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Towards Enhancing Older Adults' Medication Self-Management through Smart Packaging

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Abstract*: *In 2018, 18% of Great Britain's residents were aged 65 and above, with 50% of this demographic failing to adhere to prescribed medications. Medication non-adherence not only jeopardizes patient health but also imposes significant burdens on healthcare systems, such as increased hospitalizations and care costs. In this paper, the potential of smart packaging to enhance medication self-management for older adults is explored. Furthermore, the critical gaps in existing UK market solutions are identified, which often lack user-centric design features tailored to older adults, particularly those managing complex medical regimens and experiencing rapidly evolving health conditions. Through a combination of literature review, market gap analysis, and direct user interviews, in this study barriers older adults face, including unclear instructions, poor labeling, and difficulties with current pill dispensers due to cognitive and physical impairments are highlighted. Findings underscore the need for personalized, context-aware solutions to improve medication adherence and user engagement. In this paper, authors propose a framework for smart packaging designed to meet the diverse needs of older adults. This includes user-friendly features such as enhanced labeling with vision-aware colors and bold fonts, intuitive instructions, and digital tools like QR codes for real-time information and connectivity with caregivers. These innovations aim to empower older adults, foster medication adherence, and reduce dependency on healthcare providers. By bridging the gap between user needs and product capabilities, the contribution of this study is in advancing in-home healthcare solutions tailored to an ageing population. The work presented in this paper provides actionable insights for healthcare providers, designers, and policymakers to develop inclusive technologies that address the evolving challenges of medication management in ageing societies.

Keywords*: *Context-Aware, Medication Management, Self-Management, Smart Packaging.

I. INTRODUCTION

A growing ageing population and the rising number of people living alone with long-term conditions lead to increasing demand for resources to support healthcare in a pandemic-impacted world [1]. As a response, many countries are increasing the proportion of in-home healthcare with a vision to move routine medical checks and other healthcare services from the hospital to the home environment to reduce the total expenditure on medical care or treatment [2]. The advances in Information and Communication Technologies (ICT) and Artificial Intelligence (AI) facilitate the real-time processing of data enabling in-home healthcare with connected patients. This transformation better known as digital healthcare creates new opportunities to increase patients' independence and sustain their (self-) management at home [3]. However, medication (self-) management or adherence remains a major challenge that creates additional pressure on the global healthcare system. Currently, two million people aged 65 and overtake at least seven prescribed medicines per day, while the number of prescribed medicines at specific times and combinations increases with age [4]. According to WHO, 50% of older adults with chronic and long-term conditions increasingly multi medicated fail to adhere to their medication, putting them at risk of poor health outcomes, increased mortality, and burden on the National Health Service (NHS) resources such as care professionals` time, hospital beds and subsequent costs [5]. It is utterly important to enhance adherence across all patients, conditions, and settings for the most vulnerable in our society, including older adults.

Medication non-adherence is a multifactor challenge associated with biomedical, behavioural and social sciences and defines the problem but does not generate socio-technical solutions that are sufficiently context-aware [5]. A context-aware solution for medicine adherence refers to an approach that recognizes and addresses the various contextual factors influencing an individual's ability to adhere to their prescribed medication regimen. These factors can include socioeconomic status, cultural beliefs, access to healthcare, health literacy, family support, mental health, and physical abilities, among others. The engineering and physical sciences have sometimes sought a one-size-fits-all solution to 'companion technologies' around medications but the need for medication management varies enormously with patients' age, time, place, and the combination of diseases and conditions [6]. To enhance patients' medication adherence, it is paramount to enhance their engagement with technological solutions for medication self-management by understanding their overall experience in terms of their needs, removing barriers, and enabling independence. The aim of this paper is to explore challenges older adults face interacting with pillboxes for self-managing their medication at home and opportunities for addressing their changing requirements through smart packaging.

The paper is organized in accordance with the main objectives for fulfilling the aim. The first objective is to identify the role of digital technologies in medicine adherence and through

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design thinking to explore the challenges of medicine adherence that older adults may face as presented in Section 2. The second objective is to explore users` needs to self-manage their medication at home through interviews as presented in Section 3. The results of interviews are presented in Section 4 followed by detailed analysis as a third objective. The last objective is to share insights from design engineering perspectives in addressing the user`s needs for personalized context-aware smart packaging in enhancing/fostering user engagement and adherence as presented in Section 5. The conclusion and an outlook on where to go from here are presented in Section 6.

