Towards the Design of a Mobile Application to Support Decentralized Healthcare in Developing Countries – The Case of Diabetes Care in eSwatini

Completed Research Full Paper

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Abstract

This study addresses the issue of decentralized healthcare in developing countries (e.g. in eSwatini). The country employs community health workers (CHW) to provide health care to the inhabitants. Although, relying on CHW as a solution to supply healthcare measures is a valuable mean to substitute insufficient healthcare infrastructure, certain issues arise due to lack of experience and education. For instance, caring for diabetes requires a high level of specific knowledge and expertise, which cannot necessarily be expected from CHW. To develop a potential solution for this problem, this study addresses the design of a mobile application, which supports CHW in their daily healthcare routines. The design of the mobile application is formalized in form a framework and instantiated as a prototype. The developing process followed the design science research paradigm and resulted in the formalization of the problem domain and in the development of design principles. During the research process, various experts were consulted to evaluate the design. Overall, this study provides valuable implications for theory and practice regarding the support of decentralized healthcare in developing countries.

Keywords

Community Health Worker, Decentralized Healthcare, Mobile Health Application, Developing Countries, Design Science Research, Smart Health

Introduction

Smart Health provides the capabilities to greatly improve a vast field of aspects in healthcare. An example of this is simplified access to data for specific needs include, more efficient management of concerns and the support of individual or organizational growth through the possibility of improved distribution and data storage (Buntin et al. 2011; Samhan et al. 2018). As Digitalization progresses, Smart Health has strong potential, especially in combination with smartphones and mobile applications, respectively. Smart Health Applications (also called mHealth) can be described as a system or systems, which, through a wireless infrastructure, provides care for individuals by reducing barriers (Varshney 2014). These digitally enabled solutions are already being introduced in industrialized countries, while developing countries have yet to be engaged to the same extend (WHO 2016). In some of these countries, the healthcare is organized differently when compared to the "classical" modus operandi in industrialized countries. The healthcare system is "decentralized", meaning there are various healthcare hubs/hospitals and community health workers (CHW) are the primary source of healthcare in many areas. CHW should assist a country in compensating the lack of central public health facilities, even though they don't experience the same education as physicians (Geldsetzer et al. 2017). In this context, diseases which require a high level of knowledgeable care (e.g. diabetes) cannot be adequately addressed and cared for by CHW.

In 2014, 422 million people were affected by diabetes, while 1.6 million of them succumbed to the consequences (heart attack, stroke, blindness, kidney failure) of this disease. Similarly, almost every ninth person now suffers from diabetes. In low-income countries, the rate is rising at an even faster pace (*WHO* 2016). Hence, decentralized healthcare (e.g. provided by CHW) in developing countries is in need for support. Against this background, this paper addresses the question of:

> *RQ: How should mobile applications for decentralized diabetes care in developing countries be designed?*

To answer this question, we applied an iterative design science research (DSR) process (Hevner 2007), resulting in the development of a comprehensive framework and prototypical interfaces, therein formalizing and illustrating the design of an appropriate mobile application for the situation. The mobile application is designed to support CHW in daily routine of visiting and counseling patients. In the research process, we consulted current literature as well as experts in the field of healthcare, developing countries and/or the field of mobile application design. Thereby, we were able to elicit 13 requirements and propose 7 design principles to address them. The design principles were formulate following Gregor and Jones (2007), enabling the transfer of them to similar problem instances or problem classes (Gregor and Hevner 2013).

Research Background

There are various definitions of Smart Health. In this study, we follow a definition based on Buntin (et al. 2011) and Samhan et al. (2018), describing smart health as the application of digital technologies in healthcare to improve data and information storage, as well as its subsequent analysis and distribution. One major component of smart Health is mobile Health (mHealth) (Perrea et al. 2014). mHealth is described as the strengthening or improvement of existing medical and public health care through the use of mobile technologies (Liu et al. 2018). mHealth aims to facilitate better healthcare through the investigation of mobile technologies regarding various aspects, such as technology interaction (Free et al. 2013), new technologies (Lupton 2012, 2015; WHO 2011), security aspects (Sunyaev et al. 2015), technology adoption (Chib et al. 2015; Dehzad et al. 2014; Hoque 2016), design, and development, in addition to testing the applications themselves (Cole-Lewis and Kershaw 2010; Evans et al. 2012).

