Automation acceptance for sustainable digital daily life

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Abstract – Digitalisation facilitated by algorithms and automation holds significant potential for reducing energy consumption, enhancing efficiencies and fostering sustainable energy systems. While various daily life activities have seamlessly integrated automation, such as bill payments and streaming recommended entertainment, those with substantial energy impacts, like home energy management, face challenges in gaining end-user acceptance. This empirical research addresses the gap of understanding factors influencing automation acceptance in different daily life activities and the possible impacts on acceptance this may have for other activities. Utilising a mixed methods experimental research design within a UK household living lab, we conducted two one-month trials, automating the planning and execution of distinct daily activities (grocery shopping and floor cleaning). Our findings reveal three key insights: 1) acceptance of automation varies across different phases of an activity, with planning aspects predominantly overridden and controlled by users; 2) when expectations, especially concerning the automation's usefulness during activity execution, were exceeded, participants reported strong positive feedback mechanisms; 3) automation acceptance occurred more frequently for the execution of mundane tasks involving household management. Whilst it is the automation of 'planning' which enables nudging of activity execution towards lower carbon outcomes, our findings highlight the challenges faced for increasing acceptance and adoption of such automation.

Index terms – technology acceptance; consumer behaviour; energy demand; digitalisation; low carbon technologies

I. Introduction

Digitalisation is a transformative force, yet we face multiple urgent environmental and societal challenges that can be helped or hindered by digitalisation [1]. Automation enabled by algorithms and AI has undergone significant advancements in technical developments, enabling the machine execution of functions or operations previously carried out by humans. Automation is exponentially penetrating certain activities of daily life, such as information acquisition and streaming entertainment. Whilst other activities, like automated energy demand-side management which offer enhanced co-ordination, flexibility, and efficiencies, struggle to gain trust and acceptance from end-users [2], [3].

Automated daily life activities have varying impacts on energy and carbon resources, and some activity domains are more saliently digital to end-users. Research is often blinkered, studying automation acceptance of high energy consuming activities and overlook the experience of other automation and how this may impact acceptance more broadly [4]. Our research aims to improve understanding of the factors which influence people's attitudes and acceptance of activity automation across different activities of daily life.

Our study advances the field of automation research, empirically evaluating the underlying characteristics of automation which lead to acceptance by drawing upon two conceptual frameworks not yet combined in this field. We use Bieser and Hilty's framework which was developed to systematically assess the impact of information and communication technology (ICT) on indivdual time and energy use [5]. The use of ICT to automate daily life activities has the potential to impact time and energy use e.g., saving the individual time by delegating the activity to technology. The framework categorises activities as distinct phases: activity planning (e.g., scheduling, planning horizon, duration and frequency) and activity execution (e.g., activity manner, duration and fragmentation) [5]. For households to participate in smart energy networks, the automation characteristic required involves the automation of the planning phase e.g., when energy is used, for how long and how often. Using Bieser and Hilty's categorisation of activity planning and activity execution [5], we investigate whether automation acceptance is likely to occur for certain phases of an activity e.g., planning, but not for all.

The second framework we use is Ghazizadeh, et al.'s extension of the seminal Technology Acceptance Model (TAM) [6], developed to provide a comprehensive evaluation of automation and user's acceptance - aptly named the Automation Acceptance Model (AAM) [7]. TAM posits that perceived usefulness and ease of use are pivotal factors influencing attitudes towards technology, subsequently shaping behavioral intentions to use and accept it. Building on this, Ghazizadeh, et al.'s AAM introduces the notion that the compatibility of technology with the task at hand, as well as, trust in the predictability and performance of automated activities influence other constructs and, ultimately, acceptance [7]. AAM also captures external variables which may impact acceptance, as well as feedback mechanisms - the impact of automation experience on acceptance and use, as a users relationship with a technology is said to progress through various phases of discovery during actual system use and exposure to it's abilities and outcomes [8]. Fig. 1 shows the key constructs of AAM and how the model builds upon TAM. It also illustrates the direction of influence the constructs have on each other, ultimately leading to acceptance and actual uasge of a technology. Fig.1 also visually demonstrates our exploration of feedback mechanisms and the categorisation of activities into planning and execution phases when applied to the acceptance model.

Since the development of AAM, literature based on the model has been predominantly theoretical (e.g., [9]) or has

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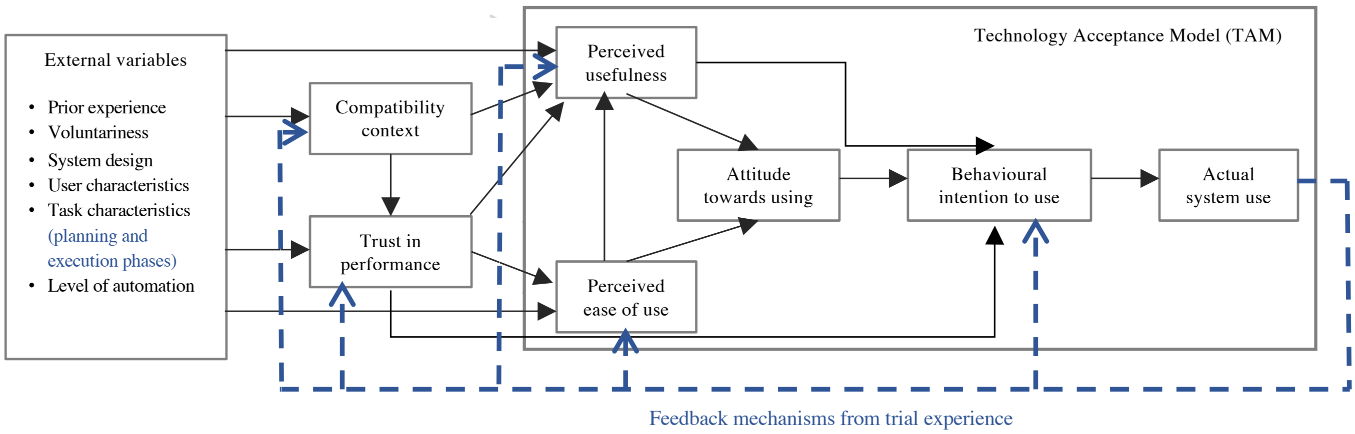