II. LITERATURE REVIEW

A. Medication Adherence

Medication adherence refers to the extent to which patients adhere to their medication regime as recommended by their healthcare provider [7]. Patients who fail to adhere to their medication are at risk of poor health outcomes, increased mortality, and a burden on the NHS resources [8]. For example, insulating medication underuse in diabetic patients where the drug level might be below the therapeutic range causes suboptimal glucose control prompting the physician to titrate the dosage. If medication adherence is not checked, this titration in dosage can result in hypoglycemic and hyperglycemic episodes causing in the long run progression of the disease [5]. In addition, frequent blood pressure medication overuse in high-blood pressure patients causes renal blood flow` putting them at increased risk of acute kidney injury (AKI) [9]. AKI is characterized as a sudden reduction in kidney function over hours or days and is a clinical syndrome in most cases caused by a combination of underlying infections, hypovolemia, hypotension and medication effects. Older adults who have existing chronic kidney disease (CDK), previous episodes of AKI and/or have neurological or cognitive impairment are at higher risk of AKI that in long run might be detrimental to the patient [9].

Factors for non-adherence are categorized as follows [8]:

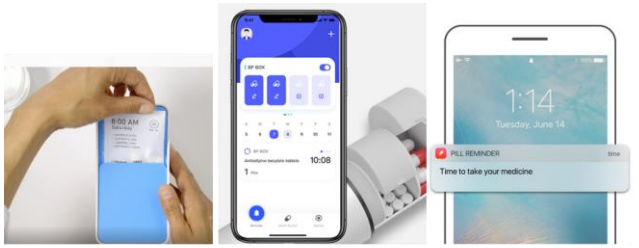
1. Patient – Individual willingness and ability of patients to adhere is based on the mental state, physical health demographics, past medical history, behaviour, attitudes, habits, knowledge, beliefs, and others.
2. Healthcare providers - play an incremental role in patients' adherence to medication, keeping them informed and establishing a trustworthy relationship.
3. Healthcare system - Lack of patient education where a patient needs to understand the importance of taking medication, lack of follow-up for adverse reactions or titrate lack of medication schedule, and short duration of prescription causing frequent visits to the pharmacy.
4. Socioeconomic factors - Lack of caregivers and huge financial burden to payers, such as government in the centralized healthcare system or patients and/or their informal caregivers in the decentralized healthcare system have a higher degree of nonadherence to medication.
5. Medication - Formulation and packaging, drug regimen and handling, adverse drug reactions, drug interactions, poor labelling instructions, cost of medication, and lack of consequences.

In this paper, the focus is on the medication factor that leads to the lack of user engagement and lack of medication adherence. There is an indication that in-home healthcare for the older population enabled by technological solutions, such as medication dispensers, pillboxes and smart packaging may alleviate medicine adherence issues, thus helping to bridge the gap between healthcare professionals and patients.

B. State-of-the-Art Technology for Medication Management

▪ *Products on the Market, Prototypes, and Theoretical Proposals*

A growing number of products are becoming available in the market, ranging from medication management and delivery services to smart pill organizers, and pill reminders apps, where prominent examples are presented in Fig. 1. For example, Amazon pharmacy [10] allow patients to have medication delivered to their home. Similar example is and MedExpress [11]. MedHub Smart Pill Organizer is an example that includes an air-drying compartment to help preserve medications, a light and noise alarm, a Bluetooth connection to smartphones, and a heart rate tracker [12]. In addition, there are many applications available on the market that send alerts at appropriate times as a reminder to take medication once uploaded with all appropriate information. One example is the Pill Reminder Medication Alarm from Aplicativos Legais [13].



Amazon PillPack Top View (Amazon, n.d.) | MedHub Smart Pill Organizer (Indiegogo, n.d.) | Pill Reminder App from Apple's App Store (Aplicativos Legais , n.d.)

[Fig.1: State-of-the-art Technology Used in in-Home Healthcare Medication Management]

Whilst all previously mentioned examples are either available products or prototypes, several theoretical concepts have been outlined within the literature [14]. proposed IoT-based solution linked with home appliances into the network that allows medication intake monitoring from anywhere [15]. also proposed a solution that created a network within the home that links specific medical devices rather than everyday appliances. They also outlined their iMedBox, iMedPack, Bio-patch and how they would interact via their Health-IoT Cloud. However, a large network infrastructure is needed to support such promising solutions [16]. developed a solution iMedBox that can register all medications within, download reminders directly from prescriptions send alerts when to take medication, record any non-compliance and update medical professionals in case of emergency.

In this paper, the gap analysis is performed to evaluate the availability of current products, prototypes, and theoretical concepts, and to identify their suitability to support medication self-management among the older population, see Table A in the Appendix. After evaluation of the current market,

it is found all the products available lack design features specific to the needs of older adults, especially those with complex medical regimes resulting in a lack of user engagement and user adherence to medication management [17].