This type of support is also becoming increasingly attractive for healthcare providers in developing countries (Al Dahdah et al. 2015). In 2011, the WHO reported on the possibilities of mHealth, focusing on support for mobile devices such as smartphones, personal digital assistants, personal patient monitors and other wireless technologies (WHO 2011). Furthermore, mHealth is said to improve care through increased availability, reachability and affordability. This is particularly interesting for countries with low primary care, as the spectrum can be extended to include crisis intervention or prevention (Dehzad et al. 2014). However, there are aspects (e.g. the quality, credibility and efficiency) of such solutions to be questioned during their usage (Akter et al. 2010).

In recent studies developing countries have gained more attention, with examples illustrated by the research of Cole-Lewis and Kershaw (2010), Evans et al.(2012) and Akter et al. (2010). The research investigates the role of mHealth solutions to address healthcare challenges in developing countries. However, developing countries usually suffer from the problem of decentralization and scarcity of medical infrastructure and healthcare professionals (*WHO* 2016). The challenges induced by the problem of decentralization have yet to be addressed in mHealth research. For example, there is no support for the process of making appointments and visiting patients (e.g. route-planning), accessing and updating patient information, not to mention informing the necessary physicians about unusual or difficult to treat illnesses or diseases (e.g. diabetes).

To give an example for a developing country operating a decentralized healthcare system, in eSwatini (a South African country), there reside, only about 275 physicians for its 1.3 Million inhabitants. Thus, the primary care for any health-related issues is provided by CHWs, of which have gained basic training alone. This leads to the issue of care intensive diseases (such as diabetes) unable to be addressed in the precise and necessary manor. Nevertheless, there are prevention measures which can also be taken without the direct consultation of a doctor. Certain preconditions (e.g. BMI, age, predisposition) are well known and can be readily assessed (Wu et al. 2018), providing the basis for treatments selections, even directly by CHWs. However, the lack of supporting solutions for CHWs displays a research gap, which will be addressed in this paper following the example of diabetes in developing countries (eSwatini).

Research Approach

Following the DSR paradigm is a well suited approach for the development of solutions for relevant and emerging problems via the application of information systems (Hevner et al. 2004). In light of the previously described challenges of decentralized healthcare in developing countries, we decided to apply a research process based on the DSR paradigm in order to systematically develop the design of mHealth application. Our research approach corresponds to the DSR Framework based on Hevner (2007) illustrated in Figure 1. For the procedure, we conclude all three cycles (relevance, rigor, design) in an iterative approach based on the description of Brendel et al. (2017).

