Abstract—Falls are a major health concern and pose a significant health challenge to an ageing population. The assistive equipment provision process (AEPP) is carried out with patients to identify and mitigate intrinsic and extrinsic fall risk factors within the home environment. However, existing technology-based falls research has concentrated on intrinsic risk factors and neglected to develop applications that focus on extrinsic factors such as the accurate measurement and assessment of the home environment and prescription of appropriate assistive equipment/home adaptations. Currently, over 50% of installed assistive equipment is abandoned by the patient. This paper presents a 3D measurement aid prototype (3D-MAP) application, which provides enhanced AEPP measurement and assessment guidance to clinicians via the use of 3D visualisation technologies. The aim of this study is to explore the perceptions of clinicians with regards to challenges and opportunities of utilising 3D-MAP to support the AEPP in practice. Ten occupational therapists participated in interactive sessions with 3D-MAP, utilising the think-aloud method and semi-structured interviews. Usability of the application was measured with the System Usability Scale (SUS). Results showed participants scored 3D-MAP as ‘excellent’ and agreed strongly with items relating to the usability and learnability of the application. The qualitative analysis identified opportunities for improving existing practice, including, improved interpretation/recording measurements; enhanced collaborative practice within the AEPP. Future research is needed to determine the clinical utility of this application compared with 2D counterpart paper-based guidance leaflets.

Index Terms—3D visualisation technology, assistive equipment, falls prevention, healthcare, occupational therapy.

I. BACKGROUND

Falls are a major health concern and pose a significant health challenge to an ageing world population. The number of falls and related injuries has risen in recent years, in part due to a growing population aged 80 and over [3]. Falls often cause debilitating injuries which precipitate early retirement and long-term care admissions, resulting in an increased burden on health care services [4]. The cost of falls to the National Health Service (NHS) in the UK is estimated at over £2.3 billion per year [5]. Recent policy directives within the UK highlight the need for new and innovative technology-based applications utilising Information and Communication Technologies (ICTs) within the falls prevention domain, which are seen as having the potential to reduce health care costs whilst also reducing the burden that an ageing population has on the demand for health care services [6, 7]. Furthermore, use of ICTs are seen as having numerous additional benefits such as the potential to deliver more effective, personalised, patient-centred interventions and to improve levels of patient engagement and adherence which are likely to improve patient satisfaction and overall quality of life [6, 8]. In the context of occupational therapy, falls prevention activities are carried out as part of the assistive equipment provision process (AEPP). AEPP involves working closely with patients to assess intrinsic and extrinsic fall risk factors. Intrinsic fall risk factors focus on functional ability deficits presented by the patient and typically relate to balance and cognitive impairments. Extrinsic fall risk factors focus on risks that are apparent within the environment in which patients carry out day-to-day occupations, such as within the home. Some examples of extrinsic fall risk factors include poor lighting, slippery surfaces, raised door thresholds, stairs and steps, clutter, and trip hazards apparent within the assessed environment [9]. Extrinsic fall risk factors also include the improper use of assistive equipment (AE), or an absence of assistive equipment such as stair handrails, toilet raisers, bath boards, and bathroom grab rails where these would be deemed necessary. When considering the range of existing technology-based falls prevention research and associated applications, to date it seems that significant effort has focused on addressing intrinsic fall risk factors and detecting falls, however, little effort has been invested into developing technology-based interventions that address extrinsic fall risk factors [10].

A. AEPP, measurement and falls prevention

The goal of the AEPP is to identify and reduce barriers that impact patients’ ability to carry out activities of daily living (ADLs) and mitigate the overall risk of falling. This is typically achieved by recommending minor and major adaptations to the home environment in order to accommodate functional changes, assist with ageing in place, and to reduce the patient’s overall risk of falling [4]. During the AEPP, clinicians assess whether AE is needed to help maintain independent living and/or to overcome potential fall hazards. A crucial part of the process involves clinicians taking measurements of home furniture dimensions and measuring specific parts of the patient’s body. These measurements are used to determine the specific nature and detail of the adaptations that are necessary in order to reduce the overall risk of falling and to enable patients to successfully engage in their ADLs. The recorded measurements are used to determine
the specific sizes of AE that are prescribed for fitment within the patient’s home environment. An appropriate fit between the equipment, an item of furniture and/or the patient, is only possible if measurements of the patient and their home furniture are taken from the correct locations on a given item and are measured and recorded accurately. Adaptations to the home typically include Occupational Therapists (OTs) prescribing the installation of AE such as chair raisers, grab rails on stairs, bath boards, toilet raisers and bathroom grab rails to help with transfers when bathing [11]. To recommend a chair raiser, for example, the OT measures the height of the patient’s leg (popliteal height) and the height of the chair. The OT calculates the difference between these two measurements, which provides the height that the chair must be raised by accordingly. Measurements are used as a means to ascertain whether the height of furniture either facilitates or hinders functional independence. The customisation of measurements plays a vital role in ensuring the successful fit of the assistive equipment to the patient [12]. Clinicians may receive some training in relation to the provision of assistive equipment, however, there is currently no mechanism in place to ascertain whether they are prescribing safely.

Current AEPP practice involves utilising paper-based forms designed to guide the clinician through the AEPP and to ensure that measurements are taken and recorded accurately along with any necessary patient related data. These paper-based forms often provide additional measurement guidance in the form of 2D representations of home furniture and the patient. The key function of the 2D representations is to help the clinician to identify the precise points within 3D space that must be measured on each respective item of furniture/patient and make an unambiguous record of these measurements, with a view to accurately calculating and prescribing AE that will facilitate ADLs and mitigate the risk of falling [13]. Some existing AEPP paper-based forms are presented in Fig. 1.

