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‘Making the dust fly’: (A case study of) design research promoting health and sustainability in addressing household infections

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Abstract: Global health crises, such as antimicrobial resistance, threaten planetary health, as they have a direct impact on the environment, as well as to humans and animals. Personal and environmental hygiene form the best and most natural ways of reducing home infections and hence the need to take antibiotics. Despite this, our understanding of cleaning in the home and interventions on home cleaning are limited. In this paper we present a project, which combined design research with environmental microbiology, to address this issue and to co-design sustainable cleaning interventions for human and planetary health in Ghana. We focus on the design of a co-design workshop, which led to the development of cleaning interventions tested for a month by several households. We share the challenges faced and the lessons learnt, which we envisage will help guide design researchers moving into this exciting research field of planetary and human health.

Keywords: co-design; planetary health; global health; design for behaviour change.

1. Introduction

This paper explores the challenges and opportunities created by taking a design-led approach to address a global health crisis.

Antimicrobial resistance (AMR) is a complex global challenge driven by diverse factors cutting across disciplines. It impacts both human and animal health, as well as agriculture and the environment (Thakur & Gray, 2019). As bacteria build their resistance to antibiotics minor cuts and infections may become life-threatening (Matsunaga & Hayakawa, 2018). Antibiotic resistance is present in every country.

To begin to address this problem a collaboration between UK-based researchers and Ghana-based researchers developed the Dust Bunny project in response to a UK funding call. The

Dust Bunny project's specific aim was to develop an understanding of the home as a source of infection from AMR bacteria carried by dust by exploring hygiene practices across different home environments in Ghana. The project had the ultimate goal of reducing bacterial infection in the home environment in order to reduce AMR. In adopting these aims, the Dust Bunny project's aspirations were aligned to Sustainable Development Goal 3, target 3d (United Nations, 2016), and its desire to strengthen the capacity of a developing country in making risk reduction interventions in response to a global health issue. The academic disciplines of the core research team included: design, microbiology and cultural epidemiology.

Following a brief overview of the related literature, we present the project methodology and more specifically the co-design workshop format. Then we offer an analysis of the main findings, followed by a discussion on the key challenges and opportunities for taking a design-led approach to address a global health crisis.

2. Background and related work

2.1 Link between AMR and the environment

Beyond human health, antimicrobials are also essential for animal health, welfare and productivity, in turn contributing to global food security and safety (O'Neil, 2016; Bennani et al, 2020). Population growth is driving global demand for poultry, meat and egg production; this unfortunately creates conditions in which animal diseases can spread to humans ('Zoonoses') and can also accelerate AMR (Age et al, 2018).

Overuse and misuse of antibiotics in animals is a factor in promoting AMR in humans. Exposure to AMR driven by practices such as the use of antibiotics in agriculture, leads human exposure to AMR (Van Boeckel et al, 2017; Bengtsson & Greko, 2014) with serious consequences for both animal and human health and welfare (Woolhouse et al, 2015). When subject to an antimicrobial treatment, humans, plants and animals do not fully break them down. As such, their residues can pass through the body and enter the food chain or the environment, compromising both food safety and the environment (Singer et al, 2016; Pearson & Chandler, 2019). Antimicrobial residues are often too weak to destroy microbes but may stress them enough to cause resistance to develop, thus leading to AMR. Poor hygiene, animal husbandry, water quality and sanitation can all increase the spread of AMR (Curtis et al, 2011; Thakur & Gray (2019).

2.2 Link between cleaning and environment

Evidence collectively suggests that personal and environmental hygiene reduces the spread of infection (Aiello and Larson, 2002) and remains the most important cornerstone in the control of infectious disease in the home (Bloomfield et al, 2016; Curtis et al., 2011). The environment is closely linked to the lifestyles we adopt and our cleaning practices (Robertson-Wilson & Giles-Corti, 2016) playing a significant role in terms of microbial

exposure and infection (viral/bacterial) transmission (Kembel et al, 2012; Prussin & Marr, 2015).