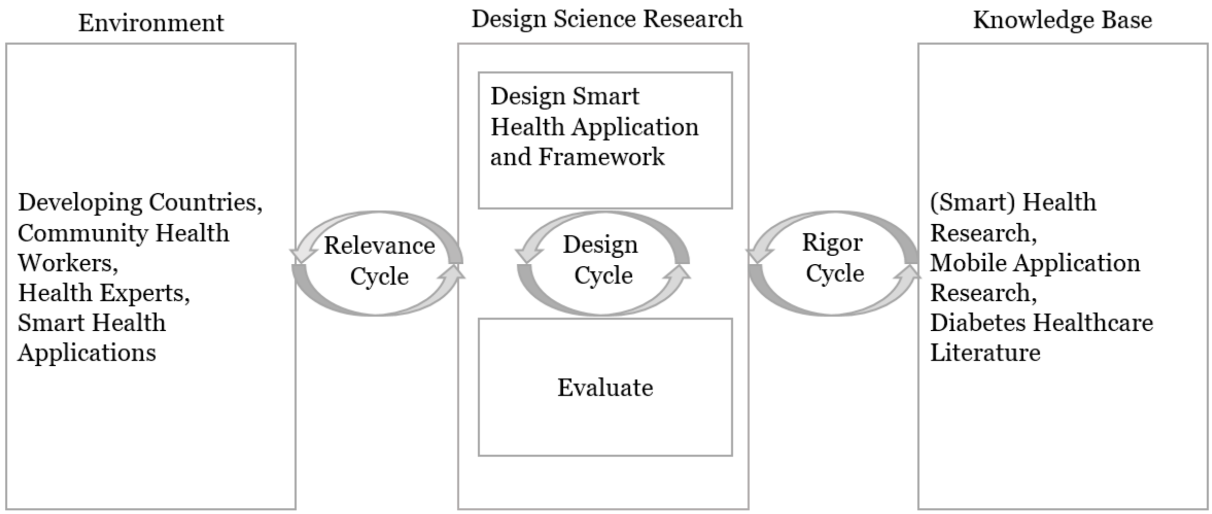

Figure 1: Design Science Research Setting (adapted from Hevner 2007)

The relevance cycle enables the ability to link the design activities with the application environment. This relationship enables the gathering of requirements for real-world problem. In addition to eliciting a problem representation, the developed artifacts can be evaluated directly within their environment of application. The rigor cycle grounds the development process in existing knowledge, by connecting the design activities with existing research and related solution design, which are subsequently integrated and referenced in the artifact development process. The design cycle is the center of the DSR research process and consists of an iterative creation and evaluation of the to be developed artifacts (Hevner 2007).

Iteration 1 – Development of Conceptual Mobile Application Framework

In the first relevance cycle, to investigate the problem dimensions decentralized healthcare in developing countries and elicit requirements for a potential supporting IS, we gathered and examined relevant literature (see Research Background section). To supplement the gathered insights, experts were consulted in regard to requirements for the elicitation problem. To be specific, we spoke with the employees of the ministry of health in eSwatini to get more information about the current technical infrastructure and the overall organization of the decentralized healthcare system. Furthermore, we consulted experts with a background in development countries for further detailed insights regarding infrastructural and healthcare system related issues.

During the rigor cycle, in order to determine the highest current development for mobile application and smart health information systems, another literature review was conducted. This resulted in the identification of various solutions for different application areas, but no solution was present for the combination of smart health applications in developing countries with decentralized structures to combat diabetes. For this reason, we decided to investigate the design and implementation of such a solution.

-	Iteration 1		
	Relevance Cycle	***Rigor Cycle***	***Design Cycle***
Inputs	• mHealth Literature • Diabetes Care Literature • Experts on Healthcare in Developing Countries • Ministry of Health of eSwatini	• Literature review on mHealth Applications • Review on Solution Designs of Healthcare Applications in Developing Countries	• Requirements
Methods	• Literature review • Expert interview	• Literature review	• Framework design method
Steps	• Literature search • Analyze relevant publications • Formulate research gap • Evaluate findings with experts • Elicit requirements	• Gather literature • Analyze literature • Identify inputs for design cycle	• Prototype framework design • Evaluate against requirements
Results	• Need for Support of Health Workers in Decentralized Healthcare Systems • Requirements	• Need for supportive health application	• Prototype framework

Table 1: Performed DSR Cycles in Iteration 1

During the design cycle, based on the gathered requirements, a framework was created containing the functions and individual modules, systematically describing the architecture of the mHealth application. The framework is specifically based on the research of Delone and Mclean (2003).

Iteration 2 – Application Prototype Development

In the relevance cycle of the second iteration, a selection of experts from Iteration 1 were presented with the prototypical framework to determine whether it is suitable to design a mobile application based upon it. The graphical prototype is founded on Get et al. (2008). This discussion was then evaluated, with the new requirements and improvement potentials recorded in order to forward the respective conclusions. The result is a list of requirements for an information system that supports decentralized health structures and addresses the newly discovered needs (for example to mitigate illiteracy as a user barrier). The rigor cycle consisted of the research for country specifics concerning illiteracy. In this process, we identified a symbolic design language legitimately necessary (Rosselli 1993). Lastly, in the design cycle, the framework was updated to address the newly formulated requirements. Also, we developed prototypical interfaces to illustrate how the mobile application would look like and which functions it could provide.