Fig. 1. Theoretical framework – the Automation Acceptance Model (AAM) with feedback mechanisms (adapted from Ghazizadeh et al., 2012) and the categorisation of activities into planning and execution phases.

tested the model's constructs through large quantitative surveys (e.g., [10]). Empirical investigations have been missing to investigate the importance of it's constructs. We address this gap and build upon the AAM framework, qualitatively investigating the acceptance factors of technologies providing automation in daily life and focus on experiences, more than perceptions, to better understand actual usage and intention to use [11]. We do this through two experimental trials.

II. Objectives and Organisation

The aim of this paper is to improve understanding of the factors which influence people's attitudes and acceptance of automation across different activities and domains of daily life. The novelty and unique contributions of our study are fourfold: 1) collecting and analysing empirical mixed methods data using AAM to investigate the key factors influencing automation acceptance; 2) considering the automation of different phases of an activity and their acceptance; 3) a focus on automation of daily life activities which are under researched through the lens of sustainable energy systems i.e., grocery shopping and floor cleaning; and 4) assessing feedback mechanisms of technology acceptance through two distinct trials.

Our overarching research question is: **What determines household acceptance of activity automation?** We investigate whether 1) acceptance occurs and 2) whether it is more likely to occur: with particular influencing factors; or at specific phases of activities.

The following section outlines the methodological approach for our experimental research trials. Section IV highlights the key findings on the circumstances under which automation acceptance is more likely to occur. The discussion section (Section V) draws together results from both trials and discusses the implications our results have for improving our understanding of autmation acceptance more broadly in the context of sustainable daily life. We identify the current methodological challenges and future research needs, concluding in Section VI with key insights aiming to advance sustainable and user-friendly automation solutions in the context of home automation for sustainable energy systems.

III. Method and Data

A. *Experimental research design*

Reviewing the literature which categorises daily life activities into specific domains (from across multiple fields [12], [13], [14] and national surveys [15], [16], [17]), Table 1 presents an overarching and harmonised categorisation of 13 domains of daily life recognising the varying impacts of activities on energy. We use these domains to consider automation opportunities across a wide spectrum of activities.

To examine acceptance, we chose two activities to automate which fall outside the highest energy demand domains (the bottom categories in Table 1 such as travel and managing home heating and cooling), but which share common characteristics with many activities, i.e., impact the whole household, performed by all households and have innovations on the market offering automation at both the planning and execution phases of the activity. The experimental research design involved households trialling an innovation for one month between July and October 2023, automating either the activity of: 1) home floor cleaning (provided through the use of a smart robotic floor cleaner which vacuums and mops); or 2) grocery shopping to obtain ingredients for the daily main meal (provided through a subscription meal kit delivery service).

A sub-sample of 10 households per innovation (detailed in Table 2) was drawn from a broader living lab infrastructure based in and around Oxford, UK. These households are committed to trialling, learning, interacting, and sharing data with researchers on the impacts of digital daily life from their own homes, whilst living in real-world conditions. We surveyed all living lab households to gauge interest and determine eligibility for participating in the trials. Selection criteria included no prior experience of the specific trial innovation, aimed at minimising the influence of past experiences on attitudes and behaviours. Our selection process aimed to capture diverse contexts that could impact automation acceptance, considering factors such as household composition, prior automation experience, and activity levels (see Table 2).

Households were interviewed pre-trial to elicit three sets of data. The first being their current use and acceptance of automation in their daily life for 24 different individual and household level activities across 13 domains (listed in the

TABLE 1. SUMMARY OF DAILY LIFE ACTIVITY DOMAINS ORDERED FROM LOW TO HIGH POTENTIAL ENERGY IMPACTS WITH ACTIVITY EXAMPLES.

Energy impacts	**Daily life activity domain**	**Activity examples**
Low	*Communication, socialising*	*Emailing / instant messaging*[a]
	Information search, provision	*Writing blogs*[a]
	Entertainment, media	*Listening to music/ podcasts* *Watching a film/ TV episode*
	Health, fitness	*Health & fitness monitoring*
	Education, study, learning	*Language learning*
	Work (paid)	*Team meeting*[a]
	Managing home - non-energy intensive (hygiene, childcare, finances)	*Surface cleaning* *Childcare* *Petcare* *Waste disposal* *Banking and bills* *Financial planning*
	Retail - other	*Shopping (non-food items)*
	Retail - food & drink	***Grocery shopping (incl. meal planning)*** [b]
	Managing home - lighting, devices, appliances (exc. food-related)	*Laundry* ***Floor cleaning***[b] *Gardening* *Ironing & folding* *Charging devices* *Home security* *Home lighting*
	Managing home - cooking, dishwashing, other food-related	*Food prep and baking* *Dishwashing*
	Managing home - heating, cooling, hot water, + own energy (e.g., PV, storage)	*Climate control*
High	*Travel*	*Vehicle driving*

[a]Activity not included in data collection.
[b]Trial innovations.

