for information or for reasons of orientation, is directly connected to the already introduced functionality of ‘Multiple-Way Interaction’. In addition, the topic of providing information is very closely connected with the façade as room guard. Information that has been recorded by the façade as a monitoring device can be communicated internally and externally. For example, it is conceivable to present the current air quality in order to inform the user, to be more sensitive and at the same time to offer an action for improvement. Another conceivable application could be the presentation of noise levels. As hospitals are usually too noisy, but users, especially staff, are not aware of this, information on the current noise level and a reminder to avoid unnecessary noises would also make users more sensitive.

[Table D.13](#) summarizes conceivable façade functions and design features that directly relate to the presented façade function.

Table D.13 - New façade functionality and design features with regard to information: Façade provides information

<b>Specification of Façade Function and Design Feature</b>	<b>Geriatric</b>	<b>Pediatric</b>	<b>Physician</b>
Façade as a display of information, either integrated into the glazing or as opaque elements within the façade.			
Displaying personal information for the user within the room, such as daily schedules, procedures, patient charts, reminders on medication, etc.	x	x	x
Displaying general information for the user within the room date, time, etc.	x	x	x
Displaying personal information for the user within the room in order to increase the feeling of personal belonging, such as personal memories, adjusting color preferences, etc.	x	x	
Displaying information on current environmental conditions, such as CO2 levels, lighting levels, noise levels, etc. as well as necessary actions in order to improve the conditions, such as necessary ventilation, necessity of additional light sources, etc..	x	x	x
Providing information as mitigate for a user outside the room in order to minimize the necessity of entering the room. Information such as, medication intake, current condition, presence, etc.			x
Providing information at a glance while passing by.			x
Providing information by means of color coding.			x
Façade providing orientation.			
Providing instructions on orientation in case of an evacuation scenario.	x	x	x
Providing instructions in terms of wayfinding around the hospital. However, not only by displaying information, but rather by guiding the user to the desired destination.	x	x	
Providing instructions terms of wayfinding and orientation in terms of a patient emergency. Signposting the emergency location and guiding the user to the location.			x



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# E DISCUSSION

## 1 USERS AND MISFITS

Within the discussion chapter the presented results are analyzed in terms of their limitations and implications. This discussion of results is organized in three sections: First, covering the results on users and their environmental misfits. Second, addressing the results on user-centric façade functions and design features that were derived. Third, discussing limitations of general character that need to be considered with regard to the results of this dissertation.

### **Users are not users: differentiating main user groups**

This dissertation distinguishes between different main user groups. Analyzing the presented user groups and the chosen personas, the results show that users are very different in terms of their needs and associated misfits. The differences result on the one hand from factors independent of hospitals, such as demographic differences. On the other hand, differences also result from the very different roles played and filled out by the user groups in the hospital context. These different roles are associated with different tasks and daily routines, but also with various expectations, fears and emotional constitutions. Considering daily routines and tasks, the results implicate that patients and physicians show distinctly

different patterns of movement, activities and workloads. While patients usually spend most of their day in their room, physicians are rarely bound to one place. Moreover, when comparing the annual times of presence of these two user groups, it is not particularly surprising that while hospital employees are accustomed to spending a lot of time at the hospital, patients are not. Patients therefore encounter different environmental misfits, such as missing orientation.

As part of this work different initial emotional states and thus different needs were identified between the main user groups. Against this backdrop, a differentiation according to user groups is recommended. By identifying the main user groups that are influenced by the façade, the grounds for a subsequent user analysis is laid. All user groups that are identified within this first step are going to be assessed further. And vice versa: all users that are not identified, will not be assessed further. Thus, this first step of analyzing the main users is crucial and one major group of users can easily be missed.

It is therefore advisable to approach this analysis from two sides and triangulate the results. In the scope of this study,



triangulation of the identified main user groups was performed on the basis of a literature review and in-situ observations in the hospital. This way of triangulation can be seen as a first limitation. Thus, in future research projects in this field, in addition to the above-mentioned triangulation methods, the results should be verified with one and/or more users directly. A triangulation of results by stakeholders from within the field provides an additional quality and ensures that central user groups are not neglected, unintentionally.

**Patients are not patients:  
differentiating sub user groups**

In addition to the differentiation of main user groups, a further level of differentiation was made. The comparison of the two different patients - geriatric patient vs. pediatric patient with accompanying person - clearly showed that within one main user group there can be substantial differences. A generalization across user groups, meaning generalizing across all patients and referring to them as 'patients', is not effective. As needs as well as abilities and limitations differ, it is necessary to differentiate between sub user groups.

Comparing the persona of a geriatric inpatient to the persona of a pediatric inpatient and the accompanying person showed that, while speaking about user groups, patients are not patients. The general constitution of body and mind of the two (or three, when also considering the accompanying person) user groups differ widely. When compared to pediatric inpatients and their accompanying person, geriatric patients show distinctly different cognitive abilities. For example, while pediatric patients usually do not struggle with 'Delir', this clinical picture stands for geriatric patients. The accompanying person of the child represents the user group 'visitors', but can also be regarded as a representative of elective middle-aged patients. While children, especially toddlers, need a lot of care and external help too and are therefore comparable to geriatric patients, their accompanying persons shows clearly different needs. Comparing the two presented personas shows two results: On the one hand, different members of a certain user group can show distinct differences, for example a geriatric patient and accompanying person of a pediatric

patient or an elective middle-aged patient. On the other hand, there are similarities between users of different groups, for example between geriatric patients and pediatric patients.

As different initial emotional conditions and thus different needs could be identified across different main user groups, these differences are present among users within a main user group, too. By comparing different subgroups of patients it became clear that their initial conditions on admission to a hospital are diverse. Against this backdrop, a differentiation by main user groups as well as by sub-groups, meaning specific users within the same group, is recommended. This additional differentiation of sub user groups can be understood as a further specification and detailed user analysis. Thus, this additional user specification allows for identifying differences between members of the same user group, but also for highlighting similarities between members of different main user groups. In this way, both user-specific characteristics and similarities can be identified.

The dissertation collected data on differences between patients based on literature reviews, on-site observations and interviews with physicians as well as nursing staff. Direct conversations with patients could not be conducted. Systematic access to and exchange with patients was not possible due to privacy concerns in the hospital. Thus, the information was not collected directly, but indirectly, which is a limitation regarding the results. With regard to data collection and analysis, triangulation of the results is necessary, too. Ideally, data as well as subsequent triangulation should be carried out in a personal conversation with the patients themselves, so that information can be directly collected and verified.

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**Comparing the persona of a geriatric inpatient to the persona of a pediatric inpatient showed that patients are not patients.**

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**There are known knowns.** These are things we know that we know.

**There are known unknowns.** That is to say, there are things that we know we don't know.

**But there are also unknown unknowns. There are things we don't know we don't know.**

(Donald Rumsfeld)

### **Personas: differentiating by means of user characteristics, abilities and limitations**

The differentiation of users between user groups and within a user group can take place using different methods. Within the scope of this work, this was done by creating personas and the collection of environmental misfits. Thus, in a first step, by means of creating a persona, essential characteristics of the user as well as abilities, limitations and handicaps were identified. This analysis covered personal data and statistical frequencies of disease patterns, but depicts the emotional state of the user in question in particular. This way the reader is enabled to understand the person described as a human and thus to develop empathy.