Our modern lifestyle has left people confused about the nature of real threats in our environment, as they no longer have an indicator the hygiene levels expected in their environment (Terpstra, 2003). This has, on one hand, created perceptions of an over-zealous approach to cleanliness, despite evidence from research into infectious disease transmission indicating that no particular health gain is achieved from these over-zealous hygiene activities (Bloomfield et al, 2016); but perhaps, instead, hinder normal development of the immune system (Weber et al., 2015; Bloomfield et al, 2016). On the other hand, perceptions of we might be 'too clean' could have a detrimental impact on the public's perception of infectious disease risks in the home and of the importance of controlling such risks (Bloomfield, 2006). All these changes have led to a more superficial approach to home cleaning, with speed and aesthetic factors more important than hygiene and disease prevention at a deeper level (Bloomfield, 2006; Prüss-Üstün et al, 2016).

2.3 Generating insights and interventions through design research

Globally AMR constitutes a health crisis, particularly in developing countries, where infectious disease commonly leads to fatalities (Feigin et al., 2014). While Ghana is committed to the global action plan to reduce AMR, there has been little research into further understanding the domestic phenomena (Bloomfield et al., 2006). This is in part due to the difficulties of conducting detailed studies in home environments (Curtis et al., 2003) due to the moral nature of hygiene and cleaning. Guidance to tackle bacterial pathogens that are specific to different home environments and which are also appropriate for people from diverse educational and cultural backgrounds does not exist.

To combat its negative consequences new transdisciplinary approaches are needed. The complex picture of maintaining population wellbeing and health prevention has begun to emerge, and thus the role of designers indirectly in supporting the promotion of healthy lifestyle or in their contribution to illbeing. Works in this space (Chamberlain et al, 2015; Tsekleves & Cooper, 2017; Nusem, 2018) have demonstrated the propensity of design to contribute significantly in health and wellbeing. Design research has been previously employed in developing a better understanding of AMR in the Indoor and Built Environment (MacDuff et al, 2020). Several design-led projects ranging from designing ambient communications to improve hygiene in primary school toilets (Rutter et al, 2020), to changing the perception of infection risk within veterinary surgical practice (McDonald et al, 2020), to the design of persuasive community pharmacy spaces (Walker et al, 2020), to visually mapping and raising awareness of pathogens in hospitals (Backhaus et al, 2019), operating theatre design to excise infection in the surgical environment (Short et al, 2017), to exploring how housing design affects the indoor microbiome and thus AMR (Sharpe et al, 2020).

It is within the context of this emerging design research field that we present this study, which is outlined in the next section.

3. Methodology

3.1 Brief overview of methodology

The *Dust Bunny* project combined design and microbiology methods in an innovative mixed-method approach; a traditional survey design, a design ethnography, a co-design workshop and a microbiological analysis were planned to provide insights for codesign workshops in which new cleaning practices might be developed to minimise any AMR bacteria present in the home environments in the Greater Accra Region of Ghana.

As the paper focus is on the co-design of cleaning interventions (informed by the aforementioned methods) we will offer a brief overview of these and focus on the co-design workshop design.

A cross-sectional retrospective survey design was selected to provide a general description of current practices and perceptions of cleanliness and hygiene in relation to household dust and household environments (n=240). Next, a design ethnography (Millen, 2000) approach was developed (design ethnography observation and participant observation sessions) and carried out in volunteer households (n=12) to give researchers a closer understanding of the cleaning practices and the perceptions of cleanliness and hygiene, in relation to dust, of householders and the people who regularly clean homes as part of, and for, those households.

To examine the domestic microbiome and its AMR carrying capacity, household dust samples were taken from the same volunteer households (n=12) for analysis. From each sample, bacterial colonies were isolated and tested on a number of antibiotics (Sulfamethoxazole, Tetracycline, Chloramphenicol, Ampicillin and Kanamycin). Bacteria from each sample, that showed resistance to one or more antibiotics were retained, and of these 125 were identified to species level and then classified as an obligate pathogen (always causes disease), an opportunist pathogen (can cause disease when the host is compromised) and a non-pathogen (no history of causing disease).

Post-intervention, a second set of 12 dust samples from the same homes, that were either been subjected to an intervention or act as a control by not being subjected to an intervention, were collected. The samples were analysed at a DNA sequence level to reveal the microbial diversity and any differences that occurred as a result of the intervention.

3.2 Co-design workshop

The process, findings and insights were anonymised and visualised to provide the material for co-designing cleaning practices, that were effective, easy to communicate and specific to the communities in question. Specifically, four scenarios were generated from an economic segmentation of the survey data, 50 ethnographic insights were ‘presented’ and descriptions

of 12 bacteria, that represented the 125 identified species found in the dust samples, were presented to the participants in a co-design workshop.