-	Iteration 2		
	Relevance Cycle	***Rigor Cycle***	***Design Cycle***
Inputs	• Expert interviews	• How to address new requirements	• New Requirements
Methods	• Evaluation	• Literature review on mHealth Applications	• Framework design • Prototyping
Steps	• Evaluate findings with experts • Elicit requirements	• Gather literature • Analyze literature • Identify inputs for design cycle	• Update framework • Develop prototypical interfaces • Evaluate against requirements
Results	• New requirements	• New design inputs	• Updated framework • Prototypical interfaces

Table 2: Performed DSR Cycles in Iteration 2

Iteration 3 – Evaluation and Publication

The third iteration consisted of only two cycles, the relevance and the rigor cycle. In the relevance cycle, the developed prototypical interfaces were presented to the domain experts, evaluating their design. In this evaluation process, experts were satisfied with the current design, prompting towards a later implementation. As the goal of this study was to provide a first design for such a mobile application, we concluded our research process in the last rigor cycle.

Iteration 3			
-	***Relevance Cycle***	***Rigor Cycle***	
Inputs	• Expert interviews	• Framework • Interfaces	
Methods	• Evaluation	• Heuristic Theorizing • Paper writing	
Steps	• Evaluate prototypical interfaces	• Formulate design theory • Write paper	
Results	• Evaluated prototypical interfaces	• This study	

Table 3: Performed DSR Cycles in Iteration 3

Results

By performing the first iteration, we identified an essential need for the support of CHW in decentralized healthcare systems. In order to be able to support them, various requirements need to be met. According to our research, these health workers suffer from limited support during their decentralized healthcare work. For example, they are also unable to plan or organize their as appointments efficiently as could be. In addition, health workers have no medical equipment or expertise to diagnose complex illnesses or diseases (e.g. diabetes). Based on extensive literature consultation and domain expert interviews, we formulated the following set of requirements (see Table 4).

The first three requirements (R1-R3) deal with the basic question of how a smart health application should be primarily developed for its accessibility to all authorized persons with different devices for their specific use per case. R4 then refers more to the general ability of the application to be used in other contexts, e.g. a disease database which holds all relevant information and thresholds for certain diseases. The following two requirements (R5, R7) then describe the requirements described by the expert. Even users who are either illiterate, not well positioned technically, or both, should be able to easily handle the application. Further, R8 describes the problem of the possibility of an Internet interruption during transmission of possibly life-critical data. Although the spread of the Internet is guaranteed, it can come to frequent terminating circumstances. R6 and R9 deal more specifically with the technical bases for a possible reuse or extension of the application in other contexts (other countries with the same problems or the same country with different problems). The application should be extensible, guaranteed by an open interface, in addition to other usage ideas which likewise should not be limited by country borders. The subsequent requirement (R10) is more of a functional nature. An adequate result must be achieved by entering the data of a patient (even if there are few). The CHW must be able to trust the result in order to continue using the application. Moreover, the CHW should have the ability to further educate itself with this application (R11). Disease progressions, pictures and explanations could be provided to simplify learning. The twelfth requirement (R12) deals with improved planning and the reduction of unnecessary travel time, which is a major time expenditure in decentralized healthcare. The last requirement (R13) describes the specific case where the country eSwatini already has a database, creating a situation where access to this data was necessary for a smooth and adequate handling. This is also because the data will intermittently be kept up to date.

In accordance with our requirements, a mobile application poses as a potential solution. To systematical describe how such an application should be designed, we decided to firstly formulate a comprehensive architectural framework. It illustrates the individual functions and modules of such an application and can therein be evaluated by experts to determine further requirements (seen in Table 4). Within the framework, we were able to formulate three design principles (DP) which are displayed in Figure 2.