Personas always represent a generalization and therefore only represent certain parts of reality. In some aspects they are too general, in others too specific. A persona itself can serve as an inspiration and help the designer to understand everyday life and the associated problems the persona has to overcome. It is recommended to use a similar structure for the description of different personas and thus, to collect criteria that are comparable. The added value of the persona is strongly dependent on the information it contains. If important aspects, which are characteristic for the particular group of people, are overlooked, they usually do not play a role in the design process.

Together with the danger of focusing too much on the persona and the characteristics it describes, using personas can ultimately lead to a design that is not relevant for a real group of people and ignores important user-specific aspects. Thus, the content of information is particularly relevant and decisive for the further design process. The description's necessary content should be outlined in advance and if necessary, adjusted. Once the results on the main user groups and the sub user groups have been triangulated, a triangulation of the personas is not necessary.

In addition to the information that is provided by the persona's description, the selection of the personas

plays an even more important role. The selection of the personas within this thesis was made, on the one hand, to represent common users. On the other hand, however, particularly in order to highlight differences between main user groups and sub user groups. Therefore the personas presented are neither sufficient to provide a comprehensive analysis of all relevant hospital users, nor do they represent the multitude of all possible user groups.

### **Environmental misfits as guiding principles**

With reference to the personas, the environmental misfits encountered by a persona were collected. It is important to note the order in which the misfits were collected: in a second step, based on the persona's description. For one, as many misfits are based on physical and/or mental limitations that the person has to overcome, the information on a person's abilities and limitations is helpful. Physical and psychological differences have a significant influence on the environmental misfits the individual user groups encounter. A direct correlation between a persona's specific abilities as well as constitution and the prevailing environmental misfits is given. For example, the lack of mobility in geriatric inpatients leads to the misfit of impaired interaction with the façade. This impairment of interaction in turns effects the already impaired day and night rhythm of geriatric inpatients as constantly closed curtains, high window sills and insufficient window openings further amplify the phenomenon.

Thus, in order to address the relevant environmental misfits, an in-depth analysis of user groups needs to include an identification of key user groups as well as an analysis of main user differences in terms of abilities and limitations. Within this context, the guidelines of Universal Design and User Experience (UX) Design, as presented in the State of the Art, can help to identify prevailing misfits. Guidelines, such as the UX factors 'Being Useful' and 'Being Usable', provide clues for possible misfits. Thus, the guidelines can help to improve the quality of new products, while designing them, but at the same time they can help to identify product characteristics that need improvement.

The involvement of the persona helps to increase sensitivity to the needs of the user group and enables a more attentive observation of irregularities.

With the help of the personas, the basis for empathy during the observation of misfits is created. However, it is not recommended to create personas for all identified main user groups and associated sub user groups. Once the main user groups have been identified, an initial analysis of misfits may allow for the identification of users for whom the creation of a persona is purposeful, while other users are not considered further. An iterative process of user analysis consisting of an initial collection of misfits, the subsequent creation of the persona and final collection of detailed misfits is therefore advisable.

Within the scope of the dissertation, the combination of personas and a user-specific collection of environmental misfits was found to be suitable as a basis for deriving façade functions. Nevertheless, the high dependency of each of the individual steps among each other represents a limitation. The first phase of the Design Thinking process shows already a high degree of result dependency. The entire development process is based on the results of the user analysis. The derived functionalities represent an answer to the environmental misfits that are associated with the personas. The result is therefore strongly dependent on the input and its quality. Even if the individual results of the persona creation as well as the misfit identification are well triangulated, the limitation of the “unknown unknowns”.

### **Environmental misfits of user-specific, universal as well as competing character**

As implied in the hypotheses, it was confirmed that user-specific environmental misfits can be observed in the hospital context. The analysis of environmental misfits showed that all user groups encounter misfits of each main category (acoustics, air quality, emotions, information, etc.). However, comparing the most frequently used codes across all personas with the most frequently used codes by persona, confirmed the user-dependency of environmental misfits. For each persona, the top three categories of misfits differed and were only partially congruent to the categories that were used user-independently. Moreover, the actual misfits and therefore the assigned subcategories vary. For the persona ‘Physician, general care/monitoring ward, neurology’ the aspect of information is of particular importance, while for the two patient groups different priorities are observed. For the persona ‘geriatric patients’, lighting, interaction and information are critical issues. For the persona ‘pediatric patient and accompanying person’, lighting, space and view are critical. That the environmental misfits of users differ with regard to different user

groups holds not only true for the group of façade-independent environmental misfits, but can also be applied to façade-dependent misfits. However, it needs to be pointed out that while user-dependency can also be observed with regard to façade-dependent misfits, it is more prominent with regard to façade-independent misfits. Thus, generalizing environmental misfits across all user groups equally is not reasonable. However, the analysis of the environmental misfits also showed further that, in addition to user-specific misfits, there are also some common misfits that apply equally to all user groups. Common misfits can be understood as universal misfits that affect more than one user group at the same time. The example of the hospital corridor illustrated some of these common.

However, the example of the hospital corridor also illustrated very well the problem of competing needs. Competing needs occur where different users and sub user groups are present at the same time and where space is shared. In the example of hospital corridors, the visual connection between corridor and patient room illustrates such a competing need. As a rule, patients are not interested in having a constant line of sight into their patient room. Such a visual connection would restrict the privacy of the patient and take away control. From a medical and nursing point of view, however, it would be helpful to provide current information about the patient’s condition by briefly looking into the room without disturbing the patient. Another example of competing needs is the mounting height of door openers, window handles or similar interaction mediums. They must be mounted at a height that guarantees use by physically disabled users, but must not discriminate against other users who may constitute the majority. Since competing needs cannot always be solved, analyzing and raising awareness is an important first step and must be addressed in consultation with users.

To summarize, this dissertation shows that in the context of hospitals, user-specific, universally valid and competing misfits of implicit or explicit nature can arise as a result of the façade or independent of the façade. By applying the Design Thinking method, the aim is to identify the most urgent misfits of the hospital users. With regard to the derived façade functions, the universal misfits bear a higher general validity, the user-specific misfits a higher specification.

### **Major challenge: identifying implicit and unconscious user needs**

With regard to the observation, identification and analysis of the environmental misfits, two aggravating and challenging aspects and limitations need to be emphasized. It is important to distinguish between conscious and unconscious as well as explicit and implicit environmental misfits.

It was observed that there are misfits that the user is aware of and which can be stated explicitly. Predominantly, such environmental misfits are the façade-independent ones, which play a particular role to the users within the hospital. Their relative importance is not necessarily due to their leverage on improving the patient's ambient conditions, but rather because users are more conscious to these kinds of misfits. Because users are aware of them, these misfits can more easily be articulated and explicitly stated and thus, are easier to assess.

On the other hand, misfits exist that the user is not aware of and therefore cannot specify explicitly. The façade-dependent misfits are usually not in the consciousness of the user and can be referred to as unconscious misfits. In discussions or interviews These unconscious needs can only be addressed to a limited extent. Observing the hospital situation, environmental misfits that of unconscious nature and that are caused by the façade and misfits that could be solved by the façade become evident. With regard to the collected misfits, the users were much more aware of the façade-independent misfits than of the façade-dependent misfits.

In addition to the distinction between conscious and unconscious misfits, explicit and implicit needs must also be distinguished. In some cases it was observed that an explicit need was articulated, but an implicit need was hidden underneath. For example, it was observed that geriatric patients call the nursing staff under a false pretense, but implicitly need information and attention. Detecting these implicit needs poses a particular challenge within the process of identifying environmental misfits.

