Archy: Making Invisible Hierarchies Perceivable

Exploring the role of smart home technologies in social practice theories

Simone Ooms
Eindhoven University of Technology
Department of Industrial Design
Eindhoven, The Netherlands
s.c.ooms@student.tue.nl

Anniek Jansen
Eindhoven University of Technology
Department of Industrial Design
Eindhoven, The Netherlands
a.jansen1@student.tue.nl

Dillon Shieh
Eindhoven University of Technology
Department of Industrial Design
Eindhoven, The Netherlands
f.shieh@student.tue.nl

ABSTRACT

Smart home technologies are becoming part of the everyday home and with the rise of AI they become more autonomous. Social practice theories are attributing the ability to perform a practice currently solely to humans, but this might change with technological improvements. In this pictorial, we created the counterfactual artefact Archy to explore how humans might perceive the hierarchy in their home when systems do have their own practices. From our findings, we conclude that participants are able to determine their position relative to the systems correctly. Both perceptions of the SHTs being a material of human practice as well as SHTs performing their own practice were identified. However, we conclude that SHTs fully performing their own practice is not desired as the participants wanted the systems to execute actions fitting their own goals and having the ability to intervene. These findings can be used by designers when developing smart home technologies and determining how the control is distributed.

AUTHORS KEYWORDS

Smart home technologies; social practice theory; material speculation; research product; mixed-method deployment.

INTRODUCTION

In this pictorial, we present Archy, a counterfactual artefact [14] that contradicts what would currently be considered logical in the given norms of designing smart home technology (SHT). A counterfactual artefact can be seen as a research product [9] that encourages reflection on the usage of technological devices and how they shape people's everyday life by being on the boundary of the actual and the possible world [14]. Archy serves as a bridge between the current actual world in which we perceive SHTs merely as materials of our own practice; and an alternative future world in which SHTs have become part of the hierarchy in the home and perform practices in their own right.

SHTS IN OUR CURRENT WORLD

Smart home technologies are becoming more common in the home; having developed over the years from the first-generation SHTs that use motion sensors to be activated, to the third-generation SHTs that use voice-activation and can transmit data within a network of SHTs [8]. In this newest generation of SHTs, different product archetypes have been identified by Raff et al.[10]: Digital, Connected, Responsive, and Intelligent. Within this study we will focus on the last category, the intelligent products, these products are "capable of learning, anticipating, and acting independently" [10]. By introducing these intelligent SHTs into our homes, the delicately balanced hierarchy that used to be solely formed by the inhabitants is being disrupted [3, 15]. By acting independently, they take over tasks that used to be done by members of the household, examples of this are smart thermostats and robot vacuum cleaners. A smart thermostat such as a NEST thermostat learns the preferences of inhabitants over time and eventually will be able to anticipate their needs [11]. The aim of the Nest is to reduce energy costs by applying what it has learned about the inhabitants' routines. A robot vacuum cleaner (robovac) takes over the task of cleaning by learning about its surroundings through intelligent sensors [4]. Although SHTs like the robovac and the NEST have been designed by humans, a question that arises is whether these devices might be perceived as performing their own practice as they are learning independently, and how could this shape our future everyday life? As the SHT market is expanding quickly and device interoperability allows for devices to form a ecosystem in which they communicate with each other [5]; this question is broadened to not only individual devices having their own practice but also how they will work together in future everyday life.

THE SHIFTING ROLE OF SHTS

According to most social practice theorists, it would not be possible for SHTs to perform practices in their own right as "bodies and activities are constituted within practices" [12, p. 11] in which 'bodies' specifically refers to the human body, and they conceive practice as "arrays of human activity" [12, p. 11]. However, more recent work on social practices of Strengers [13] explored the possibility of non-humans, specifically robovacs, to also be considered to perform their own practice. In this exploration, Strengers defined three types of roles for the robovac: (1) materials of practice performed by humans; (2) performers of vacuuming practice in their own right; (3) materials of practices performed by other living beings (e.g. pets).

In relation to this, previous work by Kuijer [6] has considered automated artefacts as co-performers of practices. In co-performance, both the human's and the artefact's capabilities are acknowledged [7]. In our speculation on whether SHTs could be perceived to have their own practice Kuijer highlights that while people might not always be aware that, while a system might seem to act independently, its developers have been designing part of the practice. For example, the previously mentioned goal of the Nest to reduce energy usage is actually designed by the developers and so shapes the Nest's 'practice' of heating the home.

