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Development of a telemedicine virtual clinic system for remote, rural, and underserved areas using user-centered design methods

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Abstract

Introduction: Virtual clinics are an emerging form of telemedicine which can positively impact healthcare accessibility in remote, rural, and underserved areas. However, a virtual clinic system for these contexts must be designed appropriately. The user-centered design method can be employed to develop an appropriate virtual clinic.

Methods: The development of the virtual clinic used the user-centered design method. First, a situational analysis was conducted to understand the context of public primary healthcare facilities in South Africa. Literature review, observations, and interviews were conducted, which then informed system requirements. A virtual clinic system was then developed and its usability was evaluated with doctors and nurses in a lab setting using healthy participants acting as patients. Doctors and nurses completed system usability scale surveys and provided interview feedback.

Results: The situational analysis revealed 10 key themes which were translated into a problem statement and 10 system requirements. A virtual clinic system was then developed based on these requirements. 5 doctors and 11 nurses were recruited to complete usability testing with the system. The system received an average of 80.6 scores (good to excellent) out of 100 on the system usability scale. Feedback from participants revealed key areas for improvement of the virtual clinic system, as well as opportunities for further implementation.

Conclusion: The developed virtual clinic system demonstrated the application of the user-centered design method to telemedicine technologies for remote, rural, and underserved areas. The positive feedback received from the participants demonstrated the importance of the user-centered design method in developing technologies for enhancing service delivery in health systems. Further work will implement this system in real-world clinical settings.

Keywords

Telemedicine, telehealth, virtual clinics, virtual care, primary healthcare, public healthcare, electronic health records, rural health, eHealth

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Introduction

Virtual clinics are a form of telemedicine that allow clinicians to provide health services by connecting with patients or other clinical staff through virtual means.[1] During the COVID-19 pandemic, many health facilities began to offer virtual clinic appointments as an alternative to reduce transmission of the disease.[2,3] However, virtual clinics can provide advantages that span much further than the reduction of disease spread. In areas that lack

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doctors, virtual clinics can provide access to expertise which can improve the quality of healthcare.[4] Furthermore, virtual clinics can decrease wait times and travel costs for patients.[5] When developed correctly, virtual clinics have the potential to improve healthcare outcomes for areas with limited doctors. One of the areas most affected by doctor shortages is remote, rural, and underserved areas in sub-Saharan Africa. There is a lack of medical expertise in these areas due to the migration of skilled workers to urban areas and other countries.[6,7] As a result, up to 77% of rural populations in sub-Saharan Africa are unable to access healthcare due to health worker shortages.[8] Urban underserved areas, such as townships in South Africa, should also consider virtual clinic implementations, as populations here often struggle to access doctors.[9] There is therefore an opportunity to introduce virtual clinics into remote, rural, and underserved areas, which can address doctor shortages and improve accessibility to healthcare.

Virtual clinics have already proven successful at improving health outcomes for specific use cases. Mental health services,[10] specialized burn care,[11] and cardiovascular evaluations[12] have demonstrated the ability of virtual clinics to connect underserved areas to specialist doctors. Primary care has also been of interest, with proposed implementations in Pakistan,[4] Zambia,[13] and India.[14] However, implementation of primary care virtual clinics has not been widely reported. Often, when telemedicine solutions are proposed for remote, rural, and underserved areas, they can become unusable due to broken equipment, lack of training, and overall disinterest of stakeholders.[15] Considerations of network access, infrastructure, power, and digital literacy are disregarded, leading to failure of implementation.[16] With proper consideration, these challenges can be mitigated through user-centered design methods.

Problem statement and aim

South Africa is considered an upper-middle income country,[17] but has the least income equality in the world.[18] Up to 84% of the population relies on public healthcare services provided by the government.[19] There are many remote, rural, and underserved public healthcare facilities in South Africa which struggle to provide even basic health services due to a lack of skilled healthcare workers.[20] A virtual clinic that connects doctors to remote, rural, and underserved health facilities in South Africa can provide the necessary clinical guidance to field workers so that more patients can access better quality primary health services. In this project, the South African public health system was used as a case study to understand how virtual clinics can be developed for remote, rural, and underserved areas. The aim of this research was to develop a user-centered virtual clinic system for remote, rural, and underserved areas in South Africa. The user-centered design process was followed to develop and evaluate the virtual clinic system in a lab setting.

Methods

The user-centered design methodology was applied to the design, development, and evaluation of the virtual clinic system in the following configuration. There are four steps to the user-centered design process: specify the context of use, specify requirements, design and develop solutions, and evaluate solutions.[21] First, a situational analysis was conducted to understand the context, in accordance with the first step of the user-centered design method. The results of the situational analysis were then used to develop a problem statement and system requirements, satisfying step two. Then, a virtual clinic solution was designed and developed, fulfilling step three. Finally, the virtual clinic solution was evaluated by conducting a usability study, satisfying step four. The steps of the user-centered design method along with how they were followed throughout the project are shown in Figure 1. Both the interview study and usability study were approved by the University of Cape Town Faculty of Health Sciences Human Research Ethics Committee, applications 783/2022 and 283/2023. All participants provided written informed consent to participate.

Situational analysis

A situational analysis is a qualitative methodology that "draws on interviews, observations, and visual, narrative, and historical discourse materials" to understand the complexities of a real-world environment.[22] Situational analyses can be used to assess various aspects of healthcare systems within a specific context, which can then be applied to the design and development of telemedicine solutions.[23,24] The situational analysis conducted for this project focused on the healthcare environment in South Africa and telemedicine solutions that exist within this space. The research aimed to answer the following question: What is understood about the concept of virtual clinics and the feasibility of their implementation in South Africa? The situational analysis consisted of three elements: literature review, observations, and interviews.

Grey literature review searches were conducted using Google Scholar. the following key terms were used: "digital health," "telemedicine," "telehealth," "virtual clinic," "healthcare," and "South Africa." Literature was sorted based on publication date, and priority was given to the most recent articles. A review of titles and abstracts revealed relevant literature which was then examined further. One researcher conducted the literature review and extracted key themes and another independent researcher reviewed the extracted themes. The search was conducted over 6 months from July to December 2022.