No.	Requirement	Description
mHealth Application		
R1	Device independent	The application is required, to be device independent (e.g. running on desktop, smartphone and tables with various specifications)
R2	Mobile	The application is required, to be accessible and functioning out in the field, e.g. connecting via mobile internet.
R3	Secure	The application is required, to protect the sensitive patient data sufficiently.
R4	Adaptability	The application is required, to support healthcare for various diseases and illnesses, such as diabetes.
R5	Intuitive	The application is required to follow common norms and standards regarding interfaces and usability.
R6	Extendable	The application is required, to provide administrative staff functionality to add and delete information relevant for the healthcare process.
Developing Countries		
R7	Understandable	The application is required, to be understandable illiterate or technically inexperienced users
R8	Connection loss securement	The application is required to function, when the connection to the internet is lost
R9	Integratable	The application is required, to enable the integration of country specific information systems and databases.
Diabetes Care		
R10	Reliability	The application is required to offer easy to use and inexpensive functions to access a patient’s health status.
R11	Informative	The application is required to provide CHW with content to educate and inform their care for demanding illnesses (e.g. diabetes)
Decentralized Healthcare		
R12	Appointment support	The application is required to reduce driven distance while also increasing the number of cared for patients
eSwatini		
R13	Localization	The application is required to localized to eSwatini

Table 4: Requirements for the Artifact

We ensure security (R3) by using a login form with an encrypted connection to a database in the backend (DP1). Moreover, the use of a hybrid application development framework which utilizes web developing functionalities and standards (e.g. ionic), enables the required device and operating system independence (R1-6). By connecting the internal database to the interface, which communicates with the developing countries IT and infrastructure, we achieve a direct exchange of data (DP 4).

The next step was to achieve an extendibility for further information (e.g. for schooling as well as patient information) without any restriction for their appearance (e.g. different datatypes). Therefore, we aim to connect the interface throughout the country side with the internal database and the application (DP3).

The last DP displayed in this figure is the DP 4, which enables the data to be cached on the smartphones. Therefore, the upcoming three patients are stored on the device when a patient appointment is completed, and the current patient data is uploaded into the cloud and erased from the device.

Based on this framework, we developed a graphical prototype. The graphical prototype consists of a visualization of different screens with a description of the underlying functionalities. The simplicity as well as the power of the individual components are explicitly described. Hence, we want to provide a platform, as stated in the requirements. The application should face the problems for illiterate users as well as people with a non-technical background (DP2). Therefore, we made use of Symbols and a mark, which tab the user currently uses.