'activity examples' column of Table 1). As different levels of automation (LoA) exist, we drew upon Vagia et al.'s literature review of LoA [18] and Diamond et al.'s more recent categorisation of LoA [2] to develop a taxonomy with wide applicability for activities across domains. For each activity, we collected information on the participant's current LoA and then their willingness and acceptance to automate. Table 3 lists and explains the different LoA used.

The second set of data from the household pre-trial interviews obtained information on the reasons behind automation acceptance of all the different activities and the third set of data was their attitudes and expectations of the innovation they were about to trial (using 5-point Likert scale questions based on the AAM constructs e.g., 'how easy to use do you think it will be?' 1, not at all to 5, very). The AAM construct 'compatibility context' is measured through three variables to cover different aspects of compatibility – compatible to daily life, personalisable and convenient. The construct 'trust in performance' was measured by asking 'how reliable to you think it will be?'. After the interview, households began their one month trial.

During the trial, households were asked to complete weekly tasks to capture their experience (e.g., film their first impressions, note their reflections on the automation outcome). Post-trial, participants completed an online survey with discrete choice and open-ended questions to collect data on whether the trial innovation had met their expectations (e.g., 'how easy to use was it?' - less than, more than or as expected); whether positive feedback mechanisms occurred (reinforcing attitudes and acceptance for the specific activity e.g., 'would you be willing to automate meal planning and grocery shopping for all meals in the week (breakfast, lunch, dinner, snacks)?'); and whether acceptance increased or decreased for activities in the same domain or across domains (e.g., 'as a result of your experience during the trial, are there any of the following [24 activities] that you would be willing to automate more?' 'Which one(s) and why?').

B. *Mixed methods data analysis*

A large amount of data in different formats was collected pre, during and post-trial e.g., interview transcripts, participants' photos, videos, and instant messages, and discrete choice and open-ended online survey responses. Data regarding participants use of the trial innovations was categorised by activity phase (planning and execution) and activity aspect (the various steps involved in a given activity) to understand the level of automation adopted during the trial. Next, households were grouped by their self-reported overall experience – positive or negative - as this was expected to greatly influence feedback mechanisms for and acceptance of

TABLE 2. SUMMARY OF THE PARTICIPATING LIVING LAB HOUSEHOLDS IN THE TWO AUTOMATION TRIALS.

Activity automation trial	**ID**	**Household composition (f=female, m=male, age)**	**Prior automation experience**[a]	**Prior activity intensity**[b]
Floor cleaning – Smart robotic floor cleaner	101	Couple (f,m 30s) one toddler	Medium	High
	103	Couple (f,m 40s) two children <12	Low	High
	106	Couple (f,m 50s) empty nesters	High	Medium
	112	Couple (f,m 30s)	Medium	Low
	119	Couple (f,m 40s) one teenager	Medium	High
	132	Couple (f,m 60s)	Low	High
	136	Couple (f,m 40s) two children <12	High	Medium
	142	Couple (f,m 30s)	High	Medium
	143	Single (f, 50s) empty nester	Low	Low
	144	Single (f, 40s) one child <12, one teenager	Low	Low
Grocery shopping - Meal kit delivery	107	Couple (f,m 40s) two children (<12)	High	Medium
	110	Single (f, 30s)	Low	Low
	115	Couple (f,m 40s) one child <12, two teenagers	High	High
	121	Couple (f,m 30s) one toddler	High	Medium
	122	Single (f, 40s) two children <12	Medium	High
	123	Single (m, 70s)	Low	Medium
	125	Couple (f,f 20s)	Low	Medium
	130	Couple (f,m 20s)	Medium	Low
	139	Couple (f,m 50s) three teenagers	Medium	High
	147	Single (f, 70s)	Low	Low

[a] Household's adoption of automation across domains: low (none); medium (1-2 domains e.g., entertainment - smart speaker and home management devices – smart doorbell; high (>2 domains).
[b]Pre-trial activity duration (mins/week). Floor cleaning: low (<40); medium (40-60); high (>60). Grocery shopping – low (<85); medium (85-123); high (>123).

TABLE 3. LEVELS OF AUTOMATION TAXONOMY.

Level of automation	Description	Explanation
L1	Manual	No ICT automation
L2	Recommends	ICT offers decision, user decides and executes
L3	Schedule	User decides planning, ICT executes
L4	Autonomous with approval	ICT decides and executes with user's approval
L5	Autonomous with override	ICT decides, executes but user can override if desired

automation for other activities. Trial expectations were compared with reported experience through visual interpretation of graphs depicting Likert scale responses. Qualitative responses on experience were coded using the AAM constructs in NVivo v14 to identify influencing factors for feedback mechanisms. Responses from the online survey regarding the activities for which acceptance increased post trial and why, were categorised by activity domain and coded using the AAM constructs to understand the reasons.