The prescription and fitment of inappropriate AE not only results in a failure to provide necessary assistance where it is needed, but also has the potential of compounding the very falls risks that they were installed to mitigate. Despite the widespread provision of paper-based 2D visual guidance which aims to minimise the chances of inappropriate prescription and fitment, approximately 50% of AE prescribed by clinicians is reported to be abandoned by patients [14-16], largely as a consequence of ‘poor fit’ between the patient, the AE, and the furniture on which it is installed [17, 18]. The impact of such practice is therefore significant and widespread, and includes a negative impact on patient health outcomes, accelerated functional decline, an overall increase in exposure to fall risks in the home, and more generally an unnecessary depletion of valuable health care resources [19].

B. Existing and future technologies for falls prevention

The key areas in which falls prevention research is undertaken may be considered to fall within four overarching categories/sub-domains: (1) Exercise interventions; (2) Fall risk assessments; (3) Education interventions; (4) Home assessments/prescription of assistive technologies [10]. However, when exploring the technology-based applications that have been presented across the falls prevention research landscape, it appears that some of these sub-domains have received significantly more attention than others. For example, there are numerous exercise intervention focused systems such as Mirelman et al. [20], who augment treadmill exercise training with virtual reality technology to improve functional ability and cognitive function. Ferrari et al. [21], enable clinicians to supervise participants in an exercise training via the use of a customised gaming application that provides immediate feedback of their in-game performance. Fall risk assessment systems include Staranowicz et al. [22], Weiss et al. [23] who present systems using motion capture sensors to monitor gait in real-time and predict fall risks, providing early interventions where necessary. Riva et al. [24], Soaz and Daumer [25], Mazilu et al. [26], and Hsu et al. [27] analyse gait patterns via inertial and/or physiological sensors to determine the association between features extracted from gait patterns with a history of falls in order to target older adults who are in need of clinical interventions. Falls prevention education presented include Bell et al. [28], who combines a Nintendo Wii game console with falls prevention education session to enhance patient awareness of the importance of reducing clutter, arrangement of furniture in the living area, positioning of the rugs, types of flooring, lighting, and staircase and bathroom safety. Shi and Wang [29] develop uCare, a smart-phone application which utilises built-in sensors to detect falls and provides fall prevention education tips which include adapting the home environment to reduce fall hazards and 2D illustrations of how to transition into recovery position after a fall. However, with regards to home assessments/prescription of assistive technologies there do not appear to be any applications that attempt to assist in this sub-domain of falls prevention activity. A recent survey of the state of the art of falls prevention technologies supports this finding and that, more generally, there is a disproportionately small amount of research that develops technology-based solutions that assist overcoming extrinsic falls risk factors [10]. Hamm et al. [10] conclude that there is an urgent need to develop new technology-based applications and highlight the potential of applying 3D visualisation technologies to this
particular area of fall prevention practice.

The term 3D visualisation technologies refers to computer graphics software applications that capitalise upon natural aspects of human perception by visually simulating three spatial dimensions in 2D space, hence enabling the user to visualise, interact with, and control a given object within a 3D scope. The value of 3D visualisation technologies for the falls prevention research domain has already been demonstrated in a number of existing falls prevention research studies often focusing on the area of exercise intervention. Some examples include Uzor et al. [30] and Doyle et al. [31] who aim to improve uptake and adherence to home-based falls prevention exercise programmes by replacing traditional paper-based 2D illustrations exercises with equivalent interactive 3D visualisations of these programmes. One existing study begins to explore the potential of exploiting 3D visualisation technologies to assist clinicians in identifying extrinsic fall hazards. Du et al. [32] develop a robotic system to automatically model patients’ home environments in 3D space. A 3D visualisation of the environment is constructed, with the help of the robot, to assist clinicians in identifying the precise location and nature of extrinsic fall hazards. The use of 3D visualisations have also shown promise in providing opportunities to overcome challenges of existing 2D clinical tools by more sufficiently providing the visual quality necessary to conceptualise visual cues as part of a particular treatment and assessment [33]. For example, Spyridonis et al. [34] found that enabling patients to report the type and precise location of back pain using a 3D visualisation of the human body was more accurate and intuitive than the traditional paper-based 2D model of the human body typically used in practice. Other studies have found similar benefits in utilising 3D visualisations to communicate other forms of pain to clinicians. For example, Jang et al. [35] enable patients to express and communicate their symptoms of pain to clinicians by annotating specific regions on an on-screen 3D representation of the human body using free-hand drawing. De Heras Ciechomski et al. [36] use 3D visualisations for breast augmentation. Digital photos, taken in 2D are reconstructed into 3D models and subsequently used by clinicians to perform virtual clinical analysis in order to facilitate more accurate measurements for treatment.

C. Clinician perceptions and acceptance of technology

Designing tools and applications that are usable and deliver functionality that is aligned with the needs of the user may be considered to be as important as the innovation itself [37]. Patients and practitioners are more likely to engage with and adopt new technologies in practice if they are usable and are perceived to be compatible with their needs [38, 39]. Therefore, when developing technology-based healthcare applications, it is crucial that clinicians’ needs and perceptions are understood and incorporated into every stage of the design and development process [40]. User-centred design methods [37] and technology adoption theories, such as the technology acceptance model (TAM), provide a means of gaining valuable insights into the factors that must be considered to ensure users adopt, accept and use new technologies and that these are incorporated into the design of that technology [41]. Until recently, TAM has been used predominantly within a quantitative context, however, increasing the high-level TAM constructs, such as perceived usefulness (PU) and perceived ease of use (PEOU), are being to inform deductive qualitative user-centred design research to inform and scope the incremental design and development of technological health innovations [33].