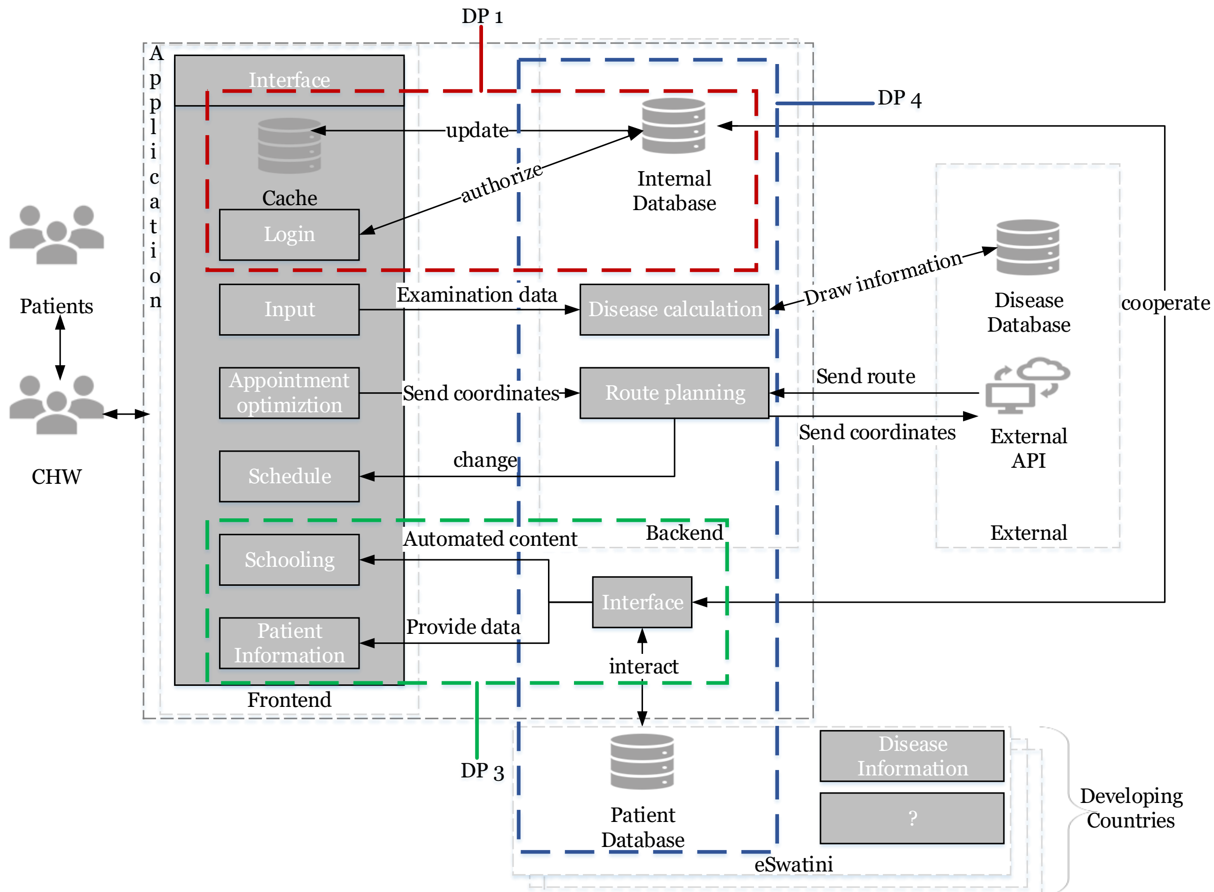

Figure 2: Application Framework

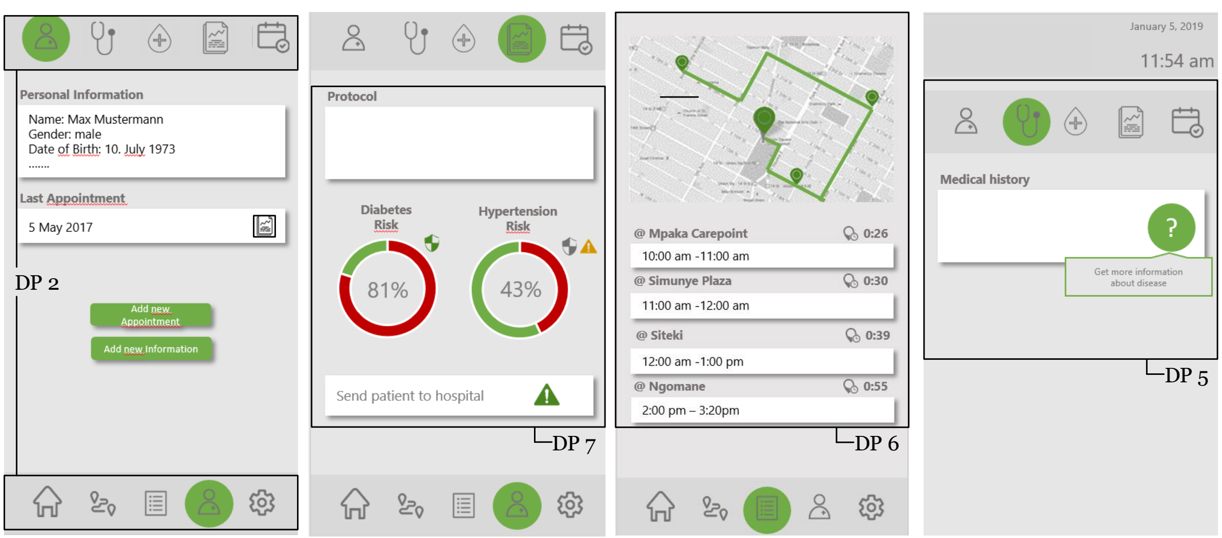

Figure 3: Graphical Prototype

The graphical prototype (Figure 3) describes four more design principles. Since developing countries have a high percentage of illiterate people, it is important to use as little written text as possible but meaningful symbols (R7). For this reason, the selection of the symbols to be tested was strongly related to the context of the application (health) (DP2). Furthermore, users with little context-related knowledge should also be given the opportunity to make a simple but efficient contribution with the solution provided. This principle addresses R7, R10 and R11 and is listed as DP7 and shows an indicator for the probability of contracting a disease with the possibility of giving the patient a recommendation to visit a hospital. It's also important to enable more efficient planning for the underlying tasks (R12). For this reason, there should be a contextual opportunity for traceable optimization. For this reason, the routes that CHW travel for their appointments are optimized and then displayed in a rehashed manor (DP6). Finally, it is essential to give the users of an application an overview of the tasks performed. This helps to make better decisions but also to keep track of past decisions and actions (R10, R11, R5). For the present case, the patient's medical data are stored and can be analyzed in order to identify potential dangers as early as possible (DP5).

The following table (Table 5) summarizes the gathered knowledge in form of a design theory (Gregor and Jones 2007).

Component	Description
Purpose and Scope	With the use of this IS, users should be enabled to achieve a better treatment for his / her patients
Constructs	Community Health Worker, Decentralized Healthcare, mHealth Application, Route Planning, Developing Countries
Principle of Form and Function	The application should be a mobile application programmed with a device independent programming language, which enables an encrypted connection to a database (R1, R2, R3). The interfaces of the application should rely on symbolic language, which enables the usage without reading capabilities or high familiarity with mobile technology (R5, R6). The application has to be structured modular, offering interfaces to interact with external databases or systems, and also provide interfaces for adding health care related content (R4, R7, R9). The application has to store patient information for upcoming appointments internally and also upload of changed information when connection to the internet is reestablished (R8, R13). The application has to provide easy to understand and directly applicable information and functionalities to support diabetes healthcare. (R11) The application optimizes appointments schedules and corresponding routes and tours by rescheduling and informing patients in real-time. (R12) The application offers standardized functions to compute indicators for certain illnesses (diabetes) without relying on extensive and expensive methods (such as blood tests or urine samples) (R10).