- *Smart Packaging*

The pharmaceutical industry is using conventional packaging that has three main functionalities protection, information, and containment of pharmaceutical products [18]. However, smart packaging (design-led, active and intelligent) is a holistic solution to transform the way we deliver, sell, and use products [19]. Smart packaging incorporates advanced technologies, such as printed electronics, the Internet of Things (IoT), or nanomaterials, to enhance the existing functions of conventional packaging [20]. Intelligent and ergonomic smart packaging enriches the consumers` experience and their engagement with the product, which shows potential to improve users` self-management for medication adherence [21]. Smart packaging can be used in both assisted medication management, such as MedExpress, and Amazon pharmacy, and self-medication management, such as pillboxes, medicine dispensers, etc. In assisted medication management packaging is delivered with medicines and medication package inserts that provide information about that drug and its use. In self-medication management packaging is delivered without medicine and it is the obligation of the user to check the drug labels for each medication that would let the user know how to take it, what is in it, and how it might make them feel. Regardless of the intended use for the design and development of smart packaging, it is critical to explore the current challenges and unexplored/hidden needs of users [17].

- *Design Thinking*

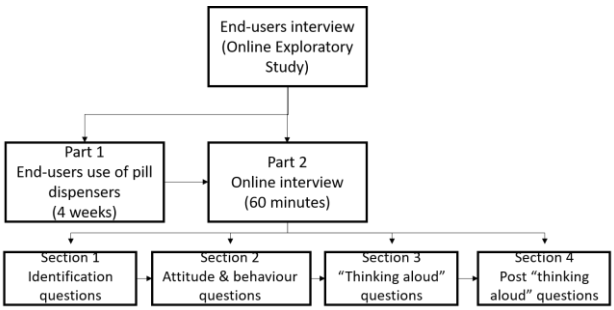
Promoting and enhancing user engagement with medication management is of great importance with a great impact on the health of the population [22]. Ways health care providers can promote better medication adherence. An important dimension of successful user engagement in medication self-management is associated with understanding diverse user needs with limited cognitive and physical capabilities [23]. Medication self-management skills and cognitive impairment in older adults hospitalized for heart failure: A cross-sectional study [24]. This leads to the enhancement of user engagement that impacts the medication consumption for older adults with a diverse range of needs. In this research, the design thinking process is adopted to explore the challenges older adults face in their medication management at home.

Design thinking is a powerful process for problem-solving and addressing challenges in the area of digital healthcare today, by recognising the opportunities to provide a human-centred experience [25]. The Design thinking embeds five stages including understanding the user needs, defining the problem area ideation, prototyping, and testing human-centred solutions [26]. Initially, the design thinking process starts with empathizing with the user through understanding their needs, followed by the identification of problems and opportunities for human-centred solutions. Ideation is a process that embodies user insights and seeks to generate, develop, and test ideas. Design thinking results in the development of ideas with a view of transforming them into human-centred products.

The power of design thinking in transforming healthcare starts with facilitating a better interaction between patients and healthcare products, services and systems. Design thinking begins with understanding user needs and the impact on design decisions for millions of people using a product and the next billions of users' experiences and interactions. In 2003, Howcroft and Wilson indicated the importance of design thinking in multidisciplinary research to understand the interactions and needs of people in their natural settings where the behaviour occurs [27]. Norman indicates that understanding people's goals and challenges when interacting with a product is a core component of the user experience to increase the usability of the design (products, systems, and services) [28]. For this research, this means user participation from an early stage and during the design process to explore their habits, tasks, goals, behaviour and motives in the context. In particular, understanding user diversity in capabilities, needs and aspirations towards medication management.

III. METHODOLOGY AND PROCEDURE

In this research, an interpretive methodology is adopted to explore the underlying challenges of older adults` medication self-management at home. The adopted methodology in this research is comprised of two parts, see Fig. 2. The first part involves familiarizing users with a range of devices for medication self-management such as medicine dispensers, see Fig. 3. The second part involves direct interviews with end-users (older adults age 65 and over), see interview questions in Table B in the Appendix. An Informed Consent was obtained from human subjects in this exploratory study.



[Fig.2: Design of User Interview Study]

A. Participants Sampling

According to the aim of the proposed research, heterogeneous sampling as a type of purposive sampling technique is adopted focused on a broad population of older adults with a diverse range of educational levels, physical ability, cognitive ability and digital fluency with Digital Literacy. In this study, the primary inclusion criteria for the (end-user) participants are based on their age, gender, digital fluency, and living conditions. The chosen sample (users) represents older adults aged 65 and over with and without different medication adherence issues caused by combinations of diseases and conditions. Furthermore, males, females, with basic, intermediate, and advanced

levels of digital fluency are included. This study explores the participants' interpretation of the illustrated medicine dispensers to explore older adults' challenges for medicine adherence. According to the aim of the study, this study requires small groups of participants based on the nature of participants' interpretation and interactions for focused and in-depth results [29]. Hence, video-recorded interviews are facilitated remotely through Microsoft Teams as it maximizes clarity to underpin the naturally occurring experience and interactions of the participants with the illustrated pill dispensers in their own environment.