The dissertation shows that in the context of user analysis both the unconscious and conscious as well as the explicit and implicit needs must be analyzed. In-situ observations have proven to be a particularly effective tool here. Nevertheless, there are a few things to keep in mind, when considering their usefulness. In-situ observations are highly dependent on the individual, who performs them. Experience with the method as well as the underlying mindset and openness to solutions play a decisive role. Thus, missing experience represents a limitation. Access to other innovation projects and good examples for the successful application of the method can convey a feeling for creativity and the vastness of possible solution spaces. By using observation protocols, the limitation of missing experience is being minimized. Observation protocols try to increase objectivity and comparability between observers and guide the inexperienced observer. While observation protocols were used within this study, it is advisable not to

conduct observations alone, but with the help of sparring partners. Ideally, these sparring partners made different experiences and are sensitive to different aspects. The aim is to blow up one's own filter bubble. Moreover, as implicit needs are difficult to detect and can easily be misinterpreted by the observer during observation, it is advisable to articulate the implicitly assumed needs to the users and reconfirm them. This reassurance with the user serves as data triangulation. Due to limited access to patients, this step was not carried out within the scope of this work.

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# 2 USER-CENTRIC FAÇADE FUNCTIONS

## **Using environmental misfits as guiding principles towards new functionality**

As shown, environmental misfits can guide the design process and provide a starting point for translating user needs into façade functionalities as well as design features. In order to address the most urgent and most important misfits, Bluyssens (2014) distinction with regard to duration of a misfit can be helpful. During the process of translating misfits into functions, such misfits should be addressed that are long enough to not be ignored.

Environmental misfits that are associated with physiological comfort are already broadly addressed by prescriptive design approaches, such as normative rules in building codes and standards. Environmental misfits of functional and psychological character however, provide leverage for user specification and thus, an increase of comfort and usability of hospital facades.

However it has become apparent that the identification of environmental misfits does not necessarily reveal a new type of function, but rather that it is quite difficult to translate the misfits into functions. Since the development of the functions is highly dependent on the performing scientist, this can be interpreted as a further limitation of the dissertation's results. The influence of the user and how to deal with it, is dealt with in detail in the section "User-centered process".

With regard to the compiled misfits the results clearly show that the identification of the misfits depends very much upon which users were surveyed and observed. Thus, this results in a limitation as any compilation of misfits and the subsequent compilation of façade functions can never claim completeness in terms of addressing all user needs. To illustrate this limitation, the necessity of a façade's flexibility shall be depicted. The personas presented within the scope of this thesis did not indicate that flexibility of a façade is important.

However, interviews with architects, hospital planners and project developers from hospital construction and technical departments have shown, that too high a specification of the façade elements should be considered with caution. In the context of hospitals, dynamics in space use and changes in terms of usage, which then bring with them different requirements, are the rule. A highly specified façade element would probably not be able to fulfill these new demands and therefore again would probably lead to environmental misfits. Thus, the interviewees posed the requirement that facades are specialized in their functionality and adapted for different users and their misfits, but not too high in terms of specialization. Modularity, which makes it possible to add façade functions in relation to usage, is asked for. This request can be overwritten with the keyword individualized standardization. An analogy can be drawn from smartphones ([Figure E.1](#)). The analogy conclusion is that façade functionalities, similar to apps of a smartphone, can be added depending on who uses the façade. This example should not mislead as to misunderstand façade functions as apps, but rather to illustrate the idea of flexibility. Moreover, this analogy points out that functions can be combined freely and in accordance with the prevailing needs. Facades do not need to offer all functions at the same time, but need to be adaptive. A too high degree of specification should be prevented and flexibility should be increased.

As these aspects on flexibility represent key information for the development of façade functions, this example on flexibility illustrated the limitation of using environmental misfits as guiding principles to derive new functionality. The requirements of flexibility and extensibility were not worked out by using the presented personas and their environmental misfits. The information is of higher abstraction and does not directly affect a particular user. However, it can be regarded as an important input for the development process of façade functionality. Thus, in order to obtain a holistic picture of all conditions that set the

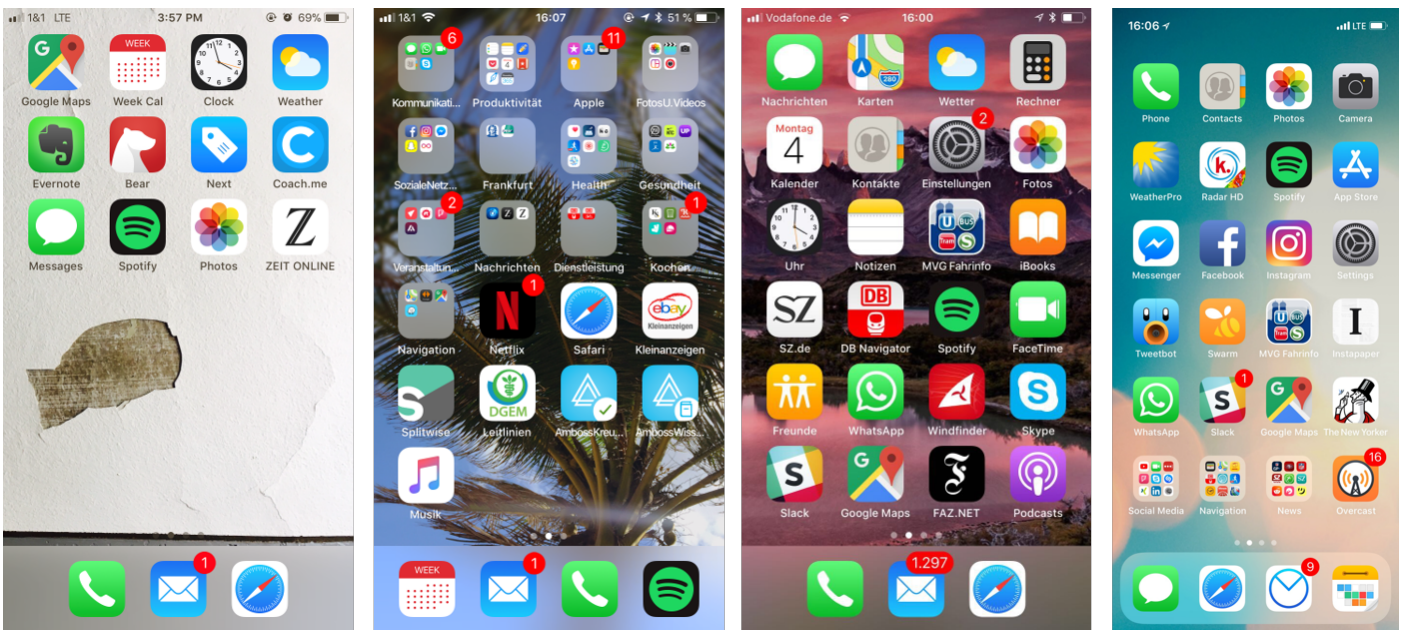


Figure E.1 - Smartphone analogy: Standardized individualization of smartphones by using apps

framework for product development, additional information is required. While environmental misfits are useful for identifying user-specific information, they do not equally identify superordinate information, which forms a framework and at the same time also has a restrictive effect.