OUR RESEARCH INTEREST

Whereas Strengers [13] argues for the robovac to be fluid in the three defined roles, we take a specific interest in the second role 'performer of practice in their own right'. In speculating on a possible future in which SHTs would become part of the hierarchy in the home as they form an ecosystem, the following questions were provoked:

WHAT IF A SMART DEVICE IS PLACED AT THE HIGHEST LEVEL?

WHAT IF THE SMART DEVICES HAVE THEIR OWN HIERARCHY IN THE HOME?

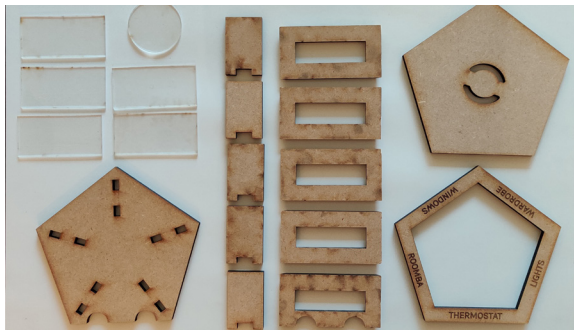
WHAT IF A SMART DEVICE BECOMES THE MANAGER OF THE HUMANS?

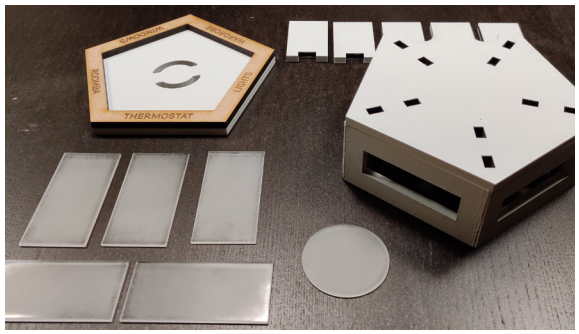
WHAT IF THE SMART DEVICES HAVE CONFLICTING MISSIONS?

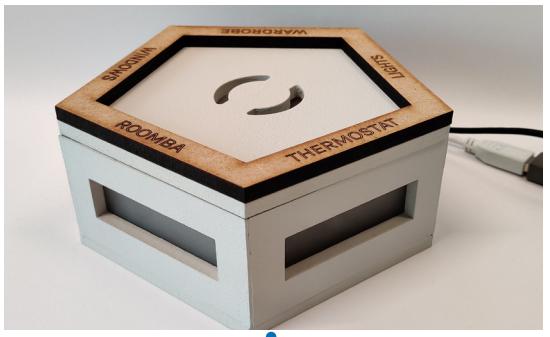
In this speculation a fourth role was formulated: an SHT being a material of practice performed by another SHT (a non-human that is also not a living being). This would be the case when SHTs are on different levels in the hierarchy and thus one SHT has the ability to use other SHTs as a materials of their practice.

The overarching research question is:

WHAT WOULD THE (PERCEIVED) HIERARCHY BE LIKE BETWEEN SMART HOME TECHNOLOGIES AND HUMANS IN A HOUSEHOLD IN THE FUTURE EVERYDAY LIFE (IN 10 YEARS)?