The co-design (Sanders et al., 2008) workshop (n=7) took place at the local partner's facility in, Accra, Ghana, with UK design researchers planning and directing the facilitation and two researchers from local partner supporting the delivery of the workshop. The workshop was intended to assist participants in drawing together the various strands of the investigation, in order that they might synthesise the findings while co-creating context-specific cleaning practices that could mitigate the impacts of AMR. The contexts, four economically segmented scenarios, were developed from the survey data, and identified different types of dwelling; a single-room compound house, a double-room compound house, a five-room apartment and a ten-room semi-detached house.

To allow participants to actively explore the problem space and advance cleaning techniques in a representative setting we set out to create a doll's house toolkit (Sanders et al., 2012, pp. 73–74) using 1:1 scale floorplans for each scenario to create four sites. To enable this, a large venue at local partner was requested for two days to prepare and run the workshop.

The sites were partially developed from the scenarios however, additional insights were required to clarify the floorplans and the internal layouts of furniture and fittings, which were to be represented in the workshop by cardboard boxes. This posed a challenge, as it was not possible to provide a house layout, due to the lack of uniformity and the wide variations from one person to another even in similar house types. So, to mitigate this, the floorplan layouts were modified on-the-fly, during set-up, with the help of local knowledge. They advised the team as to the plans and scale of their own single room within a compound house and of a multi-room compound house. These smaller sites were presented roughly at a 1:1 scale. The two larger sites were slightly reduced in scale and limited to four rooms each to fit within the available space.

To understand the internal layouts of furniture and fittings we had to vary our plans and incorporate a new activity into the workshop. Ten cardboard boxes were set up in each room and participants were asked at the outset of the workshop to decide what furniture and fittings would be present in each room. Participants wrote the item's name on the box and placed it appropriately in the space. Once complete the exercise provided the starting point for the codesign activities, however it took participants a significant amount of time to complete, affecting the available time for planned activities. It became necessary to jettison several activities to ensure we had a chance of meeting the main aim of the workshop – to create a cleaning agreement of 'new' cleaning practices that they would follow in their own homes for thirty days, prior to the last round of dust collection from the homes for microbiological analysis (see figure 1).

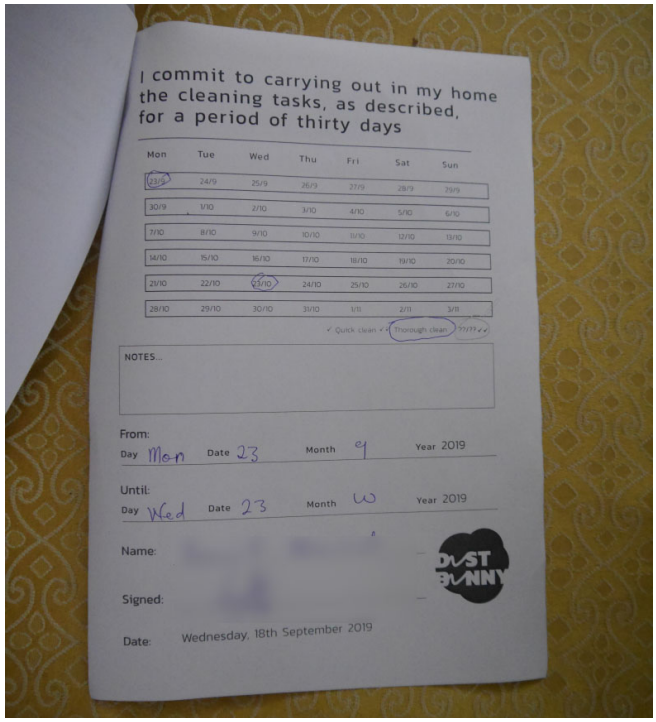

Figure 1. Cleaning agreement developed from the co-created cleaning practices

Participants were first asked to identify cleaning issues, which they did, while familiarising themselves with the scenario sites. Then they were to validate the internal layouts of the furniture and fittings in each site, making any changes necessary to better represent similar households in Accra, before clarifying the cleaning issues in the newly established layout. However, only the first step in the activity plan was made, meaning the participants opportunity to consolidate a shared understanding and validate the problem space was removed. Later in the workshop, and again due to time constraints, participants were unable to engage with the full design ethnography findings with diminishing the opportunity for participants to synthesise the broad range of findings. However, by the end of the day participants had co-created a number of cleaning practices (see Figure 2), reviewed them and selected appropriate ones to incorporate into their own cleaning regime and individual cleaning agreements.