Overall, five participants took part in the study including two male and three female participants, with different levels of digital fluency and medication adherence issues, see Table 1.

Table 1: Participants' Information

Participant Number and Code	Gender	Age	Digital Fluency	Medication Adherence	Living Conditions
1 (M,81,DF-A)	Male	81	Advance	Undertaking	Leaving with Partner
2 (F,81,DF-I)	Female	81	Intermediate	Undertaking	Leaving with Partner
3 (F, 81,DF-B)	Female	81	Basic	Overtaking	Leaving Alone
4 (M,72,DF-I)	Male	72	Intermediate	No issues	Leaving Alone
5 (F,71,DF-I)	Female	71	Intermediate	No issues	Leaving Alone

B. Prompted Pillboxes

In this research, the participant's assessment of the most popular medicine dispensers that are available in the UK market is investigated. The medicine dispensers are selected for heterogeneous older adults with different conditions and age-related needs, see Fig. 3.

[Fig.3: Medicine Dispensers: a) Aidapt Week Day Pill Dispenser [30], b) Smart Pillbox [31], c) PIVOTELL® Advance Automatic Medication Pill Dispenser [32], and d) INPHER Pill Box [33]]

For example, the first device with braille, see Fig. 3, a), is suitable for users with macular defects or permanent blindness. The second device, see Fig. 3, b), has both visual and audio reminders giving information to the user on what, how many and when to take medicine that is suitable for the user with memory lapse. The third device, see Fig. 3, c), is an automatic pill dispenser that automatically gives a dosage of medicine to a user at a particular time which is suitable for users with dexterity and dementia. The last device, see Fig. 3, d), is color-coded, which is suitable for users who are experiencing hearing loss.

C. Procedure

As discussed in Section 2.4, initially, the design thinking process starts with empathizing with the user through understanding their needs. Hence, for this research direct user involvement is important to explore participants' experience with prompted medicine dispensers for medication self-management at home see Part I in Fig. 2. Devices presented in Fig. 3 were sent to the participants unpacked with manufacturer instructions following Covid-19 regulations. Participants are instructed not to use actual medicine but rather to engage with devices to familiarize themselves over four weeks prior to the study without medicine for safety reasons.

After four weeks, the individual interviews are conducted over Microsoft Teams calls where participants are asked 36 questions over 60 minutes, see Part II in Fig. 2. This phase is focused on attitudinal and behavioural questions, divided into four groups, user identification, attitude, and behaviour, "thinking aloud" and overall experience with medicine dispensers, identifying user challenges and opportunities for further design improvements. The interview questions are presented in the Appendix, Table B. The results of the interviews are further discussed in Section 4.

IV. RESULTS AND DISCUSSION

A range of qualitative data including images, audio, video recordings, observation notes and texts are gathered from the conducted sessions with participants. In this section, direct quotations from the participants' words by using their initials maintaining anonymity for the transcription are presented. Considering the aim of the research and the selection criteria, the participants' gender is presented as [M/F] along with their age a two-digit number [NN], and digital fluency level [DF-B/I/A] as presented in Table 1.

The themes that emerged from the qualitative data analysis related to the participants persisting challenges with medication self-management at home due to forgetfulness that results from misusing and overall user experience with the prompted pillboxes are classified as requirements pre-, during-, and post-medicine use.

A. Pre-use

- *Product Packaging*

All participants stated the product package and instructions are not useful for the prompted pillboxes. They struggled to understand how to operate the digital pillboxes despite reading the manuals and prefer labelling their pillboxes themselves, see Fig. 4.

[Fig.4: The Image of a Participant's Manual Pill Box with Handwritten Labels [F,71, DF-I]]

Up to this point, the participants' primary concerns in using prompted medicine

dispensers are directly linked with the lack of clear packaging, labelling and overall set-up instructions even for native English speakers. Here are a few examples of the way they described their unwillingness to use products that are not clearly labelled:

[M,81, DF-A]: "The description is terrible, difficult to follow, no contrast, and I can't read the manual as the font size is too small."

[M,72, DF-I]: "I get tired easily, it's too much for me. I don't know which one is morning or night."

[F,81, DF-I]: "The description of the device is terrible, even for a native English speaker!"

[M,72, DF-I]: "The instructions are not clear and there are no clear labels. I can't open it. It doesn't start. I can't even open the battery. My finger got stuck inside to place the pills. It's very difficult to open it and figure it out."