In light of the equipment abandonment issues faced by the current AEPP process, issues relating to inaccurate measurement of furniture and the subsequent ‘lack of fit’ of AE to the environment and patient, there is a need explore the potential value of utilising 3D visualisation technologies to aid in the process of carrying out key measurement tasks as part of the AEPP. The aims of this study are two-fold. First, to develop and present a bespoke 3D mobile application prototype that provides AEPP measurement guidance to OTs via the use of 3D visualisation technologies. Second, to explore OT’s perceptions of the prototype application, and in particular its usability and the feasibility, challenges and opportunities of its utilisation to support the AEPP in practice. Section II presents details of an initial concept design phase deployed with OTs and provides a detailed walkthrough of the 3D mobile measurement guidance application. Section III presents the main study which was conducted with OTs to explore utilisation of the 3D mobile application within the AEPP in practice. Section IV presents the results. Section V outlines and discusses the key findings and proposes future design considerations and implications for deployment of the application in practice. Conclusions are drawn and details of future work are provided in Section VI.

II. CONCEPT DESIGN AND APPLICATION WALKTHROUGH

As a first step towards developing the 3D measurement aid prototype (3D-MAP) application, a user-centred initial concept design phase was undertaken to ensure that the design and functionality of the application was aligned with the needs of clinicians. Three interaction designers and eight OTs that currently utilise 2D paper-based guidance to support the AEPP took part in this phase. Fig. 2 presents the protocol of the initial concept design phase.

![Fig. 2. Overview of the protocol for the initial concept design phase.](image-url)

A sample of existing 2D paper-based measurement guidance leaflets were provided for participants to use as a point of
reference during the *concept design phase*. OTs were asked to reflect on their experiences of using paper-based measurement guidance leaflets as part of their role as an OT. They were also shown a low fidelity prototype application which demonstrated how 2D representations of the patient and furniture may be presented using 3D visualisation technologies deployed on a tablet, mobile phone, and laptop. Participants were asked to explore the idea of utilising a software application to assist in the AEPP and to suggest the key features and functionality that they believed would be necessary if the paper-based leaflets were to be replaced by a software application. Furthermore, participants were encouraged to develop, alongside the interaction designers, annotated concept sketches of a potential application interface and associated requirements and functionality. Fig. 3 provides an example concept design sketch produced during a participatory design session.

![Concept sketch produced during participatory design sessions.](image)

Once all participatory design sessions were completed, notes and recordings of the sessions and the annotated concept sketches were perused and used to inform the design and development of the 3D-MAP application. TABLE I presents the key design requirements that emerged from these sessions.

### A. The 3D-MAP application

The 3D-MAP application used in this study has been developed taking into account the user requirements that emerged from initial concept design phase and in accordance with the 3D visualisation guidelines found in the literature [42, 43]. The system architecture and an application walkthrough is presented in this section.

#### 1) System architecture

The deployment platform chosen for the 3D-MAP is the Android OS which is an open source platform freely available for commercial and personal use. The application may also be deployed on a range of devices including mobile phones and tablets that are running an up to date version of Android OS.

In order to support other required platform migrations in the future, the prototype was developed using Unity3D game engine that allows multiplatform deployment, including Android, iOS and Windows *(UR7)*. The system architecture is presented in Fig. 4.

![3D-MAP system architecture.](image)

The key input mechanism/user interface used for the application is the standard touchscreen interface provided by mobile Android devices. Users input measurements via the standard Android virtual touchscreen keyboard. Measurement data is stored temporarily in a local database *(DB)* on the device in order to account for situations with limited wireless network and mobile network connection. The stored data is then transmitted through hypertext transfer protocol *(HTTPS)* to a centralised *MySQL DB* which is in an encrypted format and is only accessible by authorised clinical users. Initially, the clinician sets up a *service user profile* before conducting their home assessments. All measurements are saved to a local DB and mirrored across to a centralised DB. The data collected includes details of the service users’ functional ability, personal and furniture item measurements, and their ability to transfer to and from furniture as well as lying-to-stand transitions *(UR6)*. Clinicians also have the option of generating an *assessment report* *(UR5)*.

#### 2) Application walkthrough

The 3D-MAP application integrates all of the user requirements identified in the concept design sessions. A crucial feature of the 3D-MAP application is the visualisation of the measurement guidance. The application displays 3D models of the five items (bed, bath, toilet, chair and stairs) which is most commonly measured as part of the AEPP and are also known to be the five items of furniture which are most commonly associated with falls in the home environment [44]. Measurement guidance for each respective item is accessed via the main menu shown in Fig. 5 *(UR2)*.

![3D-MAP application’s main menu.](image)
After selecting an item of furniture from the main menu, a representative 3D model of the chosen item is presented to the user along with arrows that are superimposed onto the item and serve as prompts to indicate the discreet points on the furniture items that must be measured (UR4). An example of the bath scene is presented in Fig. 6.

The measurement guidance is presented using two prompt features: 3D arrows and audio instructions which guide the user to provide the necessary measurements (UR8). Written instructions from the paper-based forms were taken and translated into audio files. Audio cues are activated when the features: 3D arrows and audio instructions which guide the user to provide the necessary measurements (UR8). Written instructions from the paper-based forms were taken and translated into audio files. Audio cues are activated when the arrows are touched providing instruction on how and where to accurately measure specific parts of home furniture (UR8). Users have the ability to rotate the 3D furniture models to view discreet areas of interest in detail. In order to do so, the figure swipe gesture input was employed which enabled the handling of rotating the models (UR3). Fig. 7 presents an example of rotating one of the models clockwise by swiping horizontally to the left, the model follows suit and vice versa.

Another key component of the design is the zoom-in and zoom-out feature which changes the viewpoint and perspective for a more detailed look at the 3D furniture models by using the pinch gesture to achieve this (UR3). An example of this function is presented in Fig. 8.