Figure 2. Co-design activity in co-creating cleaning practices

Throughout the workshop participants were given a variety of tools. The first one was intended to help them clearly identify cleaning issues. It was a single-sided printed circle, on which they had to identify their group: pink, blue or green, the area the issue related to, and describe the cleaning issue.

An intervention, a new regime of cleaning practices agreed through the codesign workshop and practiced for thirty days, was made in (n=7) households and another round of microbiological sampling (n=12) and analysis conducted to ascertain any impact on the domestic microbiome. A post-intervention interview was also conducted by going back to the households who participated in the co-design workshop. This coincided with the second round of microbiological sampling.

4. Findings

Here we present the key findings from the workshop post-intervention interviews, regarding the co-design workshop and the tools used, the intervention developed and their impact on the cleaning practices of participants.

4.1 Workshop

Respondents shared their views on their level of involvement and the design tools employed during the co-design workshop.

Level of participant involvement in the co-design workshop

Generally, participants engaged with each activity well and interacted with the workshop tools and facilitators. Some were of the view that it should have been conducted in the local language to enhance understanding and participation. This is due to some of the participants facing challenges in understanding British English as they are more familiar with the Ghanaian English accent and idioms. These positions were aptly captured in the narratives below:

> "… that some of the participants did not understand the tools being used at the beginning until it was explained to them in the local language." (Male, Middle income community)

> "I listened attentively but the Whiteman's English was too fast for me, so I didn't really hear all what he said […] The Ghanaian English was clearer, the explanation and translation that was done in English and local language was very helpful." (Female, Lower middle income/working class community)

It is clear from the above that Language can pose a barrier in successful workshop facilitation. This is the case even when English is the official language, spoken at a national level. Especially, since transporting an activity across national and linguistic borders means more than translating items accurately from one language to another (Cheema et al., 2018). In hindsight, it would have been more effective for local facilitators taking a more central role in communicating and 'translating' the workshop activities to participants.

Tools used to facilitate the workshop

The tools used for the workshop were considered useful and suitable, however, some did not see the need for the large carton boxes that were used to represent various items in the rooms. The post-workshop interviews revealed that participants preferred that household items and furniture were marked on the floor without the use of the boxes. It was also suggested that a real home should be used for the workshop to facilitate a more realistic cleaning experience.

> "I did not see the need for the boxes that were used to represent items in the room. I think we could have just marked them on the floor without the boxes. The boxes were similar, so using them to represent different items in the various home spaces were not easy to followed. I however love the smaller boxes with the names of bacteria on them." (Male, Middle income community)

Figure 4. Participants engaging with workshop tools. Large carton boxes representing furniture and small boxes representing bacteria

Here lies an interesting tool design tension between the research team's design decision (and assumptions), and the workshop participants experience of the simulated households. The research team's intention was to provide different simulated experiences of the four distinct types of households included in the study. Using an actual house for this may have influenced participants responses and actions, due to the moral nature of cleaning and commenting on someone else's home cleanliness. Clearly, though, another tool should have been employed to represent the household items, such as actual furniture to increase realism.

Nevertheless, some of the participants did see the value of the simulated household using the large boxes, as the following quote demonstrates. In particular, it helped workshop participants to a) develop a better understanding where bacteria were found across the house furniture and b) the impact of having a cluttered with items house in relation to cleaning.

> "The boxes used to construct various houses was also good. It helped us to understand how to clean our homes properly to avoid dust. The boxes helped us to create the picture of our houses in our mind with each box representing an item in the room. It made me realised at once that my room is choked and difficult to clean. Through the workshop we learned how to create space in our rooms." (Female, Lower middle income/working class community)

In contrast to the different views on the larger boxes, all participants engaged well with the smaller boxes that have the names of the various bacteria found in homes written on them (see Figure 3). As the following quote exemplifies, they found that these helped develop their understanding of bacteria found in the home. This also provided the research team

with a useful way to demonstrate the microbiological study findings in a visual and situated way to the home environment.