[M,72, DF-I]: "The instructions are confusing and the buttons are not labeled. I wish I could get help from a healthcare provider or the pharmacy to set up the automatic medicine dispensers."

[F,71, DF-I]: "I can't read the instructions in English. I don't know how to open it. Writing is too small and It's super confusing."

B. During-use

- *User Capabilities*

The participants' most concern is about their rapidly changing medical conditions and capabilities such as forgetfulness which can often be age-related. Further, rapidly changing medical conditions require more complex medication regimes such as sensory impairments (blindness or deafness), neurological conditions (Alzheimer's disease, Dementia, Parkinson's) and reduced dexterity due to a decrease in fine motor skills. The stated medical conditions manifest as changing needs such as the inability to open medicine packages and take pills, or the inability to recall and organize medicine intake on their own and carry a heavy pillbox.

As they said in their words:

[F,81, DF-B]: "For the last two weeks since I received the pill boxes, my condition has changed. I'm now diagnosed with dementia and I don't know if in a month I'll be able to use these devices at all."

[F,71, DF-I]: "I can't see the Smart pillbox buttons and understand the instructions. Too heavy and I may drop the device which is heavy and dangerous."

[F,81, DF-I]: "What if the pills get stuck, the compartments of the automatic devices are too small for me. I have arthritis and I can't open the manual pillboxes."

- *Ease of use*

All participants expressed their interest in the manual devices which are easy to use. They identified the main characteristics of automatic products such as alarms and automatic locking features of storage boxes as complex. Both male and female participants were concerned about the setup instructions, and the device's battery life would be challenging and time-consuming. This seems to be something they all experienced and important consideration and they expected support from a caregiver or healthcare provider. As the following participants said:

[M,72, DF-I]: "The automatic device needs a career, partner, or my child to help me out."

[M,81, DF-A]: "The automatic device seems a bit complicated compared to manual devices. I know better to use manual ones because of simplicity."

[F,71, DF-I]: "I can't read the alarm instructions to set it up. I prefer it to be simple, too many buttons and I need to change batteries."

[M,72, DF-I]: "If I should put all the tablets there, I don't like to use them. I need to get used to it and it takes time."

[M,72, DF-I]: "Takes too much time to set it up. I rather fill the pill box everyday with less compartments."

[M,81, DF-A]: "I wouldn't bother with the alarms, far too complex. It needs a battery and I won't be able to change it. It needs a career to change the batteries and set it up."

Further, all participants stated that the storage compartments are too small which is challenging for storing multiple doses, particularly for those with reduced dexterity and complex medication regimes. While the automatic devices offer multidose storage capacity, participants were concerned about combining pills with the same colours. The assessed medicine dispensers are not designed to support complex medication regimes and the needs of different users with a diverse range of medical conditions. In addition, all participants expressed their concern about the similar colour and small lettering of storage compartments, which can be extremely difficult to identify daily morning/evening pills for people with certain neurological conditions, such as dementia. The participants suggested that having bigger storage compartments with bold colours and big lettering, such as red and white, would help them to differentiate the components.

- *Reliability, Trust and Safety*

The following responses highlight the lack of participants' reliability, trust, and safety towards the automatic medicine dispensers because of the batteries. As they said in their words:

[F,71, DF-I]: "I arrange my pills in my manual pill box and I label it myself but sometimes I forget to take my pills. I don't want to read instructions and trust these machines as I live alone. It frustrates me and I don't know how to open it. No, I can't open it. What should I do?"

[M,72, DF-I]: "What if the battery runs down and it doesn't warn me? That makes me worried! What if the device gets stuck?"

[M,81, DF-A]: "It is hard to change the batteries as I don't use the screwdriver to change the batteries?"

[F,72, DF-I]: "Labeling letters for compartments are confusing. What "S" stands for, Saturday or Sunday?"

[F,72, DF-I]: "I want to be able to see my pills, I like see through medicine dispensers. I don`t like when everything is hidden inside."

In addition, one of the participants mentioned that she lives alone, and it is important to consider the state of her mental health linked with her engagement in medication management at home associated with external factors such as social isolation and loneliness. Automatic features such as an alarm can help this participant to avoid missing doses and the same issues arising in the future.

C. Post-use

In this research, new

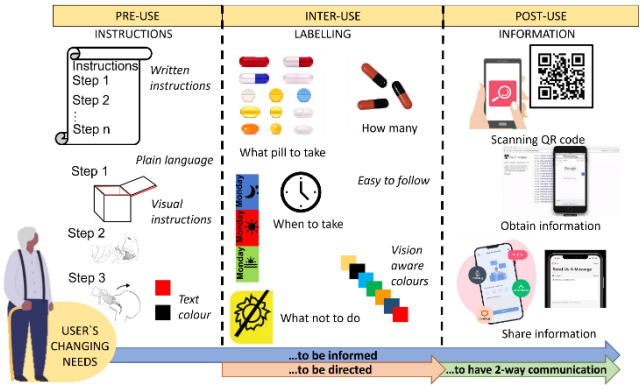
opportunities emerged in terms of obtaining and sharing information between user-product-formal/informal caretakers. Most participants expressed the need to inform their formal and informal caretakers such as family members about their medication management.