IV. RESULTS

A. Automation usage during trials

The two activities investigated during the research trials (floor cleaning and grocery shopping) were broken down into multiple different aspects which fall under either the planning or execution phase of the activity. Table 4 lists the different activity aspects which form part of the overall process of performing the activity e.g., being aware of dust/dirt and deciding when to clean categorised as 'floor cleaning planning', and retrieving brush/vacuum from storage and using in the desired area categorised as 'floor cleaning execution'. We compare the manner in which the household conducted the different activity aspects pre-trial (i.e., L1 manually with no input from ICT automation illustrated with a human figure in the second column of Table 4) to 1) the available LoA provided through the trial innovations, and 2) the household's actual usage of automation during the trial (third and fourth columns of Table 4).

Comparing the 'pre-trial' column with the other two columns, Table 4 illustrates how automation provided through innovations can simplify an activity, reducing the number of aspects in the process, e.g., removing the need to travel to the store for grocery shopping, or combining aspects through the use of algorithms. For example, once the aspect 'create meal plan' is complete (with or without the end-user overriding meal choices), algorithms at the service providers end can 'check expiry dates', 'select ingredients' and remove the need for 'making a shopping list'. These examples are illustrated using a computer icon to represent full automation in Table 4.

The activity aspect 'remove items from floor' is the only aspect that remains manual in the planning phase, even in the automated version of the activity – see 'possible use from trial innovation' column in Table 4. This requirement for the user to be actively involved in the planning phase constrained usage of automation. All 10 households trialling robotic floor cleaners reported the need to prepare the floor beforehand otherwise it would get stuck with, for example, wheels getting tangled in shoelaces or as one participant put *"it eats rugs and even curtains if I don't clear the floor before it starts"* [112_1]. Of the 10 households, none used the scheduling function for automating the timing of 'when to clean', and only one used the zonal scheduling function on the device's app to automate 'where to clean' when the robot was active. In comparison, the manual aspect towards the end of both activities' execution (empty dust collector for floor cleaning, and unpack/store items for grocery shopping) did not hinder the performance or ability of automation.

The meal kit delivery service automates grocery shopping by selecting and preparing the necessary ingredients for

TABLE 4. THE LEVEL OF AUTOMATION FOR EACH ASPECT OF THE TWO ACTIVITIES TRIALED: 1) PRE-TRIAL; 2) POTENTIAL FROM TRIAL INNOVATION (ROBOTIC FLOOR CLEANER OR MEAL KIT DELIVERY) AND 3) ACTUAL USE DURING THE TRIAL (FINAL COLUMN, BLACK ICON INDICATES 100% OF PARTICIPANTS AND GREY ICON INDICATES 80-99% OF PARTICIPANTS).

	Level of automation (LoA)		
Activity aspects	Pre-trial	Potential from trial innovation	Actual use during trial
Floor cleaning - Planning			
Awareness of dirt/dust	manual (L1)		manual (L1)
Decide when to clean	manual (L1)	schedule (L3)	manual (L1)
Decide where to clean	manual (L1)	schedule (L3)	manual (L1) (grey)
Remove items from floor	manual (L1)	manual (L1)	manual (L1)
Floor cleaning - Execution			
Retrieve brush/vacuum from storage	manual (L1)	autonomous (L5)	autonomous (L5)
Use brush or vacuum in desired area	manual (L1)	autonomous (L5)	autonomous (L5)
Follow a pattern (avoid missing areas)	manual (L1)	autonomous (L5)	autonomous (L5)
Empty dust collector	manual (L1)	manual (L1)	manual (L1)
Return brush/vacuum to storage	manual (L1)	autonomous (L5)	autonomous (L5)
Grocery shopping - Planning			
Assess dietary needs	manual (L1)	schedule (L3)	manual (L1)
Create meal plan	manual (L1) [a]	autonomous (L5)	manual (L1) (grey)
Make a shopping list	manual (L1) [b]	autonomous (L5)	autonomous (L5)
Decide when to get ingredients	manual (L1)	schedule (L3)	schedule (L3)
Decide where to go shopping	manual (L1)		
Grocery shopping - Execution			
Travel to the store	manual (L1)		
Compare products/prices	manual (L1)	autonomous (L5)	manual (L1) (grey)
Check expiry dates in store	manual (L1)	autonomous (L5)	autonomous (L5)
Select ingredients	manual (L1)	autonomous (L5)	manual (L1) (grey)
Review cart before checkout	manual (L1)	autonomous (L5)	manual (L1) (grey)
Go through checkout	manual (L1)	schedule (L3)	schedule (L3)
Pack ingredients	manual (L1)	autonomous (L5)	autonomous (L5)
Transport ingredients	manual (L1)	autonomous (L5)	autonomous (L5)
Unpack/store items	manual (L1)	manual (L1)	manual (L1)

LoA Key: manual (L1), schedule (L3), autonomous (L5)

[a] optional and either done beforehand or in-store and based or not on inventory check and considerations of leftovers.

[b] written down or mental note.

specific meals, chosen automatically by the service platform's algorithms or by the user intervening. Households which exhibited overriding behaviours during the trial, personalised their meal plans by manually conducting 'compare products/price', 'select ingredients' and 'review cart before checkout' during the planning phase in order to meet personal preferences. The dominant aspects of the activity's execution were still automated even if meal planning was overridden.