> "I really liked the boxes with the names of the bacteria written on them […] the boxes represent the test results from dust collected from our homes." (female, Lower middle income/working class community).

> "The tools were good and has improved my understating about cleaning better." (male, High income community)

Although the tools enhanced participant understanding of household cleaning, participants did not always follow the facilitator instructions on the tool use. For instance, in the case of the Hotspot tool (see Figure5) and despite the explanation and explicit direction, participants routinely used only the blank reverse side to write on. This practice continued with other tools used later in the workshop with participants reticent to write on any finished print. This revealed a very interesting cultural dimension about the use of polished materials where writing is required. It is now clear that finished material may pose a challenge when asking local participants to interact with them in ways that amends the polished look and feel of the material. We expect that this may be the case in other sub-Saharan countries with similar cultural characteristics.

Figure 5. Hotspot tool: its finished look stopping participants from writing on it.

4.2 Intervention

Here we present participant views, experiences and compliance with the cleaning contract developed (intervention) as a direct outcome of the workshop activities.

Participants views of the cleaning contract

Participants were of the view that the cleaning contract was complex and not easy to comprehend. They were emphatic that the contract should have been simplified for easy reading.

> "The cleaning contract was complex and not easy to understand […] we are not scientist, so everything should be simplified to make it easy to read and understand so that we can follow it appropriately" (Male, Middle income community).

Some maintained that the contract was very confusing to them, while others said they were helped by the explanations provided along the line.

> "The contract was not easy to understand, though I could follow it. The manual used for the workshop was easily accessible and was explained to us as we go along and this also helped". (Male, High income community).

What becomes very clear is that whatever the intervention one is designing it should maintain a balance between the formal appearance it wants to portray, as in the case of the cleaning contract, but also simplify the language to accommodate that the target audience.

Participants experiences and description of the thirty-day cleaning contract

Respondents described their participation in the 30-day cleaning contract that they signed with the project in varied ways. They generally described it as worthwhile and a period of learning and reflection. The most important element though was evidence of behaviour change. The workshop and the cleaning contract following this, enabled participants to re-evaluate their current cleaning practices and make significant changes, as seen from the quotes below.

> "At first, I used to sweep without raising items like chairs to sweep under them but after the workshop it was put in my contract to raise stuffs and clean under them to remove dust […] Within these 30 days, my cleaning has been different, it has been more and it has been a very worthwhile experience" (Female, Lower middle income/working class community).

> "During the thirty days cleaning contract period, I purchased a new mop towels and disinfectant, which I used for mopping the floor for a better result. My cleaning during this time was more intensive as I dusted every item in my rooms. I also used different tools in cleaning the toilets, the rooms and the kitchen" (Male, Middle income community).

Although, not intended to do so, the process of asking each participant to complete the cleaning contract for their own household revealed cleaning practice nuances, which were missed or not collected during the design ethnography. For example, looking at the quotes above and below, one can see that past cleaning practices were not always thorough, did not make use of detergents, were not done consistently and reused as much as possible the same cleaning tools for all rooms. Furthermore, it is interesting to see that the findings presented during the workshop (i.e. bacteria found underneath furniture during the

microbiological dust sampling) influenced new cleaning behaviours as participants took these on board in the development of their new cleaning interventions, outlined in the cleaning contracts.

> "My 30 days cleaning exercise was great, compared to my normal cleaning practices., where I clean only in the morning, after the workshop, I now clean twice in a day. […] I now combine detergents like bine or Parazone and washing powder for the cleaning "(Male, High income community).

> "Over the last thirty days, I have been cleaning my room every day. Before, I could go for five days without cleaning, thinking I am alone and therefore, there is no need to clean the rooms every day because it's not dirty" (Female, Low income/poor community).

Compliance with the cleaning contract

In terms of compliance with the cleaning contract, participants overall followed their contract 'religiously', though in most cases they had to do things differently. For some, they just wanted to see if cleaning according to what was written in the contract would make their homes neater.

> "I used to do the cleaning weekly but because of the contract I did it daily for 29 days, missing only one day out of the contract period of 30 days, I really wanted to see if there will be any change in my rooms, and I can say that there was, the rooms look cleaner than before" (Female, lower middle income/working class community).