[M,81, DF-A]: "I would like to be connected with family members through pill dispenser. I think it would be good if the pill dispenser is connected with the app, so I can keep them engaged."

[F,81, DF-B]: "I would like to be connected with family members and carriers so they know what and when I took. I think this would help them as well."

[M,72, DF-I]: "If I have option to download instructions in Persian it would be very helpful since my English is on basic level."

The results from interviews highlighted the challenges that older adults face when using standard pillboxes for self-managing their medication at home. They highlighted the need for ease of use of the product packaging in terms of visual and physical properties for users with a diverse range of needs. Further, a lack of clear labelling and instructions played a key role in the participants' lack of motivation to engage with prompted medicine dispensers. This is vital to ensure the safety of the patient regarding time-sensitive medications so they would be able to access and take medication without confusion or in a laborious manner.



[Fig.5: Users' Changing Needs Pre-, During-, and Post-Use of Medicine]

V. PROPOSED CONCEPT: PERSONALIZED CONTEXT-AWARE SMART PACKAGING

According to the WHO, better labels and package inserts could help people increase medication adherence by improving ease of access to medication, independence, reducing pill misuse, etc. [34]. This is reconfirmed in Section 4, where the need for a personalized context-aware smart packaging solution that will accommodate users' changing needs before, during and after medicine intake is identified. Users need to be informed before, during and after interacting with pillboxes, where instructions, labelling QR codes and other digital gadgets could support them, see blue arrow in Fig. 5. Furthermore, users need to be directed on how to use a pillbox, and when to use it, see the orange arrow in Fig. 5. Lastly, users wish to share the information about their medication management with their informal caretakers such as family members, or formal caretakers, such as GPs, chemists, etc., see green arrow in Fig. 5.

In this section, the insights from a design engineering perspective in addressing changing users' requirements for smart packaging are presented.

A. Medication Management Smart Packaging Instructions (MMSPI)

It is important to educate users on how to manage their medicine with smart packaging. Instruction should be included in the smart packaging that will hold the medication and provide information on how to use it easily and safely for medication management. The information should be written in plain language intended for the user who will manage the drug for themselves or another person, such as a dependent. The font style, size and colour should be pleasant for the eyes and easy to read. The figures, pictures, and tables used to illustrate and emphasize the crucial content of the text should be simple and easy to follow. Bold colours may be used to enliven the instruction text and to highlight its information content. MMSPI will be critical in pre-and inter-medication management, see pre-use in Fig. 5.

B. Management Smart Packaging labels (MMSPL)

Smart packaging labels show important details that users must know. Legally required details on the label are brand name, product name, series name, packaging size, company contact information, and barcode. The labelling should use vision-aware colours and should be simple and easy to follow. The font size of the letters and symbols should be suitable for older adults. Acronyms and abbreviations should be avoided so as not to confuse and alienate unfamiliar users. MMSPI will be critical in pre-and after-medication management, see inter-use in Fig. 5.

C. Medication Management Smart Packaging Digital Information (MMSPDI)

The patient should have the option to obtain information or share information via digital methods at any point in time while under medication management. Existing solutions for medication management are not supported by two-way communication. For example, by simply scanning the QR code on a product's packaging label using a smartphone device, the user will immediately access the information through a web browser and or send feedback information on how they feel after taking medicine ensuring delivery of quality care. MMSPDI will be critical in the pre-and post-medication management, see post-use in Fig. 5.

VI. CONCLUSION

In 2018, 18% of residents of Great Britain are considered older adults, while 50% with long-term conditions fail to adhere to their medication. In this paper, the authors explore the challenges and opportunities for enhancing medication self-management among the older heterogeneous population through a review of state-of-the-art technology for medication management and interviews for exploring users` needs to self-manage their medication at home.

In this exploratory research, it is identified that currently available products in the UK market lacked design features specific to older adults, especially those with complex medical regimes resulting in a lack of user engagement and user adherence to medication

management. In addition, the participants mentioned their medical conditions are rapidly changing with age and the assessed pillboxes are not suitable for heterogeneous older populations who are facing different age and condition-related challenges living alone under complex medical regimes. While digital health technologies for in-home medication management are advancing towards IoT-based connected devices with mobile phones, tablets, and wearables, only users with high knowledge of digital literacy can efficiently use these devices to manage their medication at home. However, older adults with a lower level of digital literacy and a range of age-related conditions that differ rapidly consider these devices overwhelming, leading to poor outcomes and high risks for their health self-management.