Despite the trial innovations ability to automate at higher levels of automation for many activity aspects (e.g., automate with approval or override), Table 4 highlights the LoA that households actually used during the trials. It is clear that during the trials, participants generally chose to: 1) keep control of the 'planning' aspects of an activity, doing what was possible manually and 2) cede control and use automation features for the 'execution' aspects.

B. *Automation experience vs. expectations*

Using post-trial survey responses, we grouped participants by the trial they participated in and their self-reported overall experience – positive or negative. We found that all 15 members of the 10 households trialling the automation of floor cleaning had a positive experience. Eight participants trialling the automation of grocery shopping also had a positive experience, and six had a negative experience. We use these three sub-sample groups throughout the remainder of our results to draw comparative insights on automation acceptance. It is important to highlight here that attitudes of overall experience may be influenced by prior expectations [19]. We therefore also compared participant pre-trial expectations across the three sub samples to detect any differences.

The mean scores of a 5 point-Likert scale for pre-trial expectations and post-trial experiences relating to AAM constructs are shown with icons in Fig. 2a and 2b, respectively, for each of the three participant sub samples. The colouring of the icons represents the sub-sample's experience (blue for positive, orange for negative) and the shape of the icon represents the trial they participated in (broom for floor cleaning automation and cutlery for grocery shopping automation).

Overall, pre-trial expectations were predominantly positive across all three sub-samples (represented by the three different icons being to the right in Fig. 2a). The robotic floor cleaner received the most optimism for convenience, followed by perceived usefulness. Participants expected the other attributes of the floor cleaner to be generally 'somewhat' e.g., somewhat easy to use. Expectations of the meal kit delivery service were similar across the two sub-samples of participants with regards to how easy to use, compatible to daily life, convenient and frustrating it would be. However, differences for the other attributes are apparent. Those who ended up having a negative experience, had slightly higher expectations for usefulness, and personaliability, while those who had a positive experience had higher expectations for its reliability and level of enjoyment.

Assessing participants' experiences during the trials, Fig. 2b reveals wide variation between the three sub-samples as to which attributes exceeded or failed to meet expectations.

Experience of the robotic floor cleaner exceeded expectations in many respects, with the innovation being more useful than expected for all but one participant (who already had high expectations that it would be 'very' useful). Reliability is the one attribute that was 'as expected', and from pre-trial data (Fig. 2a) we can see that participants expected it to be roughly 'somewhat' reliable.

Experience of the meal kit delivery service differs in terms of meeting expectations for the trial's two participant sub-samples. However, experience of its usefulness was loosely 'as expected', and leaning towards being 'more' easy to use than expected for both sub-samples, suggesting these two attributes were not associated with the overall experience being positive or negative. Other factors appear to be linked more to the overall experience of meal kits, with compatibility, convenience, personalisability and enjoyment not meeting expectations for those who had a negative experience.

A key issue, reported by the participants who had a negative experience, was that the automation of grocery shopping caused changes to their households' regular habits, routines and preferred ways of preparing meals (another activity linked to the outcome of grocery shopping). All six

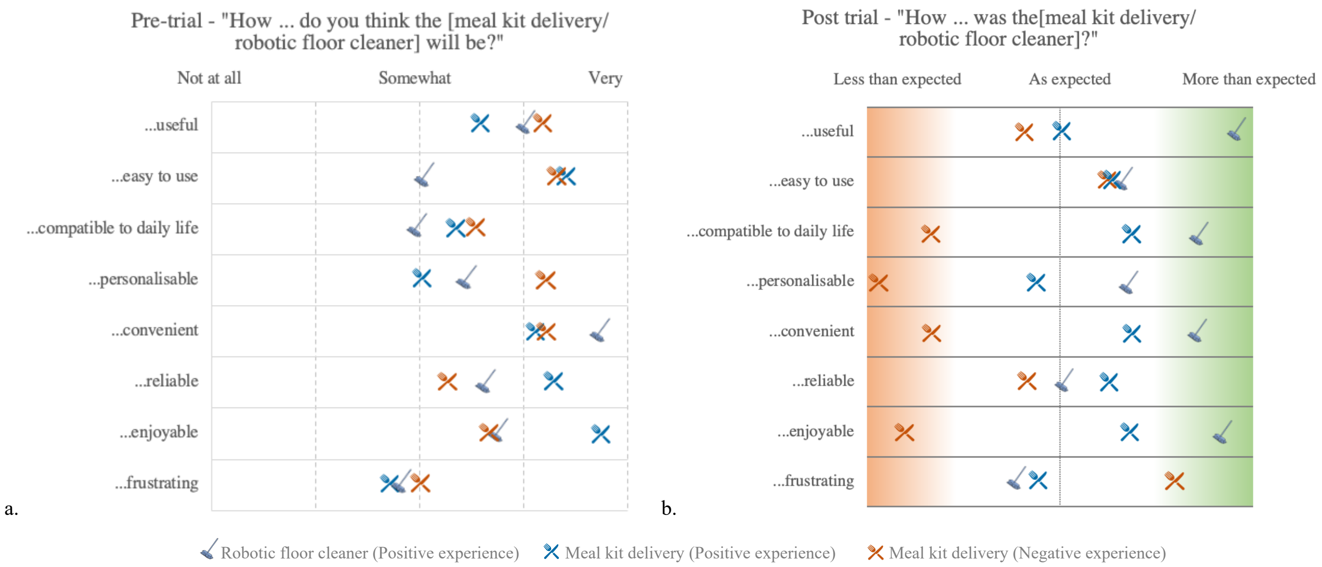

Fig.2. Participant responses to the discrete choice questions on a) their expectations pre-trial and b) their experience post-trial. Three participant categories are shown based on the trial they participated in and their overall experience.

participants did not like that the meal kits pre-determined the planning phase for meal preparation, removing the decision-making process from them.