### User-specific functionalities and design features

From a user-centered point of view, the derived façade functions are broad and include a multitude of highly diverse ideas on new façade functionalities. It has to be pointed out that user-centric functions are not meant to be applied to only one user group, but can be applied to others as well. Following the idea of Universal Design, the goal is to implement functions into the façade that can be used by as many user groups as possible, without neglecting and disabling users with special needs. As pointed out by the Microsoft team on inclusive design, design features that improve the environmental quality of a permanently disabled person, also improve the experience of someone with a situational or temporary disability.

However, the initial idea for the functional features originated from a specific user group and their environmental misfits. This collection can never really be completed, but is continuously expandable. The sheer number of function suggestions as well

as their diversity emphasizes the necessity of a user-specific scope of façade functionality that responds to the users' scope of abilities. Moreover, the resulting functions clearly show that previously passive façade surfaces should and can be turned into active surfaces. These previously unused surfaces offer great potential and possibilities for standardized individualization.

Due to the case study character of the thesis, the developed functions can only be transferred to a limited extent. With regard to the transferability of the results, it is necessary to keep in mind that the data collection was not carried out as a representative study, but rather examines two hospitals of different sizes and care levels.

Another aggravating factor within hospitals is that individual groups of people, especially palliative patients or intubated patients in intensive care units, can only be interviewed to a limited extent, maybe after their hospital stay. For such cases, observation in the field is an easier tool to collect data. But even if the functions do not claim to be universally valid, they can still provide a basic idea of the concept of user-specific façade functions and show that there is great potential for innovation in the façade. It is therefore worthwhile to rethink the façade.

The compilation of user-specific façade functions shows that these façade functions subordinately address aspects related to indoor environmental quality, such as acoustics, air quality, temperature and lighting. This may erroneously lead to a reduction of their relevance. Ultimately, however, it is not a problem that these topics lack significance, but rather awareness among users. As a result, more functional as well as emotional aspects are translated into façade functions. The method presented can therefore be considered an ideal addition to the existing façade development process. Suggestions about functions that are otherwise often only taken into account to a limited extent are thus incorporated. However, no guarantee can be issued that the key problem has been identified or that the best solution has been found. For the later product development, in order to decide which needs to be realized, criteria of exclusion and general conditions must be formulated.

The results show that trying to solve functional and psychological misfits on a façade-direct and/or a mediate level allows for expanding the potential functional scope far beyond the so far existing functional scope of the façade. In particular, the unconscious and implicit needs that the users cannot articulate are of major importance and a connection to the three types of product attributes used within the Kano-model can be drawn.

The Kano-model on product development and theory on customer satisfaction, developed by Dr. Noriaki Kano in 1984 distinguishes three types of product attributes: Basic or ,must be'-attributes, performance attributes and excitement or attractive attributes (Figure E.2). Following the Kano-model, functionalities and design features can be assigned to one of the three attribute categories (Zacarias, 2015). With regard to the Kano-model, functionalities that are derived from unconscious and implicit user needs – as they cannot be articulated and therefore are not anticipated and expected from the façade – offer most potential for excitement and surprise. Thus, the unconscious and implicit needs offer potential for innovative product solutions and enable new façade functions to be developed that extend the existing scope of functions and contain additional enthusiasm factors in addition to basic functions.

Regardless of the types of attributes assigned to a façade functionality, the results show that enhanced utility can be provided in two ways: through light-tech or high-tech functions as well as design features. While one often tends towards high-tech alternatives, in a technology-driven environment, it is more difficult to develop low-tech or mid-tech alternatives. In order to overcome this limitation a reference to Universal Design and User Experience Design is useful. Implementing the principles of Universal Design and Experience Design allows for a shift from technology-

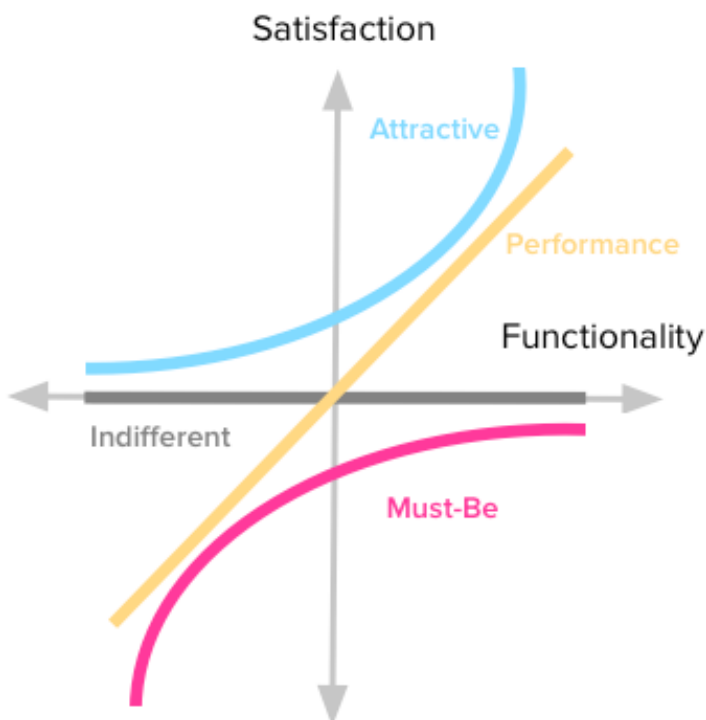


Figure E.2 - Basic structure of the Kano-model by Daniel Zacarias from folding burritos (Zacarias, 2015)

centeredness towards user-centeredness and can lead to both minor improvements and completely new functions. For example, the question of voice control for the façade is a new function, while a variable height of windows handles only represents an incremental change - both, however, address the issue of interaction with the façade. It must be added that often a new product development is not necessary, but existing products simply have to be applied correctly - that means in favor of a context-specific, user-centered need. As an example, the light bands in the upper part of the inner walls can be mentioned.

### **User-centered adaptivity**

In comparison to the traditional façade functions as summarized by Knaack et al. (2014), the presented user-centric functions exceed the functional scope. Against this backdrop of scope enhancement by user-specific façade functionalities, an additional façade adaptivity in terms of user-centricity is suggested.

The term adaptivity is not to be misunderstood as environmental adaptivity and thus, requires clarification. In contrast to adaptivity as in climate adaptive facades, user-centric adaptivity inevitably is triggered by the users within a room. From a visionary point of view: A user-centered adaptive façade can be envisioned as a façade that ‘recognizes’ the user groups in the room, ‘analyses’ the users’ present abilities and needs and ‘takes action’ in order to compensate prevailing environmental misfits considering temporally, occupationally as well as personally varying requirements. This notion of user-centered adaptivity is the foundation for the illustrated façade functions. All of the introduced façade functions follow the idea of a dynamic and adaptive façade, based on user needs.

### **User-centered process**

The user-centeredness throughout the entire course of the dissertation can be understood in two different ways. First, user-centeredness manifested itself in this thesis as applying the idea of user-centered design

into the design process of façade functionalities. The identification of needs and the subsequent derivation of façade functions were highly user-driven, so that the work is in line with the approach of a user-centered method. Nevertheless, user centricity can be questioned with regard to non-collected user feedback. Due to the lack of an iterative feedback process to involve the users themselves, the overall process could be considered only partially user-centered.