The application enables users to input home furniture measurements via the use of the arrow prompts augmented with sound instructions (UR1). The application is flexible in relation to the interface used and the visualisation capability and audio cue options provided to clinicians are also optional for users who have grasped the use of the application and no longer require audio assistance.

### III. METHODS

This section provides details of the data collection and analysis methods used to explore the perceptions of OTs regarding the use of the 3D-MAP application within the AEPP in practice. Fig. 9 presents an overview of the study design.

#### A. Participants

A purposive sampling strategy was used for this study, for which a total of 10 OTs were recruited. Participants were recruited via a range of sources including online OT groups on social media networking websites (e.g. Facebook and LinkedIn) and by approaching local social service departments, NHS trusts and specialist fall services. Candidates were initially sent an email invitation to take part in the study with a £10 voucher offered as an incentive. The inclusion criteria was that participants were required to be practicing OTs, have relevant clinical experience of carrying out home visit assessments, prescribing assistive equipment, and have familiarity with using a smartphone, tablet, and desktop computer. The sample size of 10 participants is in excess of the five-user assumption typically considered as a reliable guideline to carry out usability and interaction design studies [45]. All participants were female, which to a large extent reflects the female dominated OT [46]. TABLE II presents a summary of participant profiles.

#### B. Protocol and instrumentation

Participant sessions were conducted on a one-to-one basis and
were approximately 90 minutes in duration. Informed consent was obtained at the start of each session. Initially, participants were given a brief demonstration of the 3D-MAP application, and were shown how to use the key functions of the application, record measurements, and generate assessment reports. Participants were then asked to use the application and were given written instructions outlining a series of interactive tasks to carry out. The concurrent think-aloud technique was used to capture participant thoughts and preferences in real-time whilst interacting with a software application [47]. This involved encouraging participants to share their thoughts whilst interacting with the 3D-MAP application and using think-aloud prompts, such as “what are you thinking?” and “what are you doing now?” if extended periods of silence were observed. The interactive task involved measuring home furniture items. Participants were asked to do the following:

1) Start app. and select item of furniture from main menu
2) Rotate 3D model left/right and up/down
3) Zoom in/out using pinch gestures on the touch-screen
4) Touch arrow prompts for additional clinical guidance
5) Measure the five home furniture items
6) Input measurements using the virtual popup keyboard
7) Press the main menu (move on to the next item)

On completion of the interactive task, participants were asked to complete a System Usability Scale (SUS) questionnaire [48], which was used to insight into the usability of the prototype application. SUS is comprised of 10 statements which users are required rate using a 5-point Likert type scale ranging from 1—strongly disagree to 5—strongly agree. After completion of the SUS instrument, each participant was asked to discuss the score they attributed to each SUS item. Semi-structured interviews were subsequently carried out to reflect on the experience of using the application, and discuss the feasibility, challenges and opportunities of using a 3D-MAP application as an assistive tool in practice. All interviews were recorded and transcribed verbatim.

C. Data analysis

Statistical analysis of SUS responses was carried out using IBM SPSS v 20.0.0. Initially, the approach presented by Bangor et al. [49] was used to analyse and interpret the SUS scores. This involved calculating a SUS score from the completed questionnaires, and generating a value on a 100 point rating scale which may then be mapped to descriptive adjectives (Worst imaginable, Poor, OK, Good, Excellent, Best imaginable), an acceptability range (Acceptable, Marginal, Not acceptable), and a school grading scale (i.e. 90-100 = A, 80-89 = B etc.). These baseline ranges and gradings are derived from a sample of over 3000 software applications which provide the comparative baseline [49]. Furthermore, Lewis and Sauro [50] propose that SUS is composed of a two-factor structure in which two sub-scales, namely Usability (SUS items S1, S2, S3, S5, S6, S7, S8, S9) and Learnability (SUS items S4, S10) underpin the SUS instrument. Additional statistical analysis was performed using one-sample t-test to establish whether there were significant differences between the respective mean SUS scores and the mid-point value of three of the five point Likert type scale responses for each individual SUS item and for the Usability and Learnability constructs.

Transcripts of audio recordings of the interactive task sessions and semi-structured interviews were subjected to thematic template analysis. Thematic analysis is a qualitative analysis method used for searching and identifying themes that occur within textual datasets [51]. Using this method enabled patterns in the dataset to be identified and categorised. Analysis of the semi-structured interview data, was both inductive, as the development of the themes were data driven, and deductive, beginning with pre-defined (a priori) themes that are theory driven and linked to the analytical interest of researcher(s) [52]. The first stage involved creating a template which used the pre-defined codes specified by the Technology Acceptance Model (TAM). Hence, analysis considered the participant perceptions of the 3D-MAP application in the context of the two high-level TAM themes: Perceived Usefulness (PU); Perceived Ease of Use (PEOU) and themes that emerged in addition to these. The entire dataset was then read and comments were assigned iteratively through several stages of splicing, linking, deleting and reassigning sub-themes within each pre-determined high-level theme.

D. Ethical Considerations

The research study was reviewed and ethically approved by Brunel University Research Ethics committee prior to any data collection. Informed consent was sought from each participant prior to taking part in the sessions. Each participant was guaranteed confidentiality and anonymity, and was informed of their right to withdraw from the study at any time, both verbal and in written forms.

IV. Results

This section presents the results of the analysis of the SUS, think-aloud and semi-structured interview data.

A. SUS evaluation

The overall SUS score for the 3D-MAP application was 85 (85 out of 100) (SD = 5.6) which according to the evaluation criteria for SUS [49] indicates that the application delivers ‘excellent’ (Descriptive adjective), ‘acceptable’ (Acceptability range), ‘Grade B’ (School grading scale) levels of usability. An analysis of the SUS Usability and Learnability constructs revealed that both constructs achieved mean scores significantly above the neutral mid-point value of 3.00, which were 4.56 (p = 0.000) and 4.85 (p = 0.000) respectively. This indicates that users were positive about Usability and
Learnability of the application. The Cronbach measure of consistency for both constructs was above the threshold of acceptable reliability of 0.6 for small sample studies [33], however, items S1, S5 and S8 were removed to reach the consistency threshold. Results individual SUS items compared against the mid-point is presented in Table III.