C. Feedback mechanisms of automation acceptance

AAM hypothesises attitudes influence intentions and actual use, and that innovation use or experience, influences feedback mechanisms which reinforce the factors influencing attitudes. Through our post trial survey, we examined whether participants who had a positive or negative experience reported different constructs as reasons for their level of acceptance when asked about future usage of the automated activity i.e., willingness to automate floor cleaning and then all types of cleaning, or automate grocery shopping for main meal and then for all meals.

All 10 households involved in the robotic floor cleaner trial reported at the end that they are willing and intend to buy one for themselves. This is the contrary for the 10 households who experienced meal kit deliveries, none of whom wanted to continue their subscription, even those who had a positive experience. When asked about the wider variant of the automated activity (all types of cleaning or grocery shopping for all meals), there was acceptance for a higher LoA (L4 - autonomous with approval) amongst participants who had a positive experience across both trials. In comparison, the meal kit participants who had a negative experience mainly reported acceptance of no automation and a preference for doing the activity manually (L1 – manual).

We assessed qualitative data from the post trial survey using AAM as a framework to understand participants' rationale for accepting various LoA. "Autonomous with approval" was the LoA selected by participants in the floor cleaning trial. They expressed a need to retain the possibility to control activity execution, especially for cleaning tasks beyond floor cleaning. Open-ended responses shed a light on why households hesitated to fully delegate cleaning tasks to automation. Common concerns included frequent instances of the robotic cleaner getting stuck. During the trial nearly all households preferred to be present at home to manually initiate activity execution after preparing the floor area, highlighting their reluctance to relinquish control entirely to automation. The device's scheduling feature lacked compatibility for those with flexible or last minute changing routines. With this being the dominant reason for wanting to maintain some control at the planning phase through approval.

Usefulness and compatibility were the most frequently cited factors for reasons of acceptance of higher automation levels for those who had a positive experience with grocery shopping automation. The meal kit delivery service was reported to be useful for reducing mental load for those accepting of 'automation with approval' but this usefulness wouldn't apply to other meals. As one participant stated *"the main advantage for me was the reduction in mental load and the main mental load relates to the evening meal so I would not really see an advantage in automating other meals"* [115_1].

Participants who had a positive experience overall but selected 'manual' or 'only recommendations', found the meal kits not to be compatible for their households' tastes thus leading to the need for controlling the planning phase to ensure compatibility – *"our family has such different preferences that a one size fits all approach wouldn't work for every meal"* [139_3]. Such participants suggested additional features which would improve the service's personalisability and compatibility with their preferences e.g., recipe options that don't use the oven or batch cook to save energy and time, greater flexibility for dietary preferences e.g., dairy free or vegan, which also promotes environmental food choices. One participant suggested it would help to have the ability to rate your meals so the algorithms select them for you in the future, and then confessed they were not aware that this option was already available from the meal kits.

Compatibility and trust in performance, or lack of, were the dominant reasons participants who had a negative experience opted for 'manual' when it came to all grocery shopping. One participant's response sums this clearly – *"We had to change almost every one of the options chosen for us each week. It continually selected the same fairly generic and relatively bland (unexciting, uninteresting) meals which appeared simpler and likely cheaper in ingredients than others offered. I would not trust it [meal kit service] to automate any choice-making for us"* [125_1].

D. Automation acceptance for additional activities

Looking beyond the trials' impacts on automation acceptance for the specific trial activity and additional variants of the activity, we next present findings on acceptance for other activities. Our results are drawn predominantly from the qualitative insights provided via the post-trial survey and during trial tasks. However, to visualise the changes in acceptance for other activities, Table 5 presents a heatmap of each sub-samples' acceptance of automation across activities and daily life domains post trial, taking into consideration pre-trial acceptance which was collected during the pre-trial interviews. Table 5 displays only the 19 activities (of the initial 24) which were found to be applicable to all participants.

From Table 5, it is possible to see that positive experience of grocery shopping automation resulted in an increase in automation acceptance for non-grocery shopping, and that the robotic floor cleaner had the biggest influence on acceptance of other household chores, namely dish washing and waste disposal.

Content analysis of the qualitative responses in the post-trial survey revealed that when experience positively exceeded expectations for either trial innovations, participants were more likely to report positive intentions to automate more generally post-trial. "*I was surprised by the ease and reliability of the [robotic floor cleaner]. This has made me consider automating more."* [101_1]. One participant with low prior automation experience remarked that after their experience of the meal kit delivery *"I am now more open to automated experiences as I have had a much more positive experience with this than I was expecting"* [122_1]. Another participant from the robotic floor cleaner trial stated*"Now I believe anything's possible! After the trial I am now more than happy to automate anything that doesn't bring me joy!"* [106_1]. This particular participant, along with three other women, reported the floor cleaning trial had been a life changing experience.