However, the user-centeredness of this work, can also be understood in a way that the entire process was user-dependent. Basically, Design Thinking is a process for structuring innovation processes and for product development, but objectivity can only be guaranteed to a limited extent. The entire process of Design Thinking is and will depend very much on the individuals who carry it out. Personal experience and personal mindsets are essential. This is true in particular, when it comes to the identification of implicit needs. With regard to the identified misfits, it could be observed that different aspects were noticeable depending on the individual’s sensitivity. The presented design principles, such as guidelines on universal design or user-experience design, help to sensitize for possible misfits. With the help of mixed teams of individuals and methods, such as observation protocols and the use of qualitative methods for data evaluation, subjectivity can be restricted. However, this type of limitation is not only evident in data collection, but also in the ideation phase. Depending on the input and the ability of abstract thinking, different solutions for problems can be found. Ultimately, however, the influence of the individual cannot and should not be eliminated altogether. As in every interaction between humans, humans play a crucial role and are essential for the success in the context of the solution identification. Rather, the challenge should be to formulate the demands on the characteristics and abilities of the individual carrying out the task, to sensitize them to their own subjectivity and to provide tools that reduce this subjectivity.

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**A user-centered adaptive façade can be envisioned as a façade that ‘recognizes’ the user groups in the room, ‘analyses’ the users’ present abilities and needs and ‘takes action’ in order to compensate prevailing environmental misfits considering temporally, occupationally as well as personally varying requirements.**

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# F CONCLUSION

The dissertation posed the question which user-specific functions and design features can be incorporated into future façade design to address and satisfy the diverse sets of user needs that occur within buildings. Against this backdrop, the research objective was to compile user-driven environmental misfits that result from the façade or other environmental conditions (façade-independent) and translate these misfits into future façade functionalities and/or design features. With regard to this research question and associated research objective, three hypotheses were formulated. To conclude this dissertation the three hypotheses are evaluated.

**Hypothesis 1: Future facades need to offer an enhanced set of functionality that exceeds the traditional scope by means of user-centered functions and design features.**

It has been shown that future façade concepts hold considerable potential with regard to user specification and user-centered design. The potential by which the façade can affect the indoor environmental quality of a room has not been fully exhausted, yet. Especially with regard to non-traditional façade functions many potentials of improving indoor quality arise.

The users usually expect proper functioning of traditional existing façade functions, such as operable windows, sun shading, ventilation, air- and water-tightness, and might demand their improvement. According to the Kano-model these traditional façade functions can be referred to as basic functional requirements of a façade. The user expects them and is unsatisfied if they are not provided or do not function properly.

Within this dissertation an enhanced scope of façade functions is suggested. However, such additional functions that exceed the traditional scope of façade functionality are usually not demanded and asked for by the users. An extended functional scope is not (yet) explicitly demanded by the user due to a lack of awareness and imagination. From today's point of view, such an enhanced functional scope does not represent basic façade requirements, according to Kano rather has an enthusiasm factor and holds innovative potential. However, this holds only true for nowadays users and their expectations. For example, an increasing digitalization of our everyday lives could change this in a way that functions that are of enthusiasm quality today are turning into basic requirements. To summarize, from

nowadays point of view and user needs, facades do not have to offer an enhanced scope of functions to satisfy user needs, but in order to future-proof against the background of the prevailing megatrends, such as demographic change, urbanization, individualization, new work and new mobility, the functional scope needs enhancement. This enhanced functional scope should be understood in terms of a user centered façade adaptivity. It is recommended to broaden the pure environmentally driven definition of 'adaptive facades' by a user-centered understanding of adaptivity. As shown in the discussion of this dissertation, future-proof facades can be understood as facades with a user-centered adaptivity that 'recognize' the user groups in the room, 'analyses' the users' present abilities and needs and 'take action' in order to compensate prevailing environmental misfits considering temporally, occupationally as well as personally varying requirements. In order to turn this notion on user-adaptive facades into reality, an extension of the existing functional scope is necessary.

**Hypothesis 2: By analyzing user-specific environmental misfits, user-centeredness can be implemented into façade design.**

It has been shown that by focusing on environmental misfits, a strong user-centeredness can find its way into the design process of facades. The analysis of user-specific environmental misfits helps to incorporate a user-centered perspective into the design process as it obliges one to engage with the user. By focusing the analysis on users' misfits rather than on considering how new and/or available technology can be put to profitable use, the method helps to adopt a user-centric approach. However, a limitation occurs, if the user, who performs the analysis, is not sensitive enough and cannot empathize with the users, who are to be analyzed. Thus, a certain human-centered attitude is necessary in order to realize a user-centered design by means of environmental misfits and should not be neglected.

**Hypothesis 3: Environmental misfits can serve as a point of reference for new functionalities and design features of façade design.**

It has been shown that the analysis of environmental misfits serves as a starting point for a subsequent functional development as most problems with facades usually result in environmental misfits that are experienced by the user. Thus, functions can be derived on the basis of environmental misfits and the misfits can be regarded as a point of reference that guides the design process towards user-centeredness. In order to achieve a holistic user-centered approach, it is important not to limit the diversity of misfits, but to include all types of misfits in a first step. Especially the misfits that are not associated with the façade provide leverage for new functionality and improvement of façade design and therefore environmental quality. The

use of misfits leads to the development of a diversified field of specifications and to the development of façade functions that were not associated with the façade prior to the project. An open mindset and detailed observations are necessary.

However, there are three restrictions with regard to the hypotheses. A first restriction is that the process depends very much on which user groups are involved in the process and therefore are being assessed. Depending on the user groups interviewed and observed, there are different emphases in terms of most urgent environmental misfits. The understanding of users must therefore be very broad and encompass not only the directly affected users, but all relevant stakeholders. Due to this high interconnection, a generally valid derivation of functions on the basis of a collection of very specific misfits is not possible - but also not useful. The derived functions will not be of general nature and do not apply to all user groups commonly. In any case, the set of derived functions needs to be evaluated and assessed with regard to the initial user groups that provided input and information on misfits. A second limitation is that in order to identify a broad range of environmental misfits by means of interviews and observations, it is necessary to have a broad range of information upfront and during the process. While some environmental misfits are obvious and raise awareness no matter what, others need some extra information to be noticed. Information on context, activities, etc. are helpful. Thus, the environmental misfits that are collected in interviews and observations need to be completed by information that is collected during an initial as well as an ongoing 360° research, such as literature and desk research. By providing additional information, the observation and interview data can be put into context and a framework is provided. Finally, the third restriction to this third hypothesis is that the translation of environmental misfits into functions is quite difficult and the derivation of a new function does not automatically become apparent. The derivation of functionalities is rather highly dependent on the person, who is conducting the study.

To conclude, this dissertation has illustrated that a user-centered specification of façade design is necessary and should no longer be neglected. With regard to improve the quality of our built environment, nowadays façade constructions hold potentials. The potentials manifest in low-tech as well as high-tech functions and design features and can result in incremental as well as disruptive innovations. A mere application of technology is not sustainable, 'less is often more'.



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# G SUMMARY

Humans build shelters to protect them from the environment they are otherwise exposed to. The façade fulfills this function of providing shelter. Generally and during the design process, the façade construction is being optimized with regard to the predominant boundary conditions. The main functions can be summarized as summer and winter thermal insulation as well as daylight supply. This functional scope of the façade – providing shelter, insulation and daylight supply – has not been significantly expanded over the years.