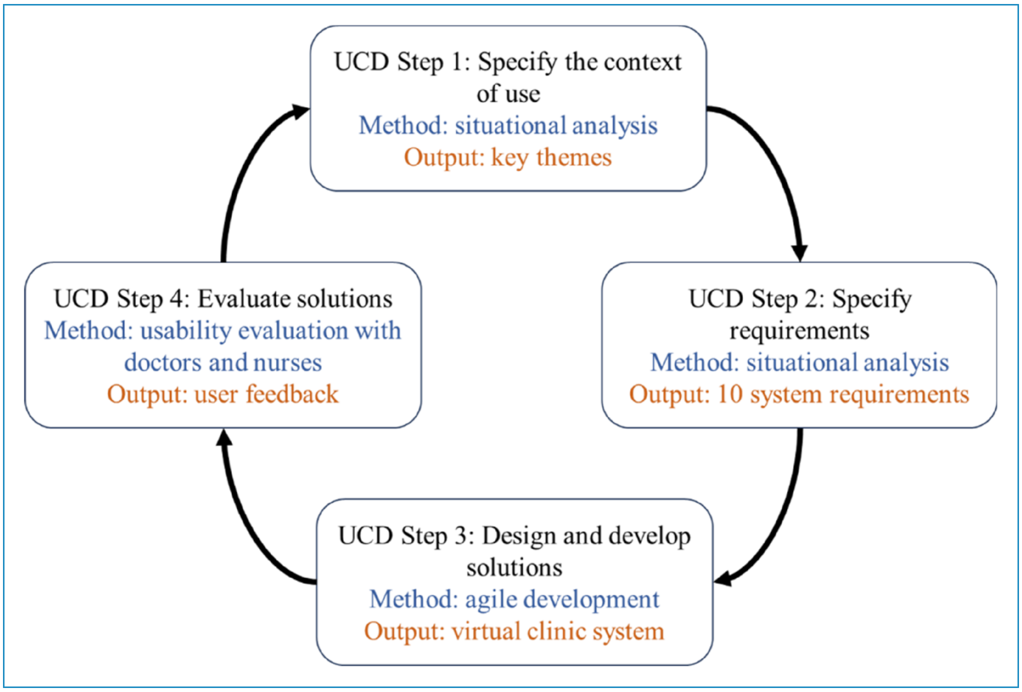

Figure 1. How the user-centered design method was followed to develop a virtual clinic system.

Naturalistic, overt, qualitative observations were conducted at three healthcare facilities in the rural town of Carnarvon in the Northern Cape province of South Africa. The town has ~ 6600 people and the local healthcare facilities include a governmental occupational health clinic, the local clinic, and the local hospital.[25] The location of observation was selected due to its existing relationship with the research institution and interest in implementing a virtual clinic solution. Each healthcare facility was observed during working hours. Notes were taken on equipment, services provided, challenges faced, and other key information. One member of the research team conducted observations and another member of the research team reviewed the observations and codes developed for the thematic analysis.

Semi-structured interviews were conducted with key stakeholders, which belonged to the following categories: doctors, nurses, patients, government entities, and industry members in healthcare and telemedicine in South Africa. The recruitment process for interviews followed the snowball method, where doctors who had previously expressed interest in digital health were first approached and interviewed.[26] These participants then recommended other participants from various stakeholder groups, who were then approached and interviewed. This process was followed until 14 participants were recruited. Interviews were conducted virtually through Microsoft Teams. Participants were asked about their experience with telemedicine, their attitudes toward telemedicine solutions, and the challenges they have encountered within the public healthcare sector. The audio of each interview was recorded and transcribed. Interview transcripts were analyzed through thematic analysis using NVivo qualitative data analysis software. The constant comparative method (CCM) and strengths, weaknesses, opportunities, and threats (SWOT) methodology were used to conduct the thematic analysis, which resulted in the synthesized themes.[27–30] CCM involves three rounds of coding, which output open, selective, and axial codes. Axial codes were defined as the four SWOT categories.

After interview coding was completed, the main themes from the literature review, observations, and interviews were synthesized to develop a problem statement and system requirements for a virtual clinic. Notes from the literature review and observations were coded based on the CCM/SWOT thematic analysis as used during interview coding. The resulting 10 axial codes were then used as system requirements. The selective, axial, and open codes developed during the thematic analysis are included in Supplemental Material A.

Design and development

The design process began by defining the system and identifying the key subsystems in accordance with systems engineering concepts.[31,32] Then, a selection process was followed to determine appropriate medical devices for the system. Collections of digital medical devices paired with integrated software, known as telemedicine kits, were investigated. Existing telemedicine kits were defined, and a decision matrix was used to choose the best kit for the clinic.

The decision matrix, developed by Pugh, is a tool used to compare similar products based on the specific needs of a project.[33] First, evaluation criteria are defined and weighted based on importance. Then, a baseline is established, which is defined as the current product or solution in use. Then, the products to be compared are evaluated based on each of the criteria as performing better (worth 1 point), at the same level (worth no points), or worse (worth −1 point) than the baseline product. These raw scores are multiplied by the weight of each criterion category and added up to result in a total point value for each product being compared.

Following the Pugh methodology, evaluation criteria were first identified and weighted.[34] The 1–5 weighting method was used, where 1 is the weight of the least important criterion and 5 is the weight of the most important criterion. The baseline was identified as the Tytocare TytoHome virtual clinic solution, as this was a widely available and utilized virtual clinic solution in South Africa.[34] TytoHome is a mobile-compatible virtual clinic system that utilizes an adjustable module to send stethoscope audio, ear/nose/throat video, and vital signs to a remotely located doctor during virtual video consultations. A modified baseline was defined for this project, where the Tytocare was used to define four of the criteria (basic diagnostics, extra diagnostics, open source devices, and locality), and the allocated budget for the project was used to define the price criterion. The telemedicine kits were then ranked in comparison to the baseline, with 1, 0, or −1 points being assigned. Table 1 outlines the evaluation criteria definitions and weighting used to perform the analysis. The points were summed and weighted for each kit, and the highest point total was selected for the virtual clinic.

The virtual clinic included both hardware (medical devices) and software components, which are outlined in the system architecture in Figure 2. The virtual clinic software was a web application, which was developed using agile practices with the Kanban framework. The agile approach to software development aims to produce outputs quickly and efficiently.[35] There are six phases of the agile practice: concept, inception, iteration, release, maintenance, and retirement. The web application completed the first four phases of agile development, using the Kanban framework during the iteration phase. The Kanban framework provides a way to organize and streamline tasks for the development of a project.[36] The first release of the software, combined with the hardware components, was used for evaluation.

Evaluation

Usability testing was conducted in a lab setting with end users of doctors and nurses to gain feedback and improve

Table 1. Decision matrix evaluation criteria.

Criterion	Description	Weight	(+1) Definition	(0) Definition	(−1) Definition
Basic Diagnostic Capabilities	Kits with devices that check vital signs (heart rate, blood pressure, respiration rate, temperature) and have a stethoscope	5	Contains capabilities to measure basic diagnostic information (vital signs and stethoscope)	Has the same basic diagnostics as Tytocare (temperature and stethoscope)	Does not have temperature and/or stethoscope diagnostics
Extra Diagnostic Capabilities	Kits with additional diagnostic tools that provide additional health data	4	Has more than one additional diagnostic device	Has one additional diagnostic (TytoHome has an otoscope as an additional diagnostic device)	Does not have any additional diagnostic devices
Open Source Devices	Kits with devices that can integrate with third-party software (rather than exclusively with proprietary software)	3	Devices are open source	Devices are not open source (TytoHome does not allow for the devices to work with outside software)	N/A
Locality	Where the kit and devices are produced	2	Produced in South Africa or sub-Saharan Africa	Produced internationally	N/A
Price	Whether the price is within the allocated budget (R50k)	1	Within budget (< R50,000)	At budget (R50,000)	Above budget (> R50,000)