This exploratory research which leads to a range of possible functional and non-functional requirements for personalized context-aware smart packaging and co-design sessions with older adults, aged 65 and over, is created for tailoring solutions to enhance/foster user engagement and accommodate users' changing needs in medication self-management.

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DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** Each author has individually contributed to the article. The authors confirm contribution to the paper as follows: study conception and design: Jelena Milisavljevic-Syed and Bahar Khayamian Esfahani; data collection: analysis and interpretation of results: draft manuscript preparation: Jelena Milisavljevic-Syed and Dirk Schaefer. All authors reviewed the results and approved the final version of the manuscript.

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AUTHOR'S PROFILE

Jelena Milisavljevic-Syed assumed the role of Associate Professor in Manufacturing Systems at Cranfield University within the Sustainable Manufacturing Systems Centre in September 2022. Prior to her current role, Dr Milisavljevic-Syed held an Assistant Professor position in Industrial Design at the University of Liverpool and a leadership position as a Director of the Systems Realization Laboratory (SRL) since 2022. Dr Milisavljevic-Syed received her PhD in Mechanical Engineering in 2018 from the University of Oklahoma, Norman, USA. She is an internationally recognized leader in AI-supported Design for Dynamic Management of Evolving Cyber-physical Systems. Her primary area of expertise lies in the development of modelling capabilities and decision-making tools for the design of highly networked and dynamically complex systems. Her work is instrumental in advancing digitization and sustainability in the domains of smart manufacturing and healthcare systems. Throughout her distinguished career, Dr Milisavljevic-Syed has made substantial contributions to the field. She has co-authored a monograph, along with an impressive portfolio of thirty journal publications thirty-five technical publications, and several magazine articles all of which have delved into the dynamic management of manufacturing systems, as well as the design and analysis of complex systems. Dr Milisavljevic-Syed is an Honorary Research Fellow at the School of Electrical Engineering and Electronics, University of Liverpool. Her professional affiliations underscore her commitment to the field, with memberships in esteemed organizations such as IEEE, MIET, ASME, ASEE, Design Society, and the EPSRC Peer Review College.

Bahar Khayamian Esfahani is a visiting lecturer at the University of East London. Prior to her current role, Dr Khayamian Esfahani held Assistant Professor positions in Product Design Engineering and Industrial Design across various UK universities. She has been a key member of the Systems Realization Laboratory (SRL) since 2018, providing multidisciplinary expertise in human-cantered design and digital healthcare products and services. Dr Khayamian Esfahani has a track record of excellence in high impact internationally leading research into human-centred design principles evidenced by her significant research publications, awards, and senior fellowship in higher education. Dr Khayamian Esfahani's vision has led to national and international collaborations across academia, and industry with a proven track record of leading qualitative and quantitative research at all stages of agile product development.

Dirk Schaefer is a Professor of Mechanical Engineering and currently the Dean of the Faculty of Science and Engineering at the University of Hull in the UK. Prior to his current role, Professor Schaefer held leadership positions at the Universities of Lincoln and Liverpool, establishing a track record of effective leadership and management in Higher Education at scale. His academic journey further includes positions at the University of Bath, the University of Durham, and the Georgia Institute of Technology in the US. Professor Schaefer holds a PhD in Computer Science from the University of Stuttgart, Germany. He is an internationally recognized specialist in cloud-based design and manufacturing in the context of cyber-physical production engineering (Industry 4.0). Additional research interests include digital/smart healthcare provision systems of the future, smart packaging solutions, and pedagogy and systems to support personalized learning. Professor Schaefer has published more than 200 peer-reviewed publications, including 10 books, and has delivered numerous presentations globally, further enhancing his academic impact. Professor Schaefer is an elected Fellow of the Institution of Mechanical Engineers (FIMechE), the Institution of Engineering Designers (FIED), the British Computer Society (FBCS), the Institute of Mathematics and its Applications (FIMA), the Royal Society of Arts (FRSA), the Higher Education Academy (FHEA), and the American Society of Mechanical Engineers (FASME). He is a Chartered Engineer (CEng), Chartered Technological Product Designer (CTPD), Chartered Scientist (CSci), and Chartered IT-Professional (CITP).