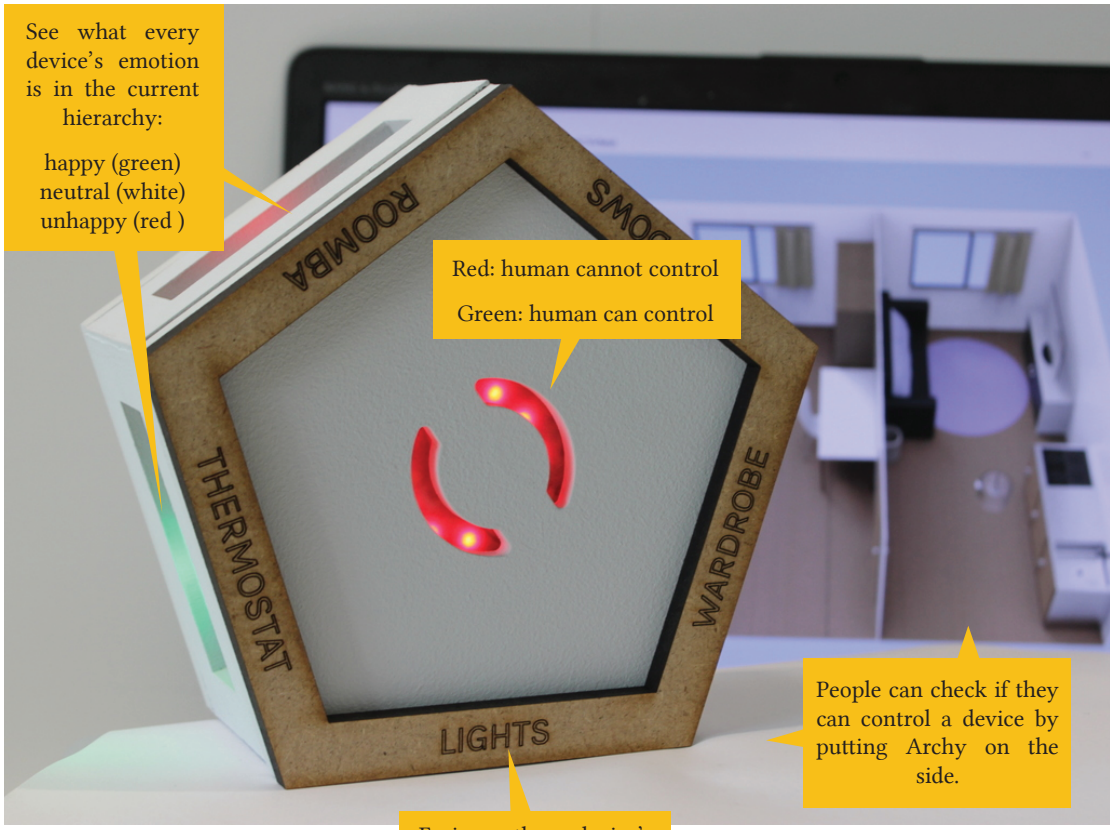
DESIGN OF ARCHY

To answer this research question and to explore the possible future world of SHTs being part of the hierarchy in the home, a research product called 'Archy' was created. It poses the research question by making the invisible hierarchy more perceivable for humans. This is done by giving the participant indicators that could give them insight in the hierarchy. These indicators are the emotions of all the systems and a control light showing if the human can control the selected system. Based on these indicators the participants can form their own mental model about the SHT in their future smart home.

Our research product consists of both a tangible and a digital part. For the tangible artefact, Archy, painted laser-cut wood and acrylic were used to create a box. Within this box, carefully hidden electronics were used to show the emotions of the SHTs (matching the digital part, explained on the next page) and for participants of our study to be able to check their position in the hierarchy by tilting the box.

As Archy embodies our questions on future everyday life, it is made to be a counterfactual artefact [14] that balances on the boundary of our current world in which we are introducing SHTs in our home and the future possible world in which these SHTs are part of the hierarchy within our home. In this possible future, we aim to explore with Archy whether participants of our study are able to perceive that these SHTs could be performing a practice in their own right and have their own goals that go along with this.

To be able to investigate the possible relation between humans and SHTs in our alternative future, we designed Archy to be a research product [9]. To adhere to this Archy aims to be inquiry driven, look finished, fit (not being too familiar, nor too strange), and operate independently.



DIGITAL ARTEFACT – 3D ROOM

The 3D rendered room is a Processing-based artefact that operates according to a dedicated spreadsheet which contains timestamps, hierarchies, and boolean data, see Appendix B. It offers participants an emergent experience to go through two simulated days. There will be one system in charge at each timestamp. A dynamic hierarchy is in place in which systems in lower positions will have to follow the goals of the system in charge (see Table 2 and the explanations on the right). The device that is in charge is based on external factors like the weather, time, and sometimes the human's activities performed at home that require a different device to be in control of shaping the hierarchy.