For others it was because they learnt from the workshop that there are bacteria in their homes, so they wanted to do whatever possible to reduce or eliminate these.

> "I did what I said I will do, that is cleaning on a daily basis because there is lot of dust in my area and I now know from the workshop that the dust carries bacteria into our homes, some of which can cause infections. I also added disinfectant to the water I used for cleaning floors and other surfaces in my home" (Male, Middle income community).

> "I did all what I said I would do in the contract […] I am sure that the dust from room will record low bacteria" (Male, High income community).

Moreover, the post-intervention interviews provided more details on the amount of work and level of commitment required by workshop participants during the 30-day cleaning contract period. As one can see from the quote below, adopting the new cleaning practices, following the findings presented at the workshop, was time consuming. Nevertheless, as participants could see the impact of their effort and understood the why (bacteria present at home that can cause disease) before the what (i.e. lifting furniture, using different cleaning tools for different rooms, etc.) it changed the way they cleaned (the how) and enhanced their resolve in continuing with the new cleaning practices post-intervention.

> "It requires commitment to do it because at first, I only sweep under my bed up to where I can see or reach but now (during the contract period) I have to push my bed when cleaning and then push it back to its normal position after cleaning. […] lift up

> things on the floor when cleaning to clean under them […] it was time consuming but the end result is good. I managed to clean according to the contract, twice everyday but I couldn't complete all the 30 days, I did it for 28 days because I have to be out of the home for a few days. […] I have resolved to continue practicing what I have signed to do even after the project". (Female, Lower middle income/working class community).

4.3 Cleaning Practices

We sought to find out from participants, who took part in the observational study and participated in the co-design workshop, whether the personalised interventions developed influenced their cleaning practices. We discovered that they were influenced by the project in one way or the other as represented in the narratives below. More precisely, we documented new cleaning practices adopted. Most of these practices refer to a) a more structured approach to cleaning in the home; b) increasing the cleaning frequency; c) use of cleaning detergents; and d) use of different cleaning material for different surfaces and rooms.

> "The project, especially the workshop has influenced my cleaning. At first, we clean the sink before cleaning the bath but now, we clean the bath, then the sink and also wash and dry the brush before use again" (Female, High income community).
>
> "The project has influenced me […] I used to clean ones a week, now I do it twice or sometimes three times in a week… "(Female, Lower income/working class community).
>
> "I learnt so much from the project to improve on my cleaning. At first, I used only washing powder but now I use detergent to wash and clean. I now use different brash and bucket to clean the toilet area put detergent into the closet after use to protect the next user infection" (Female, Middle income community).
>
> " […] before the project, I used to mop using the same mop for all the rooms (living, sleeping, kitchen, toilet and porch) but I realized from the project that it is not a good way of cleaning" (Female, Low income/poor community).

All participants who took part in the co-design workshop would like to participate in the process all over again. However, they have made some suggestions that will help to improve the workshop, among them were that, the cleaning contract should be made simple, so that even those who did not attend the workshop could be able to work with it; the workshop should be done in a community, where actual houses will be used for practical cleaning experiments; to be done in, or translated into a local language; there should be enough time allocated to the workshop such that videos on cleaning can be shown to participants.

Participants expressed the view that they would happily recommend the workshop and the cleaning exercise to others, mainly because of the benefits they that they have derived from participation. Some of the key benefits mentioned include: offering a practical opportunity to learn and apply knowledge, help to prevent infections and sickness at home, and develop a clear understanding of the importance of cloning one's home in a structured way. Several of the workshop participants expressed their willingness to recommend the workshop to

others and become cleaning ambassadors in their communities, which indicates the perceived value of the workshops and project.

5. Discussion and conclusions

In this section we discuss some of the key lessons that emerged from the findings presented above. We envisage that these would help researchers who wish to adopt a design-led approach to address a global health crisis by engaging communities of users and develop interventions in the Global South.

5.1 Workshop design and execution

There are three main lessons to consider in relation to workshop design. First, the importance of local facilitators and the crucial role they play in in communicating and 'translating' the workshop activities to participants. As Global North researchers we found that the best method in terms of getting 'buy-in' from local workshop participants in engaging with the activities was to enable the local facilitators to run the sessions. This took the form of training prior to the workshop and sometimes 'facilitating' the local facilitators during the workshop.