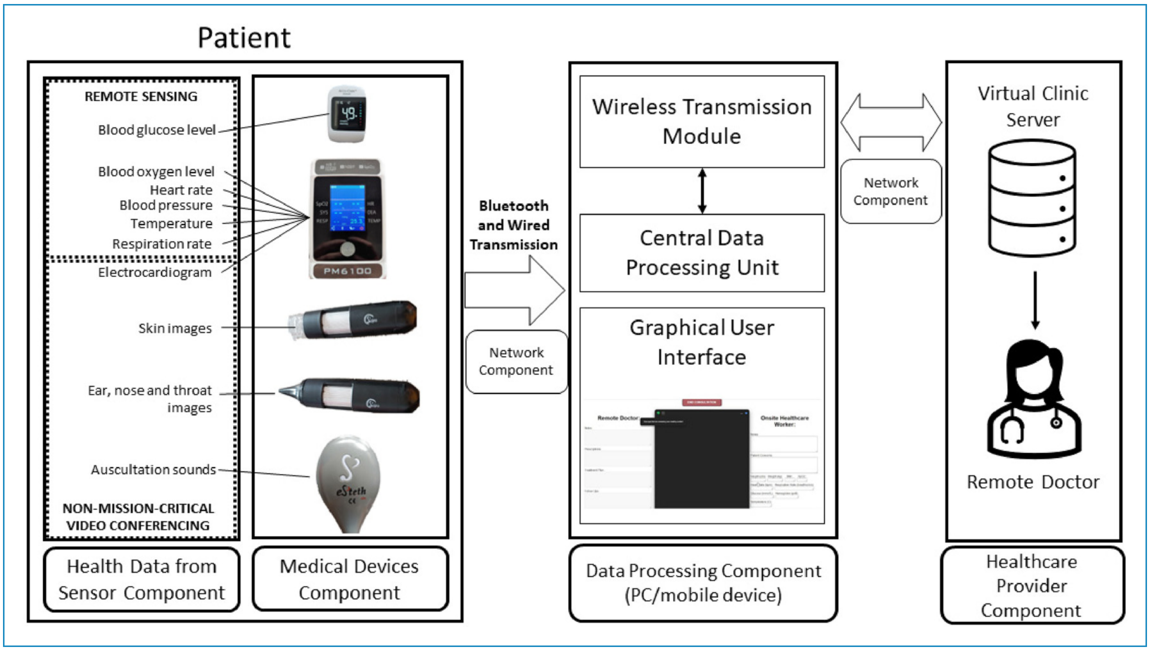

Figure 2. Virtual clinic system architecture with five components.[22]

the system further. Each doctor and nurse participant took part in a task completion session, utilizing healthy participant actors as mock patients, to gain a basic understanding of the system. Tasks involved adding simulated patient information to the system, conducting a virtual consultation, and reporting a maintenance issue. Tasks were specific to the nurse and doctor participant groups. The study consisted of two types of participants: practicing medical doctors and practicing nurses. A total recruitment of five participants per group was targeted, as the literature recommends that five users can identify up to 80% of usability issues with a system.[37] Figure 3 displays an overview of the study design for each participant group. Doctors and nurses participated as end users of the virtual clinic system and provided feedback in individual sessions. Healthy subjects were used during nurse sessions to simulate real consultations with patients. Doctor and nurse participants first watched a video tutorial on how to complete the task. The video tutorials were developed specifically for the virtual clinic system and were available in the resources section of the web application. The videos allowed participants to familiarize themselves with the system before using it. Then, the participant would complete the associated task. Each participant would repeat this cycle for each of the tasks they were assigned. Doctor participants used a PC in a lab setting to access the virtual clinic web application. A researcher sat in a separate room and acted as a field nurse and patient to mimic the remote setup of a true virtual clinic consultation. Nurse participants used a laptop to complete tasks with the virtual clinic system. Healthy subjects participated as mock patients during nurse usability evaluation sessions. This was done to simulate a real-world experience of the virtual clinic system to promote a more realistic experience and to receive more useful feedback.

After the tasks were completed, the users ranked the system based on the system usability scale. The system usability scale is a method of evaluating both hardware and software systems with end users. The system usability scale consists of a survey with ten statements that the participant must rank on a Likert scale.[38] Users also provided both verbal and written feedback. Users filled out four free response questions and then elaborated further during an interview session. Interviews were recorded and transcribed, then analyzed using NVivo software. Responses were coded using the CCM with the SWOT method, which was also used during the interview analysis.

Results

Situational analysis

The situational analysis revealed key takeaways about telemedicine and healthcare in South Africa. The literature review revealed 11 key themes, which were supported by the work done by Faruk et al.[16] on factors affecting telemedicine implementations in sub-Saharan Africa. South Africa was examined using a modified version of these factors, which were poverty, prevalent primary health conditions, security and safety, workforce shortage, stakeholder adoption, health information systems, network connection, electricity, technical cost and maintenance, language, and digital literacy. The literature revealed the state of South Africa in relation to these factors, where then the key themes for use in developing a virtual clinic solution were identified. These themes are described in Figure 4.

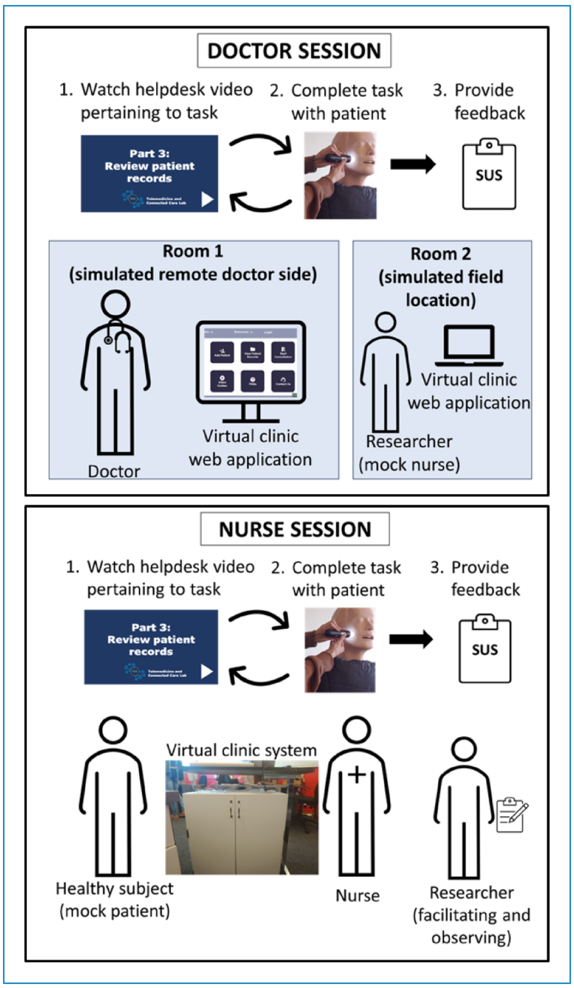

Figure 3. Study design overview of usability testing for nurse and doctor participants.