<table>
<thead>
<tr>
<th>SUS item</th>
<th>Mid-point Mean ±SD</th>
<th>Gap score</th>
<th>t-value</th>
<th>P-value (2-tail)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1: Use 3D-MAP frequently.</td>
<td>3.00</td>
<td>3.20 ± 1.14</td>
<td>0.20</td>
<td>9</td>
</tr>
<tr>
<td>S2: Unnecessarily complex.*</td>
<td>3.00</td>
<td>4.60 ± 0.52</td>
<td>1.60</td>
<td>9</td>
</tr>
<tr>
<td>S3: Easy to use.</td>
<td>3.00</td>
<td>4.60 ± 0.52</td>
<td>1.60</td>
<td>9</td>
</tr>
<tr>
<td>S4: Support of a technical person*</td>
<td>3.00</td>
<td>4.80 ± 0.42</td>
<td>1.80</td>
<td>9</td>
</tr>
<tr>
<td>S5: The various functions were well integrated.</td>
<td>3.00</td>
<td>3.30 ± 0.95</td>
<td>0.30</td>
<td>9</td>
</tr>
<tr>
<td>S6: Too much inconsistency.*</td>
<td>3.00</td>
<td>4.00 ± 0.94</td>
<td>1.00</td>
<td>9</td>
</tr>
<tr>
<td>S7: Learn to use 3D-MAP very quickly.</td>
<td>3.00</td>
<td>4.60 ± 0.52</td>
<td>1.60</td>
<td>9</td>
</tr>
<tr>
<td>S8: Cumbrous to use.*</td>
<td>3.00</td>
<td>4.30 ± 0.95</td>
<td>1.30</td>
<td>9</td>
</tr>
<tr>
<td>S9: Confident using 3D-MAP.</td>
<td>3.00</td>
<td>4.60 ± 0.70</td>
<td>1.60</td>
<td>9</td>
</tr>
<tr>
<td>S10: Learn a lot of things before using 3D-MAP*</td>
<td>3.00</td>
<td>4.90 ± 0.32</td>
<td>1.90</td>
<td>9</td>
</tr>
</tbody>
</table>

* Responses of negative items were reversed to align with positive items
* Indicates statistically significant <= 0.05 confidence level

All mean scores were above the mid-point indicating that overall, participants tended to be positive about the 3D application. In statistical terms, eight of the ten SUS items (S2-S4, S6-S10) were significantly higher than the mid-point benchmark. Although items S1 and S5 were above the mid-point benchmark, there was no significant difference between the means and mid-point.

Item S1 asked participants to report how frequently they would like to use the application. While the mean score was higher than the mid-point benchmark, the difference was not significantly different (mean = 3.20, p = 0.591). There were mixed opinions about using the application frequently, some expressed an interest in its regular use, provided they had access to a tablet computer. Others suggested that the application required additional functionality before it could be fully incorporated into daily OTs work activities, such as assisting in the task of recommending items of assistive equipment.

“... if it’s around, I would use it, purely because you know I’ve not got scraps of paper... and provided that we have a tablet, which we haven’t got.” (P5)

“As the application stands ... I don’t think I would use it. If it was providing ... a more visual impression to somebody in 3D ... so I’m showing them a virtual drawing of what the rail is going to look like beside their bath ... then possibly yes.” (P1)

Results for S2 revealed that participants were positive about the application and tended to disagree that application was unnecessarily complex (mean = 4.60, p = 0.000). The purpose of the application appeared to be clear to participants, however, one participant working with patients with complex needs felt that additional functionality such as a note taking facility would be a useful addition.

“It’s not complex, what it’s lacking is the complexity. So as an OT, I’m looking into so many little details, so for example, I’m working in neurological ward at the moment, I need to consider so many abilities, disabilities of the patient, risks, that one, two, three measurements per furniture might not cover ... I would have to write extra notes about that piece of equipment and extra take measurements because this wouldn’t give me enough information later on.” (P6)

Responses to S3, regarding the application being easy to use, were significantly higher than the mid-point (mean = 4.60, p = 0.000). Participants noted that the voice and written instructions provided by the application were basic but effective, and that overall it was easy to use the application. Some expressed concerns about the alignment of measurement arrows for the chair which they felt may provide ambiguous guidance.

“Some of them I was doubting. What do you want me to measure, the width of the chair with the arms ... or just the seat ... it was somewhere in between, the arrow, so that wasn’t very clear, but otherwise using it ... that’s very easy.” (P5)

For S4, participants tended to disagree that there was a need for a technical person to be able to use the application (mean = 4.80, p = 0.000). One participant commented that the application could even be used without a demonstration (P9). There was however a feeling that technical support should be available if the application malfunctioned.

“No, I’m OK with technology, so, and that was fairly easy, ... but I think a normal person would be able to manage.” (P9)

“if it went wrong you ... you’d like to know there was somebody on the end of the phone.” (P6)

Mean scores for S5 were only marginally above the mid-point (mean = 3.30, p = 0.343). Explanatory comments relating to this statement revealed that the application provided the necessary measurement guidance, additional functionality needed to integrated into the application, such as the enabling the recording of additional information to supplement/contextualise the recorded measurements.