Research projects on adaptive façade systems address future concepts of facades and focus on providing enhanced shelter and support by adjusting the façade's properties according to prevailing exterior conditions. In order to ensure stable indoor environmental conditions, different approaches in terms of façade systems can be pursued. Most often adaptive façade systems use a variety of new technologies and new materials to realize the façade's adaptivity. However, this rigid implementation of (digital) technology into the façade has to be questioned and user-centered design approaches have to come into play. User-centered design approaches envisage that technology is being used as means to create immediate and sustainable

added value for the user. Thus, technology should not be the trigger for a novel design, the design process should rather start with the needs of the users for whom one designs. Afterwards, technology can trigger the design solution. Implementing such a user-centered design process, requires a shift of user perception, an in-depth analysis of user needs and finally, a different form of user involvement. User-centered design does not stop at the level of consumer goods and services as it does now, it can and should also be applied at a broader scale, such as buildings and their facades. This brings up the question of how the quality of nowadays façade design can be improved by applying user-centered design methods. It can be strongly questioned, if the functional scope of nowadays common façade design sufficiently meets the diverse needs that are posed by different building users, now and in the future.

Given this introduction, within this dissertation the question of improving façade design quality by applying user-centered design methods is addressed and the functional scope of nowadays façade constructions is being questioned with regard to user-centered functionalities. Building on a user-centered understanding

of design, this dissertation poses the question which user-specific functions and design features must be incorporated into future façade designs in order to support users within the building and satisfy diverse sets of user needs. This research question is being answered for the context of hospital buildings. This building type was chosen due to its high complexity, its inherent diversity of user groups and the possibility of extremely competing user needs.

Due to the interdisciplinary nature of this research question, findings from the fields of Building Physics, Environmental Psychology, Façade Design and User-Centered Design form the state of the art. In the beginning, the basics of building physics in terms of Indoor Environmental Quality are illustrated and enhanced by hospital-relevant findings from the field of Environmental Psychology. Among building physicists and environmental psychologists it is well established that users of built environments are influenced by their surrounding environment in a physical, functional and a psychological manner. While the research field of environmental psychology focuses in particular on the less physical, more functional and psychological effects of an environment, the discipline of building physics traditionally studies the impacts of physical environmental parameters, such as operative temperatures on the user's perception of comfort. From an environmental psychology point of view as well as a traditional building physics point of view, users usually encounter environmental misfits. Environmental misfits are such environmental conditions and design aspects that either do not meet the prevailing user needs in terms of physiological, functional as well as psychological comfort or even pose an additional burden on the users. Within the discipline of building physics these misfits are traditionally associated with Indoor Environmental Quality; within the discipline of environmental psychology the misfits are of functional and psychological nature.

Facades and their current scope of functionality as well as research findings from the field of adaptive facades are examined. Just as the many-faceted effects of the built environment on its users have been scientifically examined by the scientific community, the façade's influence on the indoor environment has also been confirmed. It is well established that the façade influences the interior environment and is decisively responsible for prevailing interior conditions, such as temperature levels, indoor air quality and the use of daylighting. In order to ensure stable indoor environmental conditions, different approaches can be pursued – ranging from extremely massive, non-dynamic on the one hand as well as non-technical constructions to dynamic and adaptive façade designs on the other hand of the spectrum. Both design extremes fulfill the primary need of providing shelter and protection via the façade. However,

while the former does not allow for any short-term changes or control by the user, the latter is designed exactly for this purpose. Nevertheless, both ends of the spectrum do not follow a truly user-centric design approach that serves diverse user needs or takes into consideration diverse abilities by providing different forms of interaction. Especially the effects of a (in) direct interaction between the façade and the user are often underestimated.

To address the key question of user-centered façade system, selected design approaches that are not yet associated with the façade, but claim a user-centered design method, are briefly introduced. Among the multitude of user-centered design approaches, approaches with different basic assumptions, guidelines and tools exist. In this dissertation, the approaches of universal design and user experience design are of particular importance. Universal design approaches call for products – and thus, also facades – that are designed so that they can be used equally by as large a group of users as possible. Interaction and Experience Design argue that design is seldom universal and stress the necessity of deep immersion in user needs, abilities and limitations. Despite their differences, both approaches require a detailed examination and analysis of the different user groups and pay particular attention to appropriate forms of interaction between users and products.

Against this backdrop of the relevant state of the art, the dissertation's core task is the development of user-specific, need-driven façade functions for various hospital users. Therefore, the research objective is to compile user-driven performance specifications for facades of healthcare buildings and to translate them into future façade functionalities and/or design features. Here, incremental improvements of existing functions are not much considered, the dissertation rather focuses on extending the existing scope of functions disruptively in order to increase the benefit for various users. The focus is not on developing a certain construction in detail or integrating a certain technology into façade design, but rather developing a future vision of hospital facades on the basis of an in-depth user need analysis. To do so, environmental misfits are used as guiding principles to identify these necessary functionalities. Hereby, misfits are taken into account that arise directly from the façade and its interaction. However, it is not sufficient to only focus on the misfits caused by the façade. The dissertation's aim is to identify environmental misfits that are not directly caused by the façade, but could be reduced by it. This is due to the fact that an enhancement to the functional scope of nowadays facades can be achieved by means of services are not yet addressed by the façade, but where the façade can provide additional support.

In order to solve the dissertation's core task, the mindset inherent to the user-centered design and innovation process 'Design Thinking' as well as methods that are associated with Design Thinking are applied. The Design thinking process as taught at the Hasso Plattner Institute of Design at Stanford University (d.school) comprises five modes: EMPATHIZE, DEFINE, IDEATE, PROTOTYPE and TEST. Any Design Thinking process starts by building empathy for the user one is designing for. Given the insights of the empathy mode, the define mode seeks to determine an actionable design challenge on the basis of the users and their environment. The objective of the ideate mode is 'going wide' and generate a high quantity of highly diverse ideas. The goal of any prototype is to get your ideas out of one's head and into a physical form one can interact. The testing mode should be used to test the prototype and the underlying idea, but also to make sure it's the right problem definition one designed for. The traditional phases of scientific research are aligned with the different phases of the Design Thinking methodology as well as the method of abstraction. Figure G.1 summarizes the methodology and methods.

Data collection is undertaken during a 360°-research phase, within which the methods of in-situ field observation as well as expert interviews are applied. In order to analyze the collected data, a qualitative content analysis according to Mayring (2016) is conducted and the results are put together in form of personas as well as lists of corresponding

environmental misfits. To illustrate the methodology and methods applied within this dissertation, three personas are created. The personas represent the group of geriatric inpatients, the group of pediatric inpatients and their accompanying person as well as the group of physicians of a neurology department and working in a stroke unit. These three personas are chosen to highlight differences between different main user groups (patients vs. physicians) as well as to sensitize for differences within a user group ('patients are not patients').

The results of the data analysis are used as input for the Design Thinking phase of Ideation. During the IDEATE phase, the Design Thinking method of adding constraints to the solution space as well as the method of questioning single aspects of the problem are used. By applying these two methods, ideas for abstract problem solutions are generated. Subsequently, these ideas are structured with regard to the main function and the personas affected by these functional improvements.