Observations were conducted at three sites in the Northern Cape province of South Africa over the course of one day. A government occupational health facility was observed first. The facility provides primary care to roughly 150 employees at the site. There is a nurse practitioner who runs the clinic and a doctor who visits once every two months to provide care. The nurse provides basic care and treatment as well as wellness information for employees. The clinic currently works on a paper-based system. There are secure storage lockers within the facility that house patient files. The local clinic was observed next. The clinic provides primary health services to about 180–200 patients per day, with approximately twenty staff members. There is only one doctor who works at the clinic. Similar to the occupational health clinic, the local clinic still utilizes a paper-based system for patient record keeping. The clinic does not have a fiber connection and relies on 3G mobile networks to access the internet. The local district hospital was the last site to be observed. Parts of the hospital were damaged in 2019 during a fire, so there is currently only one functional unit of the hospital. Most care is provided by nurses and other healthcare workers, as the doctor who services the clinic also services the hospital. Basic trauma care is currently provided, but cases that require specialist care need to be referred to higher-level care centers. The closest regional hospital is two hours away and the closest tertiary hospital is four hours away. The facilities cite difficulties in recruiting and keeping clinical staff in the area. From these observations, seven key themes were determined and are highlighted in Figure 4.

A total of 14 participants were recruited to participate in the interview study. Two patients, two nurses, two government entities, one doctor, three industry members, and four doctors in industry were recruited for interviews, with the last category being developed to describe

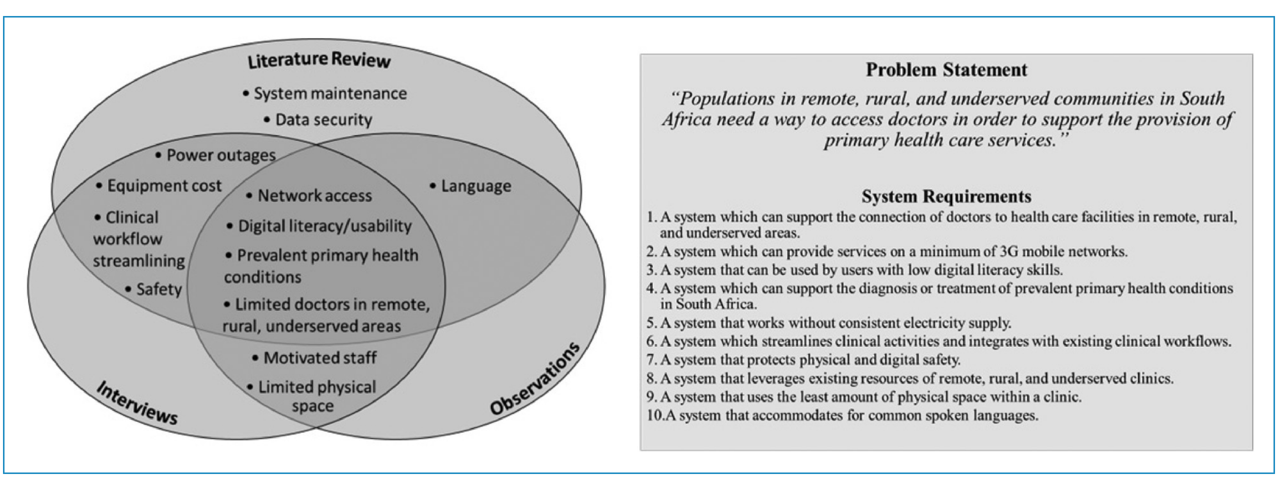

Figure 4. Themes identified by the situational analysis and their corresponding problem statement with system requirements.

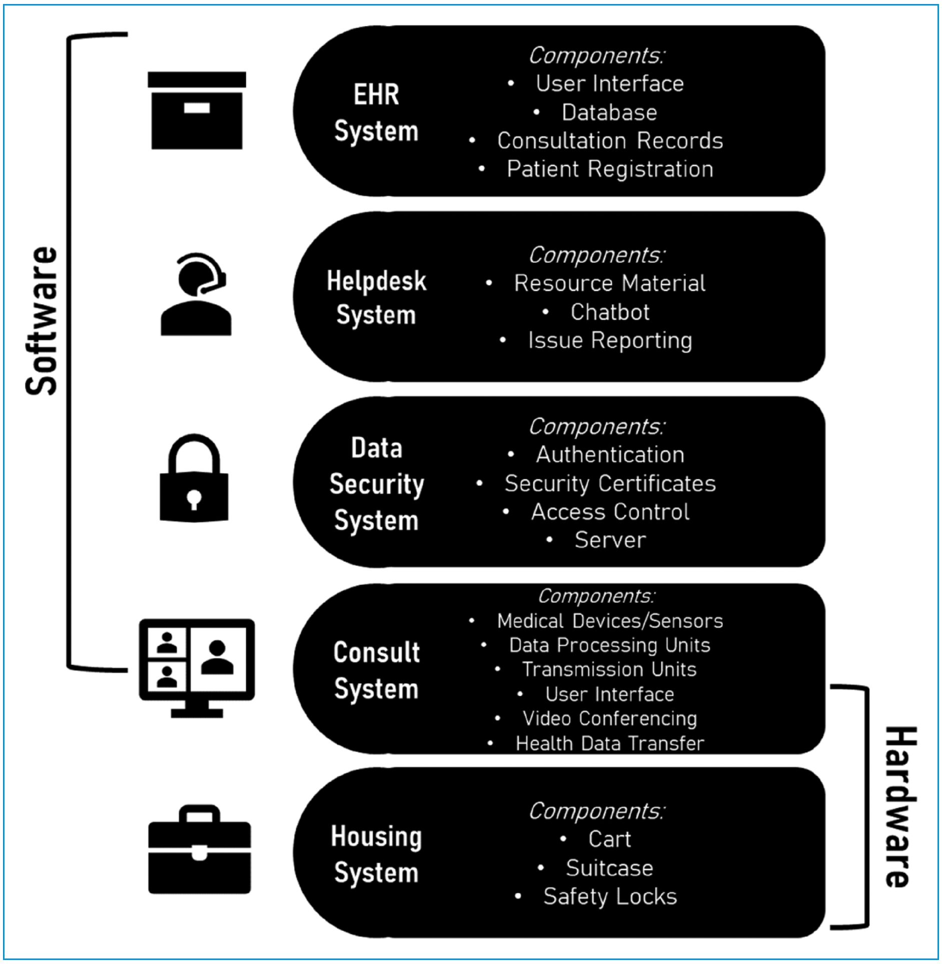

Figure 5. Subsystems of the virtual clinic system and their associated components.

participants who belonged to both doctor and industry categories. Industry members with existing virtual clinic solutions in South Africa were targeted for recruitment, to capture an understanding of the most relevant existing virtual clinic solutions. The first round of CCM coding revealed 26 open codes, which were refined to nine selective codes. These selective codes were then fit into the axial codes, which were assigned as strengths, weaknesses, opportunities, and threats in accordance with the SWOT methodology. The codes are provided here as the Supplemental Material. In total, this led to the definition of 10 key takeaways from the interviews. Figure 4 demonstrates the relationships between the main ideas from the interviews along with the results from the literature review and observations. The main ideas were then translated into a problem statement with 10 system requirements, which are also shown in Figure 4.