“Yes, you’ve got the measurements for certain things but ... I’d still need to have paper to write down all the additional information ... it would be good to have it in one place.” (P4)

Participants tended to disagree with (S6), the statement that there was too much inconsistency in the application (mean = 4.00, p = 0.008). However, some participants did suggest that the application would benefit from additional features, such as the ability to create bespoke measurement arrows.

Participants strongly agreed with S7, that the people could learn to use the application very quickly (mean = 4.60, p = 0.000). However, one participant noted that some older adults...
may struggle if they were not familiar with touch-screen devices.

“... if you were asking ... somebody older, it’s not true of all older generation but just some people who aren’t familiar with that type of technology might struggle a bit more with it.” (P4)

Participants tended to disagree with S8 and the notion of the application being cumbersome to use (mean = 4.30, p = 0.002). The application interface tended to be perceived as simple in design with intuitive features and clear measurement instructions.

“I think it’s quite simple in design. It’s quite clear what object you’re measuring ... and easy to learn, easy to remember how to use it.” (P8)

Participants tended to agree with statement S9 that they were confident using the application (mean = 4.60, p = 0.000). The ability to change measurement values, as opposed to having to cross out paper-based recorded values, was seen as a factor that helped participants have more confidence when using the application.

The results for S10 indicates that users disagreed with the notion of having to learn a lot of things before using the application (mean = 4.90, p = 0.000). Particularly, participant comments reported that the application is user friendly, however, some emphasised that having a basic understanding of touch-screen technologies is a prerequisite for using the application.

“If they’ve got kind of a basic understanding of technology, are able to use it, then yeah, it’s very user-friendly.” (P4)

B. Semi-structured interview results

Four high-level themes and numerous sub-themes were identified as a result of the thematic analysis of the think-aloud interactive task data and semi-structured interview data, these are: perceived usefulness; perceived ease of use; application use; application functionality. Fig. 10 presents a thematic mind map of the key themes and sub-themes.

Fig. 10. Thematic mind map of key themes and associated sub-themes.

Perceived usefulness

Participants reported that they were satisfied with the enhanced visual capability of the 3D application compared with the equivalent 2D diagrams presented in paper-based measurement guidance leaflets. In particular, participants highlighted that the 3D models seemed more realistic representations of the item they were measuring, and aided them to better comprehend the precise measurement locations. Some participants believed that the visual clarity of the 3D visualisations may also help improve patient’s understanding of measurements that must be taken and how this translates to fitment of assistive equipment within the home. However, the application in its current form does not show how assistive equipment fits onto items of home furniture, or indeed how these fit within the context of the home environment, which is a function which some participants felt enhance its usefulness.

“...it was useful looking at a 3D model, rather than just you know a flat model ... as an OT you’re kind of used to doing it but ... if service users are (going to look at it) it’s good to see it in 3D, it’s more easy to understand” (P5)

“...so they can have a look and then look at the 3D dimensions, it might give people a better idea.” (P9)

Some felt, however, that whilst the look and feel of the 3D models posed a significant improvement, the accuracy of measurement prompts was lacking in some examples, which could affect how the measurement guidance is interpreted and impact negatively on the reliability of measurement data collected.

“... Some of the arrows were not working when pressed and I think it could have done with more aligning ... you know, showing you exactly where you measure from.” (P4)

Participants felt that the use of the application would help support enhanced and wider ranging stakeholder involvement in the AEPP. For example, it was felt that the application could be used by patients’ family members or carers who may be able to take furniture measurements on behalf of the service user. The application was also seen as having potential educational value for OT students to practice and familiarise themselves with measurement tasks.

“I would use it to give it to family members to measure things.” (P7)

“As the application is now, probably it would be useful for OT students, you know just like for practise, to get used to measuring and recording measurements” (P6)

It was, however, also suggested that whilst the application may not necessarily make the act of carrying out a measurement any easier, it would have value helping to inform assessments, i.e. provide more effective prompts that ensure the relevant dimensions of items are measured and collected in accordance with existing guidelines.

“It could serve as a prompt. I don’t know if it would make measurements ... any easier, but I think it would help.”(P7)

Perceived ease of use

Overall, participants felt that the 3D application was easy to use. However, one participant felt that the rotation of the 3D models was awkward especially when trying to get the model back to its original starting position, hence, a feature to reset the 3D model position was suggested.

“Yeah, fairly easy, just the rotation was a little tricky to kind of get it back to normal view. Maybe if you had a button to reset it back to what it was when you first moved it.” (P5)

Participants noted the clarity and look and feel of the application and the instructions it provides were clear. In particular, the icons on the main menu, which clearly indicated what each section included (participant P4).

“I think the simplicity ... all you do is add a number basically (a measurement) and the visuals are very clear.” (P4)
Application use

Benefits of using the application compared to paper-based approaches were also highlighted. Some participants also expressed their intention to use the application but stressed the need for access to a tablet if they were to be able to use this application in practice.

“I thought it was easy to use and not more complicated certainly than a pad or a form that you would otherwise fill in by hand. So yeah, the simplicity of it I think is making it user-friendly. I would use it ... is this only available on a tablet because we don’t have access to these” (P9)

It was also suggested that using the 3D-MAP application in practice could be of clinical value to collaborate with other clinicians and service users. More specifically, it was felt that the application would be useful for handing over a case to another OT. Value was also seen in integrating recorded measurements with other information such as assessment notes about service users, which would save time and effort.

“I think if it incorporated more of the whole report thing, so you weren’t kind of having to go from paper to tablet, then definitely, it would be even better” (P7)

“Sometimes, like if I want to order rails for instance, I’ll take a picture, go back, e-mail it to myself and then go on to paint and draw a rail on top of the picture and then send it to the equipment company. So ... if I could just screen shot that rail on the bathroom, then that would make my life easier!” (P8)

Application functionality

Participants felt that using the 3D-MAP application would provide clinical value and were enthusiastic with respect to measurement collection, which with the help of the application, they felt could be done in a more standardised and systematic fashion. Some additional application features were suggested, particularly with regards to enabling better control and handling of the 3D models within the application. Some participants expressed a need to include a function to photographically capture patient’s home environment, particularly the item being measured so that a photographic record of what was measured could serve as a point of reference alongside the annotated 3D model of the item of furniture. It was felt that having photographic records of the item, and ideally the context in which it is placed within the home, would help shed light on issues that may be fed into the decision making of selecting assistive equipment later on.