Artifact Mutability	The interfaces and the dynamic programming method allow content-related extensions, so that modules can simply be loaded into the backend and then appear directly in the frontend.
Testable Propositions	The application improves the level of healthcare and the information quality
Justificatory Knowledge	Mobile Application Healthcare, (Smart) Healthcare, Developing Countries

Table 5: Design Theory of a Mobile Application to Support Decentralized Healthcare in Developing Countries (following Gregor and Jones 2007)

Design Theory

According to (Gregor and Hevner 2013), every research has contributed to practice and theory. In terms of theory, DSR can continue this tradition of contribution by providing design theories, e.g. explaining how to solve relevant problems (Gregor 2006). For this reason, we have summarized the results of our research process in form of a comprehensive design theory. The form of the developed design theory is based on the Gregor and Jones model (2007) and consists of 6 components (purpose and scope, constructs, principle of form and function, artifact mutability, testable propositions and justificatory knowledge). The Design Theory is established in Table 5.

Discussion and Conclusion

In this paper, we developed a framework and a graphical prototype of a mobile application for the collective support of decentralized diabetes care in developing countries. Thus, we contributed to the field of healthcare by showcasing the potential of mobile applications in addressing urging issues in decentralized healthcare WHO (2011). To be specific, the developed artifacts display various design principles that formalize how such a system should be designed, enabling the eventual transfer to similar problem spaces. For instance, we proposed a solution to address the issue of connection loss or expensive mobile internet, respectively (DP4). Moreover, we conducted research (by consulting experts from the ministry of health) on the degree of illiteracy among the CHW and are confident to tackle this problem with the displayed design principle (DP2).

We look forward to re-evaluating these results with the future users of this application and later on providing this solution to the successive users in July 2019.

Lastly, we would like to outline the limitations of our work. First, we spoke purely with experts and did not speak with CHWs directly. In order to counter this limitation, the developed design knowledge will be applied in eSwatini. Second, another limitation is that the context of this work is noticeably specific. We refer solely to African developing countries by using the example of eSwatini. However, despite this, an attempt has been made to develop an abstract design theory, with the greatly beneficial availability of the design principles to be applied in other contexts. For this reason, this work ought to also be used for future research to confirm or extend our theory and/or results.

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