Design and development

Using the system requirements, a virtual clinic system prototype was developed. The virtual clinic system was developed to be implemented in existing health facilities with the support of existing healthcare workers. The virtual clinic system functions as follows. The patient enters the health facility and is paired with an onsite healthcare worker. The healthcare worker logs on to the virtual clinic system and pulls up the patient record. They can then review the patient's information and history. If the healthcare worker needs the support of the doctor for the case, they will then start a consultation. The remote doctor will also join the consultation and can chat over video with the healthcare worker and patient. The doctor also has access to the patient information and history through the virtual clinic platform. If needed, the nurse can collect real-time health data from the patient so the doctor may review it. This can support clinical decision-making including diagnosis, follow-ups, and prescriptions. This information is all stored in real time on the patient record, where it can be accessed afterward.

Five subsystems were defined, with three software subsystems, one hardware subsystem, and one subsystem with both hardware and software components. The subsystems are outlined in Figure 5 and include a consultation subsystem, an electronic health record subsystem, a help-desk subsystem, a security subsystem, and a housing subsystem.

A decision matrix was used to determine the best telemedicine kit for use in the virtual clinic system. Figure 6 depicts the workflow of the matrix. Initially, it was determined that there were 35 unique telemedicine kits offered on the market. Companies that were unresponsive to queries about price were excluded, leaving 22 kits remaining. The kits were classified based on the weighted evaluation criterion, which were price, basic diagnostic capabilities, additional diagnostic capabilities, location of manufacture, and open-source capabilities. After completing the ranking process, three kits resulted in the same point value and the highest score. Each company was contacted via the contact information provided on their websites, requesting further information about their product. One company did not respond to the contact query, and one company provided additional information that resulted in the telemedicine kit being priced at a greater amount than had been listed. This left only one telemedicine kit remaining, which was the Sojro Classic telemedicine kit. This kit included a digital stethoscope, digital otoscope, digital dermascope, three-lead electrocardiogram (ECG), and vital signs monitor. A commercial blood glucose monitor was also added to supplement the kit.

The web application for the virtual clinic was developed to facilitate consultations between remote doctors and field healthcare facilities. The conception phase pulled system requirements from the situational analysis to determine what specific features must be included in the web application. Then, mockups of the web application were developed during the inception phase. During the iteration phase, the Kanban framework was used to

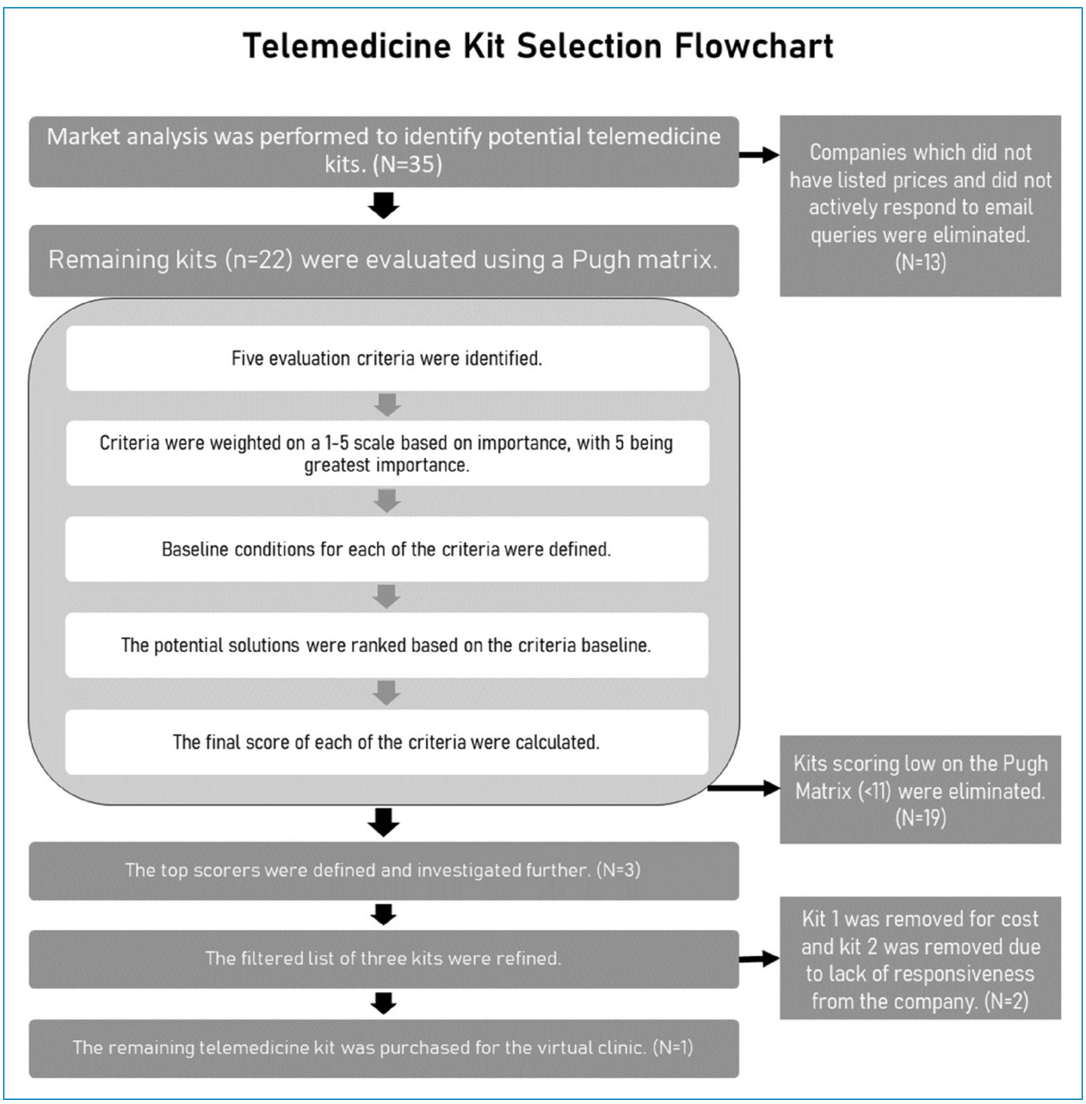

Figure 6. Flowchart depicting the process of evaluating telemedicine kits for use with the virtual clinic.

identify and classify tasks during each iteration. Tasks went through the four phases of backlog, to-do, in progress, and done. Three iterations were completed over the course of 15 weeks, with a total of 27 tasks being completed as shown in Figure 7.