“If there could be a photo, capturing more information, possibly that might be useful more than me asking them or writing and drawing on a piece of paper.” (P6)

V. DISCUSSION

This study presented a mobile application which uses 3D visualisation technology, designed to guide and assist OT’s in the taking and recording of measurements as part of the assistive equipment provision process. A total of 10 OTs used the 3D-MAP application to engage in a measurement task of items of home furniture that are known to be associated with falls and are routinely measured as part of the AEPP. Based on the analysis of the quantitative SUS data revealed that the sample attributed a score of 85/100 for its usability, indicating the application may be described as ‘excellent’, delivering ‘acceptable’, ‘Grade B’ levels of usability overall. In terms of the two SUS sub-scales OTs also tended to strongly agree with statements relating to the usability and learnability of the application. The SUS results highlighted that the general consensus was that the application was easy to use and that learning to use the application was also straightforward. These are promising results, and it is likely that the early concept design phase and participatory design sessions conducted with a separate sample of OT’s, played a role in ensuring the 3D-MAP application was fit for purpose and able to generate a range of comments about the overall concept of using 3D visualisation technologies during the main trial, as opposed to only generating comments relating to fundamental usability issues. Analysis of the individual SUS items and associated open-ended comments, along with think-aloud and semi-structured interview data provided detailed study outcomes relating to the perceived feasibility, usability, challenges and opportunities of the application being deployed in practice. TABLE IV presents a summary of the key study outcomes, and categorises these in terms of implications for deployment in practice and design and functionality recommendations.

<table>
<thead>
<tr>
<th>Areas of focus</th>
<th>Study outcomes</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implications and recommendations for deployment in practice</td>
<td>Clear and usable application without the need for technical expertise/support</td>
<td>S2, S4, S6-S8</td>
</tr>
<tr>
<td></td>
<td>Valuable tool to facilitate collaborative practice and inter-professional handover</td>
<td>AU</td>
</tr>
<tr>
<td></td>
<td>Enhanced visual quality of home furniture measurement guidance</td>
<td>S1, PU</td>
</tr>
<tr>
<td></td>
<td>Systematic, organized solution which instills confidence</td>
<td>S1, S9</td>
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<tr>
<td></td>
<td>Standardised furniture measurement guidance, clear instructions</td>
<td>PU, PEOU, S3</td>
</tr>
<tr>
<td></td>
<td>Explore use by alternative users including care givers and service users</td>
<td>S7, PU</td>
</tr>
<tr>
<td></td>
<td>Include educational component regarding AE and measurement function</td>
<td>PU</td>
</tr>
<tr>
<td></td>
<td>Access to tablets is necessary in order to use the 3D application</td>
<td>AU</td>
</tr>
<tr>
<td>Design &amp; functionality recommendations</td>
<td>Provide improved guidance to make assistive equipment recommendations</td>
<td>S1</td>
</tr>
<tr>
<td></td>
<td>Provide a facility to record notes &amp; assessment data</td>
<td>S2, S5</td>
</tr>
<tr>
<td></td>
<td>Clearer prompts to measure home furniture</td>
<td>S3 &amp; PU</td>
</tr>
<tr>
<td></td>
<td>Clear and more usable controls to rotate 3D models</td>
<td>PEOU</td>
</tr>
<tr>
<td></td>
<td>Additional function to reset the 3D models to its original position</td>
<td>PEOU</td>
</tr>
<tr>
<td></td>
<td>Capture images of the patient’s environment to provide context</td>
<td>AF, PU</td>
</tr>
</tbody>
</table>

TABLE IV Study outcomes, implications and recommendations

Each of these outcomes are mapped to their respective sources, i.e. individual SUS items (S1-S10), or the high-level interviews: PU; PEOU; AU; AF or the themes that emerged from the analysis of the semi-structured

In terms of implications and recommendations for deployment in practice, OT’s reported that they felt that the application could be used in practice without the need for technical support, assuming there was no malfunction (S4).
The interface was perceived as being clear (S2, S8), consistent (S6), and easy to use (S3), requiring minimal levels of effort to learn how to utilise key features and functionality (S7). Interestingly, it was suggested that even ‘a normal person would be able to manage with the app’ (S4) implying that there may be scope for non-OTs such as service users, care givers, or other healthcare professionals to use the application. It was also suggested that the use of such an application may help to enhance collaborative practice (AU) among a team of clinicians for handover referrals and for clinicians to work closely with patients to enable patients to take their own measurements to inform shared decisions for assistive equipment prescription. The notion of empowering patients to take their own measurements has become an important area of emerging interest in the field of occupational therapy and within the AEPP, particularly given increasing budgetary constraints within the healthcare sector [54]. This finding in particular supports the personalisation agenda which advocates the delivery of home-based healthcare services and the enablement of older patients to engage in self-assessment practice [55]. Whilst the personalisation agenda promises numerous health benefits to the patient, it is also seen as a strategy to reduce costs, and to lessen the burden on healthcare systems, specifically on OTs which make up 2% of the health and social care sector with 35% of adult care service referrals having to be handled by OTs [56]. Although further research is required to establish the extent to which this application is usable by other user types, realising this suggestion would certainly compliment the evident need to move away from the patient as a passive recipient of care, to more patient-centred models where the patient is often responsible for carrying out important aspects of their own care [57]. The observation that the application provides a systematic, organised (S1, PU) and standardised (PU) solution that helps to instil confidence in the user whilst recording measurements is a positive implication for deployment in practice (S1, S9). In particular, the fact that measurements can be input and easily changed if the initial measurement was found to be inaccurate, was seen as a significant benefit over keeping paper-based records. It was felt by most of the participants that the application provided clear prompts of where to measure via 3D arrows alongside audio measurement instruction (PU, PEOU, S3).