Second, as discussed above tool design requires additional consideration, taking into account the local culture and practices. This is very difficult unless one has been situated in the local context for a long period. Also seeking the feedback of local researchers during the tool design phase does not always help in identifying the local cultural practices and norms these. For example, in the process of designing the workshop tool although we sought local researcher advice, the fact that finished-looking material posed an issue when asking participants to write on these was completely missed. In hindsight the best way to identify these is to pilot test the tools with a handful of participants prior to the workshop.

Third, we note that plentiful time needs to be allocated to the setting up of activities and the introduction to, and exampling of the expected use of tools; particularly if tools are to be used by participants individually. Likewise, pairing participants with researchers who can act as scribes and who are primed to draw out complex responses through conversation, would improve the depth of engagement while requiring more time. Overall, design researchers should plan for longer workshops, allocating significant time and support for participants to complete individual codesign activities, even if that means multi-day workshop programmes.

5.2 Value of design in sustainable health intervention development

Based on our findings we posit the value of design in the development of sustainable health intervention development in terms of the following: translating and contextualising data visually, knowledge sharing and knowledge activating and for behaviour change.

In terms of translating and contextualising data visually, we note that the data, especially the microbiology results, made an impact. The thought of 18 different bacteria species identified in the study and the risk each of these poses to health elicited some fear in participants. This

presented the participants with the importance to improve health through the appropriate management and control of these bacteria. The participants appreciated the need to improve cleaning in the homes and adopt practices that will reduce the bacterial loads. Participants also understood that not all bacteria are bad (for instance, a participant asked for examples of good bacteria), and antibiotics and antiseptics should be used as recommended, in order not to create more resistant strains of bacteria.

Moreover, the gathering of additional research insights through the participant involvement in the workshop, revealed an unintentional added value of design research. As discussed in the previous section, the nuanced information gathered during the workshop revealed new aspects of local cleaning practices and norms, which were then further explored during the post-intervention interviews.

We also noticed the value of design beyond knowledge sharing in activating knowledge through the user engagement in the research, especially in the co-design workshop. For example, the little boxes shared at the workshop, presenting information on bacterial strains; the risks involved with infection, control methods and their effectiveness, were particularly useful as the participants used these in the various exercises and in developing their cleaning methods/practices. The realization that most bacteria species were susceptible to either bleach or antiseptic treatment or a combination of both, informed some of the cleaning practices developed by the participants. Being able to see in practice (through the simulated carton boxes and small box bacteria tools) where bacteria were found at participants' home, enabled them to discover new knowledge and then through the cleaning agreements signed to act upon these.

In addition, and with regards to the development of health-related behaviour change interventions, we found a tension between the research team and participant expectations. For instance, the research team desired a more in-depth cleaning agreement when guiding participants to finalize the agreement. But participants were careful in choosing what they were able to do, insisting that they want to sign on to what they can do effectively. The lesson learnt here is that in designing any type of intervention aiming at behaviour change, there must be a trade-off between predetermined activities that participants will not perform effectively and allowing them to select those activities that they feel they can do more effectively.

The insights gained from co-designing sustainable cleaning interventions for human and planetary health suggest that there are still challenges to address. There are, however, several opportunities arising in combining design research with environmental microbiology, to address this issue and to co-design sustainable cleaning interventions for human and planetary health in Ghana. These include providing insights into the behavioural challenges, promoting best practices for public health implementation and improved targeting of interventions at the household level. Thus, as planetary and human health topics become of great importance for the industry and governments, new funding opportunities are being created to target these. From climate change to global health, we are facing unprecedented

challenges that require a more integrated and transdisciplinary approach to finding interventions and solutions. Future work should, therefore, focus on design researchers engaging more beyond their own discipline with researchers across the different areas of human and planetary health (i.e. health sciences, medicine, environmental engineering, circular economy, etc) in order to access funding and demonstrate in practice the value design research brings.

In conclusion, we posit that design research is capable to influence and guide new (cleaning in our case) health-related behaviours that are both acceptable by participants but also sustainable. Nevertheless, extra attention should be paid in the design of the user engagement activities and tools. We envisage that the lessons we learnt and present in this paper will help guide design researchers moving into this exciting research field.

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