Evaluation

Sixteen participants were recruited for the usability study, with n = 5 doctors and n = 11 nurses. Nurses were recruited from the outpatient department of a public hospital in Cape Town, South Africa. Doctors were recruited from various

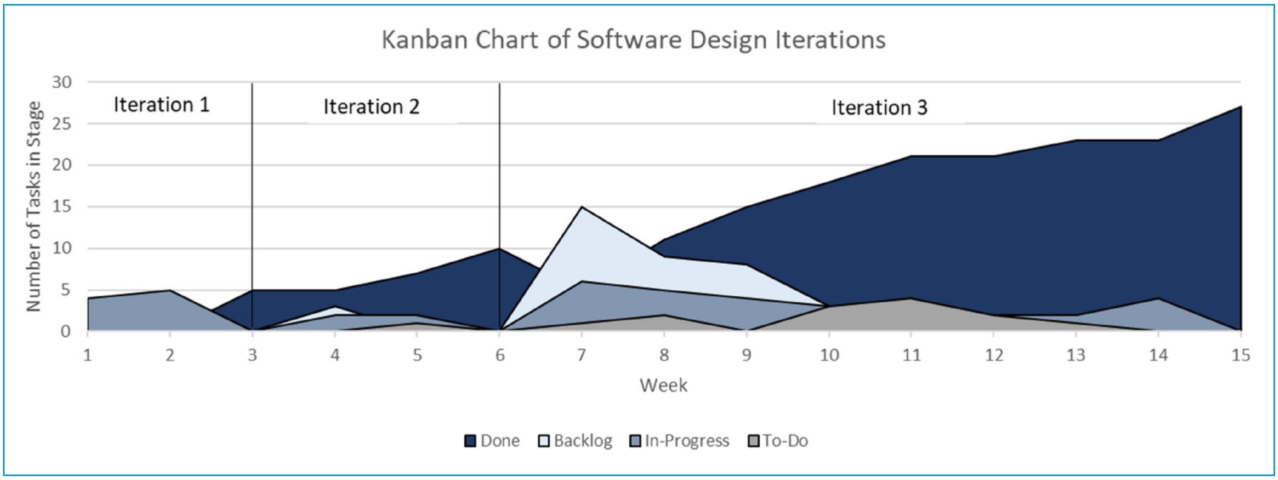

Figure 7. Chart depicting the number of tasks in each of the Kanban stages during the 15-week software development period.

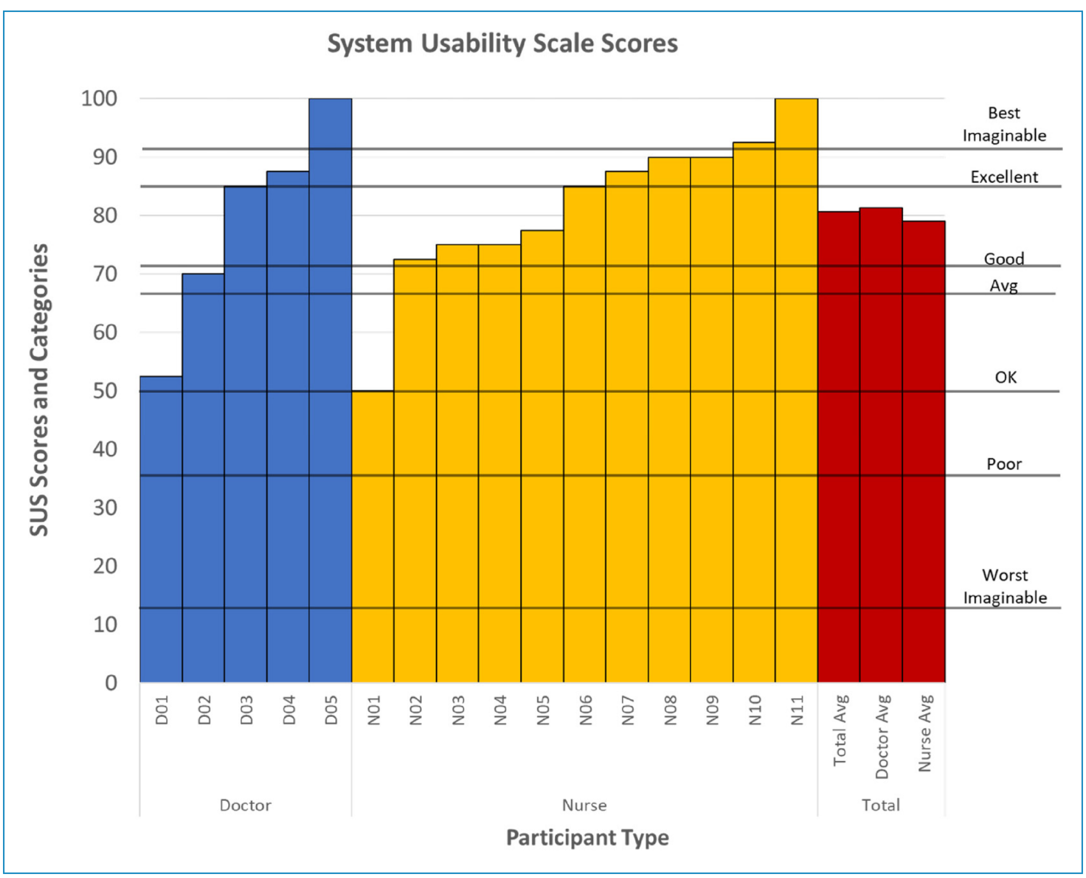

Figure 8. User scores of the virtual clinic based on the system usability scale.

Figure 9. Codes developed from the usability feedback using the constant comparative method with strengths, weaknesses, opportunities, and threats (SWOT) analysis.

public clinics and hospitals in Cape Town, South Africa. Each nurse and doctor participant completed one session using the virtual clinic system. The system usability scale scores revealed a total average of 80.6, and individual scores ranged between the OK and best imaginable categories.[39] The maximum score from both the doctors and nurses was 100, and the minimum scores were 52.5 and 50, respectively. These two minimum scores were the only scores that ranked below the acceptable average of 68. Figure 8 shows the distribution of scores and a comparison of the scores to the ranking categories.

During the coding of the verbal and written feedback, a total of 23 open codes, nine selective codes, and four axial codes were developed, with the four axial codes using the SWOT analysis categories. The developed codes are shown in Figure 9. The feedback from these codes was then organized into a Kanban chart. Specific pieces of feedback were entered into the backlog of the Kanban chart. These pieces of feedback were then translated into actionable items in the to-do column. Moving forward, further development of the system will include completing these tasks to improve the usability of the virtual clinic.