Furthermore, use within a health education setting (S7, PU) was suggested, particularly to educate trainee/junior OTs on the measurement practice. These findings are in line with a recent review that explored the value of 3D visualisation technology for educational health interventions to inform and shape clinical practice in a simulated environment prior to implementing interventions in practice [58]. This is a particularly important finding given that approximately 50% of assistive equipment prescribed is abandoned [14-16, 44] partly due to the ‘poor fit’ of equipment as a result of misinterpretations of guidance and no standardised measurement practice [44, 59]. Due to the heterogeneous practice of the AEPP across UK NHS trusts, and the lack of consensus in terms of practice [60], the 3D application was seen as having potential in improve and standardise the measurement process (PU). The present findings are also supported by a recent study which concluded that there is a need to standardised measurement guidance, particularly for the provision of assistive equipment [61]. Clinicians viewed the 3D-MAP application as a tool which improved the visual quality and detail/ clarity of measurement guidance (S1, PU) which constitutes an alternative solution to the typical 2D diagrams currently used across NHS trusts. This finding is consistent with findings of past studies by Spyridonis et al. [34], which found that 3D visualisation technology improved the visual quality of 2D paper-based assessments, currently in use, visualising and locating exact points on 3D models that are of clinical relevance and importance. Another study found that 3D visualisation enhanced visualisations of patients movement, highlighting discreet areas to target for rehabilitation exercise programmes [62]. However, one key obstacle which stands in the way of an application such as 3D-MAP being adopted in practice is availability of mobile touchscreen devices in practice. Some participants commented that they do not have access to such devices and hence although the deployment of the application in practice may be desirable, it is not feasible until such technologies are provided. Although this issue is not related directly to the usability/functionality of the application, it still poses a real obstacle to realising the benefits that such applications may be capable of delivering in practice [63].

There were numerous design and functionality recommendations that emerged from this study, which indicate how the application may be further developed to accommodate the needs of OTs who intend to use the application in practice and further enhance the application functionality. For example, the measurement guidance provided by the current version of the application requires further extension in order to help prescribe appropriate assistive equipment for the item of furniture that has been measured (S1). There were a number of suggestions made regarding the need for a facility to record notes in conjunction with the collected assessment data as the clinical decision-making process for prescribing equipment is made up of other factors in relation to clinicians’ observations of patients carry out day-to-day activities (S2, S5). Participants expressed the need for clearer visual prompts to measure home furniture items, as some prompts appear to be unclear and counterintuitive which could impact the reliability of users effectively interpreting the guidance for logging accurate measurements (S3, PU). This requirement in particular is important considering that the application was developed to enhance the visualisation of measurement guidance by the use of 3D models and arrows to sufficiently locate end-to-end points on an arrow. Participants expressed some difficulties they were experiencing whilst rotating the 3D models which concluded that the controls were counterintuitive and need further development, especially given that older patients are expected to use this application (PEOU). A number of adaptations were suggested, in particular, to better handle the
3D models by resetting its position to help remedy the current counterintuitive rotation function (PEOU). There is a need to explore possible alternative controls that can be implemented to improve the current controls for manipulating the viewpoint/position of the 3D models and to better support both patient and clinical users of the appl50%ication. Enabling the photographic capture of the patients’ home environment, particularly images of the home furniture items within the real-world context, may help to conceptualise the context in which the item is placed and the type of furniture item measured (AF) and provide important information that may be used when prescribing AE. Existing studies in the literature have explored the use of taking images of the patient’s home which provided visual aids to support clinical decision making/reasoning and served as an adjunct to or substitute for a traditional home visit assessment [64]. This feature could be useful for clinicians in recording visuals of patients home supplemented by the measurements that they traditionally collect from home visits. Interestingly, some participants mentioned using their smartphones during home visit assessment to take photographs to help with their assessments and the decision making process for recommendations. This particular feature has been reported in the literature as being a valuable technique within the provision of home visit assessments and AE to explore the feasibility of home modifications and to remotely inspect the home environment for extrinsic fall risk factors [64, 65]. As such, this shows the potential of this feature that may be of value over and above providing detailed guidance for recording measurements.

VI. CONCLUSION AND FUTURE WORK

This study investigated OTs’ perceptions regarding the feasibility, opportunities and challenges of using the 3D-MAP application prototype as an assistive tool within the assistive equipment provision process. OTs were positive about the application in terms of its usability its use by OTs as part of AEPP practice, and other stakeholders such as care givers, trainee OTs and patients. The study also showed that OTs felt the 3D-MAP application has the potential to effectively augment existing 2D diagrams and delivers numerous benefits over their paper-based equivalents. For example, OTs believed 3D-MAP enhanced the visual quality of measurement guidance via the use of browsable 3D models, more clearly articulated the discreet points of measurement, and introduces the opportunity for patients and clinicians to engage in more collaborative practice and potentially eases the handover process. One of the key challenges to deploying such applications, however, is the lack of availability of mobile touch-screen devices to practitioners. Further research is needed to establish whether such an application may be feasibly used by service users, family members and care givers. It is also necessary to further research the clinical utility of this application in terms of its efficiency, effectiveness, and the relative accuracy and reliability of measurements recorded by clinicians using the 3D-MAP application compared with 2D paper-based guidance leaflets.

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