Participants had positive intentions for automating other specific activities based on trusting the reliability and usefulness of their trial experience, "*we currently have a cleaner but she is unreliable. It was so useful having a reliable, frequent clean from the [robotic floor cleaner] and I was so impressed by it, I have looked into buying an automated lawn mower"* [101_1].

TABLE 5. POST-TRIAL AUTOMATION ACCEPTANCE, WEIGHTED TO TAKE INTO ACCOUNT DIFFERENT SUB-SAMPLE SIZES AND PRE-TRIAL ACCEPTANCE. DARKER COLOURS SIGNIFIES HIGHER LEVELS OF AUTOMATION ACCEPTANCE POST TRIAL.

Activity domain	Activity	Robotic floor cleaner (positive)	Meal kit delivery (positive)	Meal kit delivery (negative)
Entertainment, media	Listening to music/ podcasts			
	Watching a film/ TV episode			
Managing home - non-energy intensive	Waste disposal			
	Surface cleaning			
Retail - other	Shopping			
Retail - food & drink	**Grocery shopping**			
Managing home - lighting, devices, appliances (exc. food-related)	**Floor cleaning**			
	Laundry			
	Ironing and folding			
	Gardening			
	Charging devices			
	Home security			
	Home lighting			
Managing home - cooking, dishwashing, other food-related	Meal planning			
	Food prep and baking			
	Dish washing			
Managing home – heating, cooling, etc.	Climate control			
Travel	Vehicle driving			
	Travel booking			

The perceived usefulness of time saving from the activity automation was a main driver of acceptance across both trials' participants. First-hand experience of saving time resulted in particular participants remarking *"I now have more respect for the time saving…of automation*" [130_1], *"I now feel more open and willing to try automation, if it saves time and energy"* [122_1] and *"automation to me is a positive thing - and is making life progressively easier, improving quality of life and (often) freeing up time for more meaningful activities"* [106_2]. An increase in automation acceptance for the execution of home management activities was the dominant type cited by participants taking part in the floor cleaning trial, if it was perceived to free up time.

Participants provided examples of how they could now imagine the usefulness of automation for other activities whereas prior to the trial they could not. *"It has been a really interesting glimpse of the future"* [106_1]. One example explained by a participant included being able to imagine what automated waste disposal would look like, with the bin detecting when it is full and going outside in advance of rubbish collection days, even being *"..linked to the council's calendar to take account of Bank Holidays*" [106_2]. Another example based from the experience of being able to check on the robotic floor cleaner's app, the progress of the activity's execution, raised awareness of the benefits of such system design, spilling over into acceptance of other technologies offering the same attribute, "*I do the [clothes] washing on my work at home days and it [automation technology's app] would help me by being able to check on my phone the time remaining for the wash …planning breaks for when the cycle finishes to hang it up*" [101_1].

It is clear from responses that for positive attitudes and increased acceptance to transfer to other activities, automation must be reliable, and *"actually intelligent"* [106_2], adjusting to the users preferences or enabling the user to personalise it manually. 115_2 stated they would be happy to automate any task if "*automation is fully tailored… reliable and adaptable to my needs"*.

Analysing the qualitative responses reveals a lack of emphasis on accepting the automation of activity planning. There was also little mention for the desire to automate climate control or other high energy demand activities. The heat map in Table 5 shows participants did state they were more accepting of automation for climate control post trial, but did not specify in the open-ended responses specifically why. Only one participant wrote a short note *"climate control move to does with approval - save energy/money"* [130_2].

E. No change or a negative change in automation acceptance

Across all participants, no matter their trial experience, if manually planning or executing an activity either brings pleasure, a sense of satisfaction, helps create an empathy with surroundings or enables personal creativity then no change to their acceptance of automation would occurr and participants never wanted to automate it beyond receiving recommendations. Participants listed different activities that fall under this category but the most common were gardening, cooking and travel booking.

In a similar manner to positive experience and expectations being exceeded being associated with an increase in automation acceptance, a negative experience and disappointment were associated with a reduction in automation acceptance post-trial. For one household [125], the experience of *"algorithms making bad meal choices"* led them to be untrusting of service providers of automation more generally. 125_1 stated that for any automation offered through paid services *"we would be concerned around what data it [automation service] would be basing its decision-making process on, and what 'motives' are its primary focus in its software design…As a profit-generating company, we would not trust it to operate in a way that isn't cutting corners and changing our experience under the guise of automation"*.

Such perceptions and negativity highlights the important issue of a lack of trust that needs to be overcome if we want to increase acceptance of automation.

V. Discussion

Our results provide insights into the factors influencing household acceptance of daily life activity automation, with implications for the broader impact on sustainable energy systems.

A. User Preference for controlling activity planning

The trials revealed a notable preference among participants to retain control over the planning phase of activities, valuing the ability to customise and adapt automation according to their needs and schedules. Previous research has also found the need to provide opportunities for user interference in the automation process [3]. As it is the automation of 'planning' which enables nudging of activity execution towards lower carbon outcomes, our findings highlight the challenges faced for increasing acceptance and adoption of such automation. This preference for autonomy at the planning phase suggests that successful automation solutions need to strike a balance between streamlining execution processes and preserving user agency. Designing systems that offer customisable levels of automation, allowing users to maintain control where desired, could enhance acceptance and satisfaction.