Discussion

Usability feedback

There were several strengths of the system outlined by participants in the usability study. The nurse participants, when asked whether the system would integrate with their daily workflow or be a burden, all stated that the virtual clinic would not add extra tasks to their day-to-day activities. Although these sentiments may vary during implementation in a real-world setting, positive buy-in early on can be a key factor in supporting the future implementation of digital health solutions. The training resources were also mentioned to be helpful in facilitating learning of the virtual clinic system. The videos provided a level of comfort for the participants when completing tasks with the system, which is positive when considering that often, telemedicine solutions are not successful due to discomfort and resistance to new technology. While many of the comments regarding the virtual clinic were positive, feedback was also given which could be used to improve the system further. Some participants mentioned features that could be adjusted regarding the medical devices. For example, the clinic's vital signs monitor is a real-time monitoring device, which is constantly updating the patient's measurements in real-time. It was mentioned that while this level of information may be necessary for trauma cases, it may not be particularly valuable for primary health purposes. Written by one of the doctor participants was the following statement: "I do not feel the continuous monitoring is as essential in the clinic setting. I would rather have a static 12-lead ECG than a 3-lead continuous monitoring [ECG] [for primary care services]." Other feedback mentioned that the virtual clinic consultation platform was missing certain information. For example, it was highlighted that it is important when taking patient notes that the clinicians who saw the patient sign off on their notes, for legal and record-keeping purposes. This is a consideration that must be integrated into the system to make it safer and compliant with legal regulations for medical record systems.

Another consideration brought up by some of the participants was the cost of the system. While the system is still an early prototype, it is important to consider cost, especially when designing for the public sector of health care. When selecting medical devices, cost was a factor considered. Additionally, cost was considered in choosing third-party integrated APIs, such as Zoom Health. Zoom Health, which requires a monthly subscription rate, does provide HIPAA-compliant services for telemedicine video consultations at a reasonable rate for healthcare providers.[40] However, it is important to note that the system requirements derived from the situational analysis were prioritized first. The cost of the system can be optimized after a working prototype is developed that caters to the needs of the context. Moving forward, this attitude will be held in the further development of the system. The user feedback collected during testing provided valuable insight into not only how the virtual clinic could be improved, but also about the overall role of the virtual clinic in South African healthcare. Initially, the virtual clinic was posed as a solution to remote, rural, and underserved health clinics. However, usability testing revealed that well-resourced public hospitals saw a potential for the virtual clinic to improve healthcare services within the facility. Presently, there are databases that are used for some parts of the public healthcare system. It was suggested that these databases be integrated with the virtual clinic to allow for a more comprehensive patient record. The National Health Laboratory Service (NHLS) is the database where all patient lab results are entered. This was suggested to be integrated into the system to promote consistency between records. Additionally, Vula is a digital service used for referrals within public health care. Integrating the virtual clinic system to include Vula referrals would also increase consistency between records.

One of the biggest threats to the implementation of the virtual clinic was the digital literacy of end users. When a system as complex as a virtual clinic is to be implemented, it can be difficult to implement when users are not familiar with technology. Several times, age was cited as a reason to why participants were not completing tasks quickly. Age along with other factors can affect the digital literacy of a community. One piece of advice given several times was to have one "digital champion" within a unit of healthcare workers who could learn the system and teach it to others. These realizations highlight the importance of carefully developed helpdesk resources. If public facilities do not have the ability to send staff for training on new telemedicine systems, there must be a robust support system for them to access if they have issues with the system. Another observation made was the overall resilience to learn a new system when the participants saw the benefit of the system. For those who were unfamiliar with computers, they stated that despite this fact they would be willing to learn how to use the system and that they could get better over time, because they saw the value that the system would bring to their work and to their patients. Moving forward, the resources for the virtual clinic will be prioritized to maintain and improve the ability of non-digitally literate users to succeed with the system.

Application of user-centered design methods

The application of the user-centered design method to the development of the virtual clinic provided a structured guideline on how users should be involved in the development of telemedicine solutions. By understanding the relevant context through the situational analysis, considerations of remote, rural, and underserved areas were able to be better understood and designed for. Furthermore, the inclusion of users early in the prototyping stages of the development allowed for the design to be tailored to the necessary needs of remote, rural, and underserved areas. Those who wish to innovate in the telemedicine space for remote, rural, and underserved areas should consider this case study when researching how to employ the user-centered design method in their work.

Key limitations

The limitations of the work conducted include the setting of the situational analysis, the laboratory setting of the usability study, and the current limited clinical evidence regarding the virtual clinic solution. The virtual clinic system is still in the early stages of development, and therefore still requires further development before long-term implementation in a clinical setting. While the methods used in this project are transferrable to anyone designing in the telemedicine space, the results captured from the situational analysis and usability studies are specific to South Africa and the

South African public health system. It is important to note that the user-centered design process is inherently user-specific, and therefore it is unlikely that the needs of other contexts will exactly mimic those discovered in this project. Furthermore, the virtual clinic designed in this project is a prototype system, which was evaluated first based on usability. Future work will improve the virtual clinic system based on the feedback collected, and work to first implement the system in the short-term at select remote, rural, and underserved health facilities, and afterward look toward long-term implementations. Additionally, a key component of the virtual clinic system is its ability to operate successfully under different communication network systems. The performance of the developed virtual clinic system was therefore evaluated under different network conditions in remote, rural, and underserved areas, and the results have been published separately.[41] Ultimately, the virtual clinic system will continue to employ the user-centered design method throughout its development and implementation, until successful long-term implementation is achieved.

Conclusion

The user-centered design method was employed throughout the development of the virtual clinic system. The information gathered from the situational analysis provided an understanding of the relevant context, which was remote, rural, and underserved primary healthcare facilities in South Africa. This led to the development of system requirements for the virtual clinic, which were used during the design and development of the system. The resulting system was then evaluated for its usability with real end users. The results from the system usability scale and user feedback indicate that the system is suitable even for users who may not be digitally literate. While results were positive for usability, there was much feedback provided on ways to further enhance the system. These improvements will be incorporated into future prototypes of the system. Additionally, future work will explore the validation of other key elements of the virtual clinic, such as data security and clinical efficacy in the field.

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References

1. Vas V, North S, Rua T, et al. Delivering outpatient virtual clinics during the COVID-19 pandemic: early evaluation of clinicians' experiences. *BMJ Open Qual* 2022; 11: e001313.
2. Robinson J, Borgo L, Fennell K, et al. The COVID-19 pandemic accelerates the transition to virtual care. *N Engl J Med Catalyst* 2020;1. doi:10.1056/CAT.20.0399.
3. De Vera K, Challa P, Liu RH, et al. Virtual primary care implementation during COVID-19 in high-income countries: a scoping review. *Telemed e-Health* 2022; 28: 920–931.
4. Atta-ur-Rahman, Salam MH and Jamil S. Virtual clinic: a telemedicine proposal for remote areas of Pakistan. In: 2013 Third World Congress on Information and Communication Technologies (WICT 2013), Hanoi, Vietnam, 2013, pp.46–50. doi:10.1109/WICT.2013.7113107.
5. Atmojo JT, Sudaryanto WT, Widiyanto A, et al. Telemedicine, cost effectiveness, and patients satisfaction: a systematic review. *J Health Policy Manage* 2020; 5: 103–107. Available from: https://thejhpm.com/index.php/thejhpm/article/view/172.