The results of this dissertation show that hospital buildings are subject to a mixed-use mode, combining workplaces such as desk work, diagnosis, therapy and nursing spaces as well as hospitality and accommodation. Hospitals can correctly be compared to small cities. Just like small cities, hospitals can be characterized by their immense complexity that increases with the hospital's level of care and prevailing

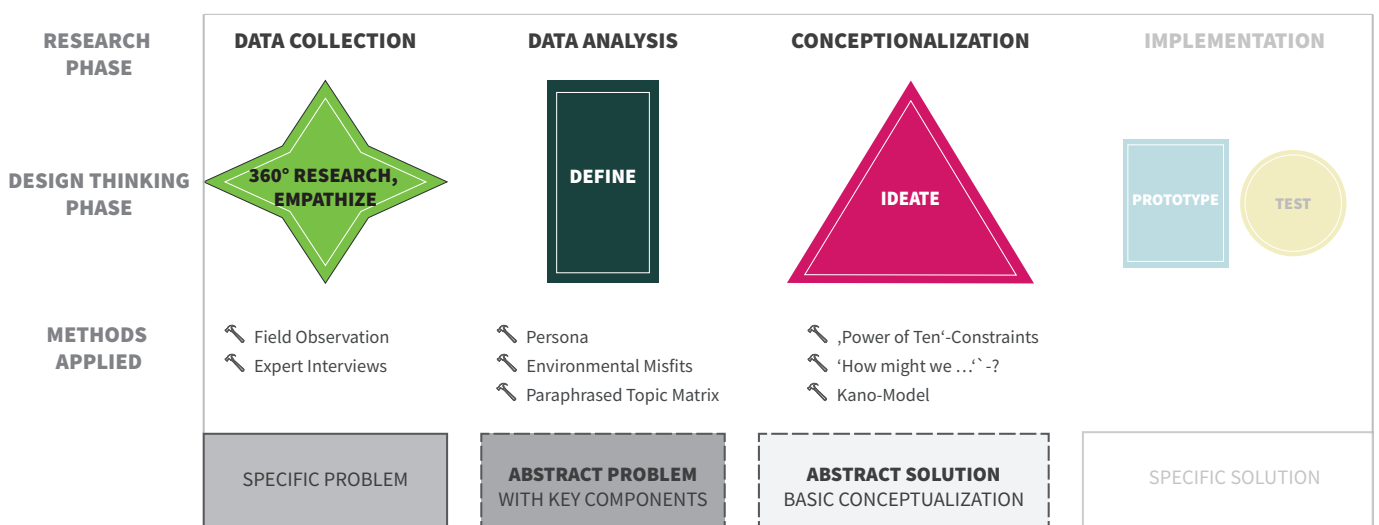


Figure G.1 - Overview of the dissertation's methodology including applied methods

users. This mixed-use mode of hospitals results in a large number of diverse users and vice-versa. Within the functional zones of the hospital, representatives of four main user groups – patients, health care providers, medical as well as operational services – are present. Analyzing the user groups, the results show differences among users. The differences result on the one hand from factors that are independent of the hospital context, such as demographic differences. On the other hand, differences also result from the very different roles filled out by the user groups in the hospital context. For example, when comparing the annual times of presence of patients vs. physicians, it is not particularly surprising that while hospital employees are accustomed to spending a lot of time at the hospital, patients who are rarely in the hospital encounter challenges, such as wayfinding. The different roles result in different initial conditions in terms of the user's emotional states. Besides the distinction into main user groups, each main group can be further divided into different sub groups. These sub groups tend to be just as diverse. For example, patients can be distinguished by sex, age and the department they are medically treated by. Moreover, a differentiation can be made with regard to inpatients and outpatients, elective vs. emergency, surgical vs. non-surgical patients as well as their level of care, ranging from general to intensive care levels. The comparison of the two different patients - geriatric patient vs. pediatric patient with accompanying person - clearly showed that within one user group there can be substantial differences. For example, while pediatric patients usually do not struggle with 'Delir', this clinical picture stands for geriatric patients. A generalization across user groups, meaning generalizing across all patients and referring to them as 'patients', is not effective as needs as well as abilities and limitations differ. However, the results also show that there are similarities between users of different groups. For example, the accompanying person of the child represents the user group 'visitors', but can also be regarded as a representative of the group of elective middle-aged patients. While children, especially toddlers, need a lot of care and external help too and are therefore comparable to geriatric patients, their accompanying persons show clearly different needs.

With reference to the personas, the environmental misfits encountered by the personas are collected. The results on environmental misfits show that the multitude of users is accompanied by a multitude of diverse environmental misfits. By means of the personas' descriptions, significant differences in user-specific characteristics as well as user-specific environmental misfits are highlighted.

The collected misfits are structured into ten main categories: acoustics, air quality, emotion, information, interaction, obstruction, space, temperature and view. As within each main category different types of misfits

can occur, the main categories are complemented by more specific subcategories. The subcategories are more diverse and therefore, more numerous. The categories and subcategories were used as codes to structure the observed environmental misfits. In addition to the categories, with regard to the façade, the collected misfits can be categorized into different types of environmental misfits. There are two different types of environmental misfits in the hospital: The first group of misfits represents a result of the façade and/or an interaction with it. The façade directly causes the misfit or is indirectly contributing to these misfits. These environmental misfits are referred to as façade-dependent misfits. The second group of misfits show no relation to the façade at all and result from other environmental conditions. These environmental misfits are referred to as façade-independent misfits. During the interviews and observations, it came clear that there are misfits that users are aware of and which can be stated explicitly. Predominantly, such environmental misfits are façade-independent ones and play a particular role for the users within the hospital. In addition, there are misfits that the users are not aware of and that cannot be specified by the users. The results show that facade-dependent misfits are usually not within consciousness of the user and therefore can be referred to as unconscious misfits. With regard to the collected misfits, the users were much more aware of the façade-independent misfits than of the façade-dependent misfits.

The analysis of misfits shows that all user groups encounter misfits of each main category (acoustics, air quality, emotions, information, etc.). Analyzing the frequency of assigned categories shows that although all main categories apply to all users, different emphases with regard to different user groups are likely. For the persona 'geriatric patients', lighting, interaction and information are critical issues. For the persona 'pediatric patient and accompanying person', lighting, space and view are critical. Thus, a user-dependency of environmental misfits can be confirmed. The fact that environmental misfits are user-specific results from daily routines, but also with various expectations, fears and emotional constitutions. For example, comparing surgeons to general physicians shows differences with regard to functional requirements and environmental misfits in relation to their daily activities. It needs to be pointed out that while user-dependency can also be observed with regard to façade-dependent misfits, it is more prominent with regard to façade-independent misfits. Further, the analysis of the misfits shows that, in addition to user-specific misfits, there are also some common misfits that apply equally to all or several user groups. Common misfits can be understood as universal misfits that affect more than one user group equally.



Given the sets of environmental misfits, several façade functions and design features can be derived. By using the environmental misfits as indications, user-centricity finds consideration throughout the design process. The derived functions and design features represent a fix to the environmental misfits and aim for providing better utility and an increased quality of space to the user. The list of functions does not claim completeness, but rather aims for illustrating how, by applying a user-centered design approach, environmental misfits can be translated into new functions and design features. To illustrate and give an example of derivable façade functions, eight different façade functions and design features that address the environmental misfits of different hospital user groups are presented. The suggested façade functions are: (1) Information/Interaction: “Façade serves as a room guard”, (2) Information: “Façade provides information”, (3) Interaction: “Façade provides multi-way interaction”, (4) Lighting: “Façade provides and redirects light into a space”, (5) Space: “Façade provides storage space”, (6) “Façade provides a place to sit and rest”, (7) View: “Façade provides views” and (8) View/Interaction: “Façade providing nature in space”.

For three out of the eight functions a more detailed description is given within the dissertation: ‘Room Guard’, ‘Multi-way of Interaction’ and ‘Providing Information’. Giving a detailed description of these three functions has two reasons: First, these functions address the most frequently used codes of environmental misfits and therefore represent the most urgent misfits. Second, these functions illustrate façade functions that not only enhance existing functions, such as provision of daylight, but enlarge the traditional scope of functionality. As this was the main objective of the dissertation, the selection was made accordingly.