We found a perceived lack of personalisability of activity automation to contribute to negative experiences during trials. Although it was possible for our research participants to personalise either trial innovation, post-survey responses highlighted many were not aware of such options or felt that the options were not appropriate, thus suggesting additional features for improvement. Such findings highlight the importance for service providers to raise awareness of personalisable offerings and develop further capabilities to enable greater compatibility.

B. Addressing expectation-reality gaps

Differences between participants' pre-trial expectations and post-trial experiences emphasise the importance of managing user expectations effectively. While participants generally held positive expectations regarding many attributes of the automation technology, their actual experiences varied. Ensuring transparent communication about the capabilities and limitations of automation technologies would help align user expectations with reality, mitigating potential disappointment and fostering acceptance.

C. Building trust through reliability

Trust emerged as a critical factor influencing acceptance of automation. Positive experiences with reliable and dependable automation during the trials contributed to increased trust among participants. Conversely, instances of malfunction or inaccuracy eroded trust and diminished enthusiasm for automation. Ensuring the reliability and consistency of automation solutions is essential for building trust and increasing automation acceptance.

D. Acceptance Spillover

The two experimental trials automated activities which have the potential to contribute only small energy reductions. However, through the lens of spillover research, our results can be interpreted for a broader set of domestic activities for which automation could have higher impacts on energy.

Spillover refers to the within-person transferal of psychological states and behaviour from one daily life domain to another [20]. The concept of spillovers has previously been investigated for different behaviours and contexts e.g., pro-environmental behaviour spillover from work to home life [21], from one environmental behaviour to another [22], [20], and acceptance of one innovation to another [23], (see [24] for a comprehensive review). Users' attitudes, either positive or negative, towards one innovation (or its characteristics) are said to influence attitudes towards other innovations with perceived similarities [25], [26], [27] - the perceived usefulness of the robotic floor cleaner translating into the perceived usefulness of a robotic lawnmower is one example from our results. This suggests that common characteristics of existing innovations may be extended to the users' perceptions toward new innovations. The exploration of how tendencies formed through existing interactions and how they can influence attitudes towards other forms of automation is becoming increasingly essential.

One of the key findings from this study is that the feedback mechanisms of a positive experience of one form of automation is not only instrumental for reinforcing positive attitudes and intentions for such automation but also for greater acceptance of other activities to occur. This may seem obvious at first but by evaluating what in particular made a positive experience helps reveal the important conditions and characteristics for spillover.

The main facilitator of spillover was found to be perceived usefulness of the automation being trialled and whether the other form of automation was perceived to provide such benefits. Automation acceptance increased the most for the execution of mundane tasks involving household management and not at all for activities that bring enjoyment. It was the aspect of saving time from activity execution being automated which was perceived to be most useful and desirable amongst participants. Results that participants would not want to automate activities which bring them enjoyment or a sense of pleasure is encouraging for our interest in low carbon outcomes as no participants stated that high energy demand activities such as, controlling home heating brought such joy.

E. Limitations and further research

A methodological challenge we faced when analysing our data was the lack of insights from participants on high energy demand activities. By taking a broad approach and studying many daily life domains, participants were not siloed or steered to provide perceptions on such activities. Further explicit research is needed to explore the specific reasons for acceptance of high energy demand activities.

The characteristics of our household sample raises interesting questions about the user and their acceptance. Previous research on demand response automation for efficient energy systems often involves highly engaged early adopters, providing only a limited viewpoint on the matter [28]. We included households with a range of prior automation experience and acceptance across different activities and domains, and therefore provide wider insights and perspectives. We also collected qualitative insights pre-trial to detect change in perceptions. Further analysis of our results is needed to evaluate the importance of user characteristics and the impact of such prior experience to help gain greater understanding behind the causal mechanisms of when acceptance is more likely to occur.

This research also discovered that robotic floor cleaners could potentially be a catalyst technology, providing clear benefits to the individual and acting as a gateway to greater acceptance of automation across other activities having had such a 'life changing' impact on several of our research participants. The smart devices appear to have advanced in capabilities since first appearing on the market [29], having addressed many of the original teething problems. However, further research is needed to assess the indirect impacts such technology and activity automation has on energy demand as there is a risk that adoption behaviours lead to greater energy consumption through rebound and induction effects [30].

VI. CONCLUSION

Using a mixed methods experimental research design with a living lab of diverse households in the UK, this research empiricially investigated the influencing factors for automation acceptance by comparatively assessing two trials of automated daily life activities. Our results focus on the impact of automation experience through feedback mechanisms and the potential increase in acceptance across activity domains that have greater consequences for sustainable energy consumption.

We identify the drivers of automation acceptance that hold across daily life activities and contexts, informing macro-level understanding, policies and intervention strategies for harnessing digitalisation and to support less energy-intensive forms of consumer behaviour.

Our empirical investigation into automation acceptance hopefully encourages the discussion and development of research on the uptake of smart sustainable activity automation with the ultimate goal of informing the common social need of ensuring smart digital daily life helps and not hinders efforts for sustainability. The findings are valuable for informing the design of smart devices, home automation systems, as well as the development of strategies for energy network automation, identifying potential gateway innovations for wider automation acceptance.

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