6. Organisation for Economic Co-operation and Development. *Geographic distribution of doctors. Health at a Glance 2021: OECD Indicators*. Paris (FR): OECD, 2021. doi:10.1787/ae3016b9-en.
7. Najib M, Juni MH and Salloum A. Brain-drain phenomenon among healthcare workers. *Int J Public Health* 2019; 6: 90–103.
8. Scheil-Adlung X. *Global evidence on inequities in rural health protection. New data on rural deficits in health coverage for 174 countries. International Labour Office, Social Protection Department*. Geneva (CH): ILO, 2015, Extension of Social Security series No. 47. Available from: https://www.ilo.org/secsoc/information-resources/publications-and-tools/Workingpapers/WCMS_383890/lang–en/index.htm.
9. de Villiers K. Bridging the health inequality gap: an examination of South Africa's social innovation in health landscape. *Infect Dis Poverty* 2021; 10: 1–7.
10. Munthali-Mulemba S, Figge CJ, Metz K, et al. Experiences and perceptions of telephone-delivery of the common elements treatment approach for mental health needs among young people in Zambia during the COVID-19 pandemic. *Front Public Health* 2022; 10: 906509.
11. Atiyeh B, Dibo SA and Janom HH. Telemedicine and burns: an overview. *Ann Burns Fire Disasters* 2014; 27: 87–93.
12. Scott AC, McDonald A, Roberts T, et al. Cardiovascular telemedicine program in rural Australia. *N Engl J Med* 2020; 383: 883–884.
13. Mupela EN, Mustarde P and Jones HLC. Telemedicine in primary health: the virtual doctor project in Zambia. *Philos Ethics Humanit Med* 2011; 6: 1–8.
14. Angrish S, Sharma M, Bashar MA, et al. How effective is the virtual primary healthcare centers? An experience from rural India. *J Family Med Prim Care* 2020; 9: 465–469.
15. Dodoo JE, Al-Samarraie H and Alsswey A. The development of telemedicine programs in sub-Saharan Africa: progress and associated challenges. *Health Technol (Berl)* 2022; 12: 33–46.
16. Faruk N, Surajudeen-Bakinde NT, Abdulkarim A, et al. Rural healthcare delivery in sub-Saharan Africa: an ICT-driven approach. *Int J Healthc Inf Syst Inform* 2020; 15: 1–21.
17. Organisation for Economic Co-operation and Development. *Development Assistance Committee (DAC) List of Official Development Assistance (ODA)*. OECD, 2021. Available from: https://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/daclist.htm.
18. World Bank. *Gini index (World Bank estimate)*. World Bank, 2022. Available from: https://data.worldbank.org/indicator/SI.POV.GINI/.
19. Statistics South Africa. *General Household Survey 2021*. Pretoria, South Africa: Republic of South Africa, 2021.
20. Heunis C, Mofolo N and Kigozi GN. Towards national health insurance: alignment of strategic human resources in South Africa. *Afr J Prim Health Care Fam Med* 2019; 11: a1928.
21. U.S. Dept. of Health and Human Services. *The research-based web design & usability guidelines, enlarged/expanded edition*. Washington (US): HHS, 2006. Available from: https://www.usability.gov/sites/default/files/documents/guidelines_book.pdf.
22. Clarke AE, Friese C and Washburn R. *Situational Analysis: Grounded Theory After the Interpretive Turn*. 2nd ed. Thousand Oaks, California: Sage Publications, Inc., 2018. https://us.sagepub.com/en-us/nam/situational-analysis/book238990.
23. Ojo A. *"M-health in Africa: a situation analysis." Handbook on ICT in Developing Countries*. New York, NY: River Publishers, 2022. https://www.taylorfrancis.com/books/mono/10.1201/9781003338376/handbook-ict-developing-countries?refId=7542f909-3ff0-453c-9ffd-da92286e7712&context=ubx.
24. Faujdar DS, Sahay S, Singh T, et al. Public health information systems for primary health care in India: a situational analysis study. *J Family Med Prim Care* 2019; 8: 3640–3646.
25. Statistics South Africa. *Census 2011*. Pretoria, South Africa: Republic of South Africa, 2011.
26. Naderifar M, Goli H and Ghaljaie F. Snowball sampling: a purposeful method of sampling in qualitative research. *Strides Dev Med Educ* 2017; 14: e67670.
27. Westerling AM, Haikala V and Airaksinen M. The role of information technology in the development of community pharmacy services: visions and strategic views of international experts. *Res Social Adm Pharm* 2011; 7: 430–437.
28. Fernández-Sola C, Granero-Molina J, Aguilera-Manrique G, et al. Strategies to develop the nursing process and nursing care plans in the health system in Bolivia. *Int Nurs Rev* 2011; 58: 392–399.
29. Boeije H. A purposeful approach to the constant comparative method in the analysis of qualitative interviews. *Qual Quant* 2002; 36: 391–409.
30. Gürel E. SWOT analysis: a theoretical review. *J Int Soc Res* 2017; 10: 994–1006.
31. Hall AD. *A methodology for systems engineering*. New York, NY: Van Nostrand Reinhold, 1962. ISBN: 978-0-442-03046-9.
32. Traum M and Iklaas J. *The engineering design process: identifying functions and subsystems. Engineering capstone design*. Pressbooks, 2020. Available from: https://ufl.pb.unizin.org/engineeringcapstone/.
33. Pugh S. Concept selection: a method that works. In review of design methodology. In: Proceedings of the International Conference on Engineering Design, Rome, Italy, 1981 March, pp.497–506.
34. Discovery Health. *TytoHome: lightweight & portable exam kit [Internet]*. Discovery Health, 2024. Available from: https://www.discovery.co.za/medical-aid/tytoHome.
35. Beck K, Grenning J, Martin RC, et al. *Manifesto for agile software development*. Agile Alliance, 2001. Available from: http://agilemanifesto.org/.
36. Coleman J and Vacanti D. *Kanban guide: definition and workflow*. Hertfordshire, UK: Kanban Guides, 2020. Available from: https://kanbanguides.org/english/.
37. Aiyegbusi OL. Key methodological considerations for usability testing of electronic patient-reported outcome (ePRO) systems. *Qual Life Res* 2020; 29: 325–333. doi:10.1007%2Fs11136-019-02329-z.
38. Brooke J. SUS – a quick and dirty usability scale. In: *Usability evaluation in industry*. Earley, UK: Taylor & Francis, 1996, pp.189–194.

39. Bangor A, Kortum P and Miller J. Determining what individual SUS scores mean: adding an adjective rating scale. *J Usability Stud* 2009; 4: 114–123.
40. Zoom. *Comprehensive telehealth platform for providers: Zoom*. Zoom, 2024. Available from: https://www.zoom.com/en/industry/healthcare/.
41. Blocker A, Datay MI, Mwangama J, et al. Evaluating network performance of a virtual clinic system in rural sub-Saharan Africa. In: Proceedings of Southern Africa Telecommunication Networks and Applications Conference (SATNAC), Drakensberg, South Africa, 2023 Aug 27-29, pp.151–156. Available from: https://www.satnac.org.za/proceedings.