APPENDIX

TABLE A: GAP ANALYSIS

Product	Description	Available on the market	Smart packaging	Reminder system	Suitable for older adults	Portable	Updated by external sources	Automatically order refill prescriptions	Challenges
[11]	Individualised daily packets containing tablets to be taken. Packets have date and time displayed clearly on the front.	x			x	x	x	x	▪ Medication management is their responsibility ▪ Cannot relate to existing prescription ▪ Limited treatments available ▪ Only available in the UK
[35]	Individualised daily packets containing tablets to be taken. Packets have date and time displayed clearly on the front.	x			x	x	x	x	▪ Medication is delivered to the patient's door; medication management is their responsibility ▪ Only available in the USA
[36]	A smart bottle and app that record when medication is taken and provides notifications.	x	x	x	x	x		x	▪ Requires a smartphone
[12]	A portable medication storage device that offers reminders, a customised dispenser, and a heart rate monitor.		x	x	x	x			▪ Requires a smartphone ▪ In development phase ▪ The initial setup may be complex
[37]	A medicine box which announces which medication is within the given compartment.				x	x			▪ Suitable for the visually impaired ▪ Only a prototype
[38]	'Ultra' smart medicine box with alarm, reminder app, medicine record tracker, misplaced & double dose alert, family monitor, pillbox finder and Bluetooth smart.	x	x	x	x	x			▪ Very technologically advanced ▪ Requires a smartphone
[39]	Medicine box sending alerts to users via SMS and speaker to remind them to take specific medicines.		x	x					▪ Limit of 3 medicines per device ▪ Complex technology ▪ Only a prototype
[14]	Medication intake monitoring from anywhere and using IoT linked appliances within the home into the network.		x	x	x		x		▪ Requires a large infrastructure ▪ Only theoretical
[15]	A network within the home linking specific medical devices rather than everyday appliances.		x	x	x		x	x	▪ Requires a large infrastructure ▪ Only theoretical
[16]	iMedBox, registers all medications within it, download reminders directly from prescriptions and send alerts when to take medication, record any non-compliance and update medical professionals in case of an emergency.		x	x	x		x		▪ Only a prototype
[13]	An application that sends alerts at specific times.	x		x		x			▪ It does not state dosages ▪ Requires a smartphone
[40]	Applications that send alerts at specific times. Alerts state what dose to take and when and allow you to connect with caregivers, who can be notified automatically if you do not take a dose.	x		x		x			▪ Requires a smartphone
[41]	Amazon's cloud-based voice service can be set up with audio reminders	x	x	x	x				▪ Requires stable internet connection

Table B: Interview Questions

Question Type	Question
User Identification Questions	1. What is your age?
	2. What is your gender?
	3. What is your literacy level, technology literacy level and experience with technologies?
	4. What is your educational level and intellectual abilities?
	5. What are your language skills?
	6. What is your experience with computers and mobile phones?
	7. What are your motor and perceptual abilities?
	8. Frequency of use
	9. Freedom of choice in system use
	10. Direct vs indirect use
Attitude and Behavior Questions	11. Please describe how do you manage your medication? Any dispensers or mobile apps? What are the challenges you are facing?
	12. How often do you take medication per day?
	13. What are the advantages and disadvantages/challenges of your medication management at home?
	14. On average, how long do you typically spend managing your medications per day? How and why?
	15. Do you use a medication dispenser (i.e. Spencer)? If yes, what's your device? How often do u use it?
	16. What's motivates you to use medication dispenser and why?
"Think Aloud" Questions	17. What is their first impression about selected devices?
	18. What behaviours would the users repeat?
	19. What part of the products would they interact with? Struggle with?
	20. What would be the technical and environmental constraints such as lighting, seating, distractions, temperature, pressures, other people? The object of the interaction; the design of the package and product.
User Experience Questions	21. How did you like selected medicine adherence devices? Range your answer from strongly dislike to strongly like.
	22. Please describe what would be your main concern when using medication dispensers?
	23. Please describe what would motivate you to use dispensers?
	24. What do you like the best about these machines? What would work for you?
	25. What would be the most confusing, annoying and challenging about these machines?
	26. Please describe what would you most want to change about them?
	27. Which (other) kinds of information/features would you like to be in there?
	28. Do you usually read the packaging instruction before the use of device? If yes/no, is it helpful/unhelpful? Why?
	29. Do you consider that the medication dispenser A/B/C/D would help you manage medications?
	30. Do you consider that the medication dispenser A/B/C/D would affect your ability to do things for yourself?
	31. Do you consider it is easy to use the medication dispenser? If so, which one A/B/C/D?
	32. Do you consider that the medication dispenser A/B/C/D would affect your ability to get around or leave the house?
	33. Do you consider that the medication dispenser A/B/C/D would affect your ability to talk with or get a hold of your nurse?
	34. Do you consider that the medication dispenser A/B/C/D would interfere with other activities?
	35. Do you consider that the medication dispenser A/B/C/D would help you with your medication management? If so, how?
	36. Would you like to use the medication dispenser A/B/C/D in the future?