#### 1. Information/Interaction: Façade serves as a room guard

In a figurative sense the façade is understood as a monitoring instrument. The information does not necessarily have to be collected directly at the façade itself, but information on the Indoor Environmental Quality of the room and its perception need to converge with information about the external conditions that are collected via the façade. In addition, the façade could also detect the presence and absence of users. Attendances and absences could be detected by movements similar to a motion detector. A particular interesting application can be seen in using the façade for the detection of falls. Geriatric patients in particular, who are only mobile to a limited extent, suffer from the consequences of falls. Such a monitoring could contribute to the safety in hospitals and provide stress relieve to the hospital staff. Turning the façade into a room guard element would benefit the patients, especially those who need

higher levels of care and attention by the nursing staff, such as geriatric inpatients. By using the façade as a measuring and observation element, another step towards higher patient safety and care is taken.

#### 2. Information: Façade provides information

Many of the misfits identified in the analysis address information. For various user groups, the provision of information plays a central role. The exact nature of the content varies from user group to user group, but the need for information is universal. Considering the misfits that can be assigned to the category (missing) information, it becomes clear that the façade can be used in different ways for the purpose of providing information. The information provided by the façade can be both user-specific or general, such as information on orientation in the building or in case of an emergency evacuation. Depending on the user specification, information can either be permanently visible to everyone or only be visible to entitled users with the aid of specific devices. Thus, the existing reality can be enhanced with information. Linking Augmented Reality (AR) technology to the façade enables the use of previously unused areas to provide information in a filtered manner. Examples for AR applications in the façade are providing information during rounds to the physician or to the maintenance staff, when assessing the conditions of a façade. Moreover, the information provided by the façade can serve as a mediator between the interior and exterior of a room. For example, nursing staff are particularly interested in being able to access information from the inside of a patient’s room without having to open a door and thus restrict the privacy of the patients. The interior façade could serve as a line of sight that at the same time provides additional information.

#### 3. Interaction: Façade provides multi-way interaction”

Multi-way interaction specifies the interactions that can take place with regard to facades. Basically, three different perspectives can be subsumed under the concept of a façade with multiple ways of interaction. First of all, multi-way interaction refers to different ways that enable an interaction between humans and a façade. Conventional interaction between a user and the façade take place, whenever the user stands directly in front of the façade and can interact with it haptically by means of touch. With regard to geriatric inpatients, the frequency of interaction-related misfits was particularly high and this affected in particular the conventional way of interaction with facades. Against the background of a geriatric patient and possible bed-riddenness or limited mobility, the requirement arises that the interaction with the façade is also guaranteed over distance or without direct haptic touch. For example, another form of interaction could take place via voice commands or gesture control. Second, multi-way interaction specifies that it is

not necessarily a human only that interacts with the façade, but rather a multitude of participants, such as objects, can constitute an interaction. Following the idea of human-machine interaction, the aspects just described refer to an interaction between humans and facades as machines. Against the backdrop of increasing intelligence of everyday objects and increasing connectivity, interaction is not limited to humans and facades, but can include everyday objects. Third, multi-ways of interaction address the multitude of consequences an interaction can have.

From a user-centered point of view, the derived facade functions are broad and include a multitude of highly diverse ideas on new facade functionalities. It has to be pointed out that user-centric functions are not meant to be applied to only one user group, but can be applied to others as well. All of the introduced façade functions follow the idea of a dynamic and adaptive façade – but not in the environmental sense of adaptivity. Against the backdrop of user-specific façade functionalities, an additional form of façade adaptivity is suggested. Usually, adaptive facades are based on the notion of being adaptive to exterior environmental conditions. However, this environmental adaptivity needs broadening in terms of user-centricity. In contrast to adaptivity as in climate adaptive facades, user-centric adaptivity inevitably is triggered by the users within a room. From a visionary point of view: A user-centered adaptive façade can be envisioned as a façade that ‘recognizes’ the user groups in the room, ‘analyses’ the users’ present abilities and needs and ‘takes action’ in order to compensate prevailing environmental misfits considering temporally, occupationally as well as personally varying requirements. Thus, the dissertation enhances the current understanding of environmental adaptivity with a user-specific adaptivity of the façade. According to the results of this dissertation, an adaptive facade should be both, adaptive to environmental conditions and to the user. This notion of user-centered adaptivity is the foundation for illustrated façade functions.

The conclusion shows that future façade concepts hold considerable potential with regard to their user specifications. The potential with which the façade can influence and affect the room has not been exhausted, yet. Many potentials arise especially with regard to non-traditional facade functions. To put it in a nutshell, this dissertation shows that a user-centered specification of façade design is necessary and should no longer be neglected. With regard to improving the quality of our built environment, nowadays façade constructions hold potentials. These potentials can manifest in low-tech as well as high-tech functions and design features and can result in incremental or disruptive innovations.



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# H OUTLOOK

The following chapter provides an outlook on recommended future research and product developments. These recommendations are partly based on the dissertation's limitations.

As stated in the discussion chapter, the methodology applied within this dissertation depends on the researcher as individual experiences influence the ability to build empathy. In order to minimize this dependency, standardized methods should be applied throughout the process. While such methods were used during the data collection phase of this work, a considerably standardized method for the translation of misfits into façade functions is still missing. The applied method to translate misfits into façade functions, used within this dissertation, is user-dependent and does not provide results that are truly objective. Since innovative ideas are usually highly interconnected with an individual, this limitation can only partly be minimized. However, within the framework of further research, a more standardized method should be applied.

Furthermore, the lack of continuous feedback from direct users within the hospital context represents a major limitation of this work. This limited user-involvement along

the entire design process could be reduced by multiple feedback rounds with users. It would be especially fruitful if - as in contrast to this work - access to patients could be granted. This aligns with the original phases of the Design Thinking process as taught at the Hasso Plattner Institute of Design at Stanford University (d.school).

By building a prototype, the initial product idea is refined and design errors become obvious. The same comes true for including iterative feedback rounds into the design process. A way of examining errors are the feedback rounds and the testing with the actual user. If problems still occur during testing with the prototype, there is still potential for product optimization. While a Design Thinking process is strictly speaking only completed once all phases, including the phases PROTOTYPE and TEST, are conducted, the phases were skipped due to the focus on the identification of environmental misfits and the derivation of facade functions. However, from a Design Thinking point of view and in order to ensure a truly user-centered design process, future research on user-centered façade functions needs to carry out these two missing phases.

While all users could benefit from an integration of new functionalities into façade designs, the future challenge will be to raise awareness for the necessity and effectiveness of these functions and thereby generate demand for previously unknown functions. With regard to the scientific landscape, the greatest challenge is to expand the existing optimization goals, which are mainly based on energy-saving and protection considerations, and to include user-specific aspects, in particular those of interaction and information provision. Future research can provide the necessary methodologies and methods to turn nowadays facades into future-proof facades that follow the idea of user-centered adaptivity. Complementary, the façade industry should bring user-centered façade solutions to the market. This requires concentrating on the implementation of a higher user focus and showing the willingness to question the existing functional scope and construction methods.

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**The greatest challenge is to expand the existing optimization goals, which are mainly based on energy-saving and protection considerations, to include user-specific aspects, in particular those of interaction and information provision.**



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