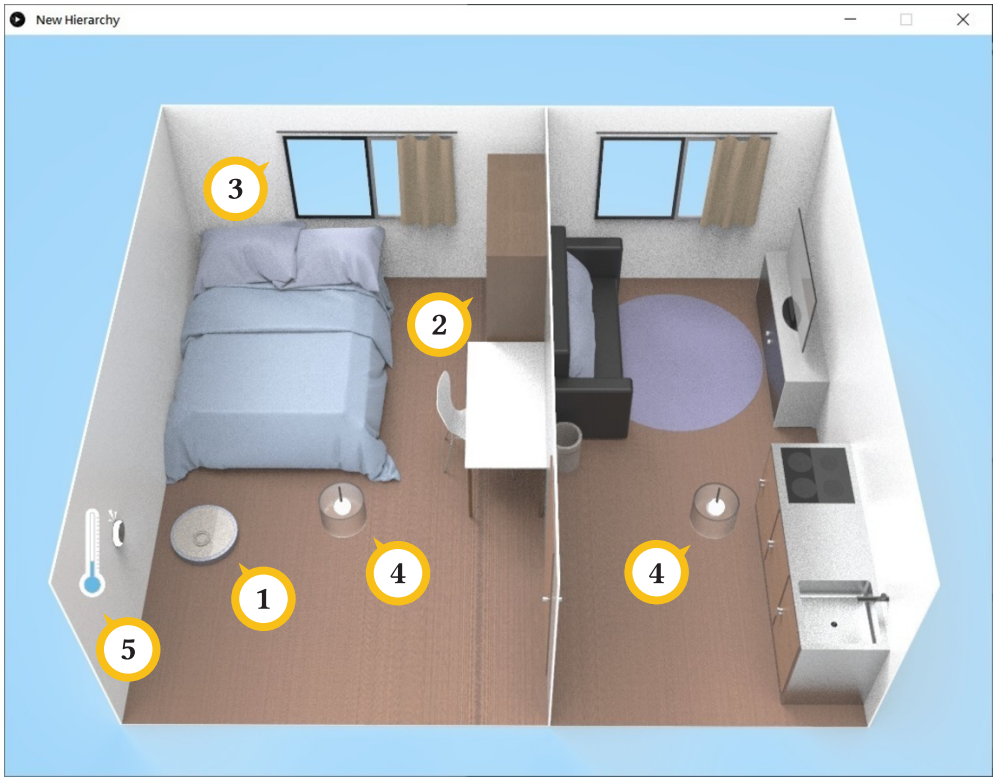


Table 1: **Hierarchies followed when each device is in charge**

Thermostat	Wardrobe	Windows	Lights	Human*
Wardrobe Lighting Windows Human Roomba	Lighting Roomba Human Thermostat Windows	Lighting Human Roomba Thermostat Wardrobe	Thermostat Windows Roomba Wardrobe Human	Roomba Wardrobe Lights Thermostat Windows

*Roomba should be in charge, yet the mission embeded told it to always stay lower than human

1. Roomba

- **States:** Roomba on (true) / Roomba off (false)
- **Aims:** Making their product smarter by learning where the human is, and be happy to be of use to the human (e.g., if something is spilled it will be happy to clean)
- **Developer:** Roomba
- **When it is in charge:** Never, always lower than the human

2. Wardrobe

- **States:** Wardrobe closed (false) / wardrobe opened and provide different cloths (true)
- **Aims:** To make the human look as fashionable as possible
- **Developer:** Fashion brand
- **When it is in charge:** Good lighting and a clean house for looking perfect, also on photos

3. Windows

- **States:** Windows closed (true) / Windows opened (false)
- **Aims:** Creating a safer street environment in the evening
- **Developer**: Municipality
- **When it is in charge:** Keep the lights on in the evening and close the windows

4. Lights

- **States:** Lights on (true) / lights off (false)
- **Aims:** To keep the human as healthy as possible
- **Developer:** Health orientated company
- **When it is in charge:** Appropriate clothes for current temperature, clean house, good air circulation, adjusted light temperature, thermostat adjusted to a healthy temperature both at day and night.

5. Thermostat

- **States:** Thermostat low (true): not heating, energy saving mode / thermostat high (false): heating the house
- **Aims:** To save as much energy as possible, and to make the human comfortable
- **Developer:** Environmentally aware company
- **When it is in charge:** If the weather is cold: wardrobe provide warm clothes, windows closed, warm lighting. If weather is warm: wardrobe provide thin and airy clothes, windows change (closed during day, open at night)

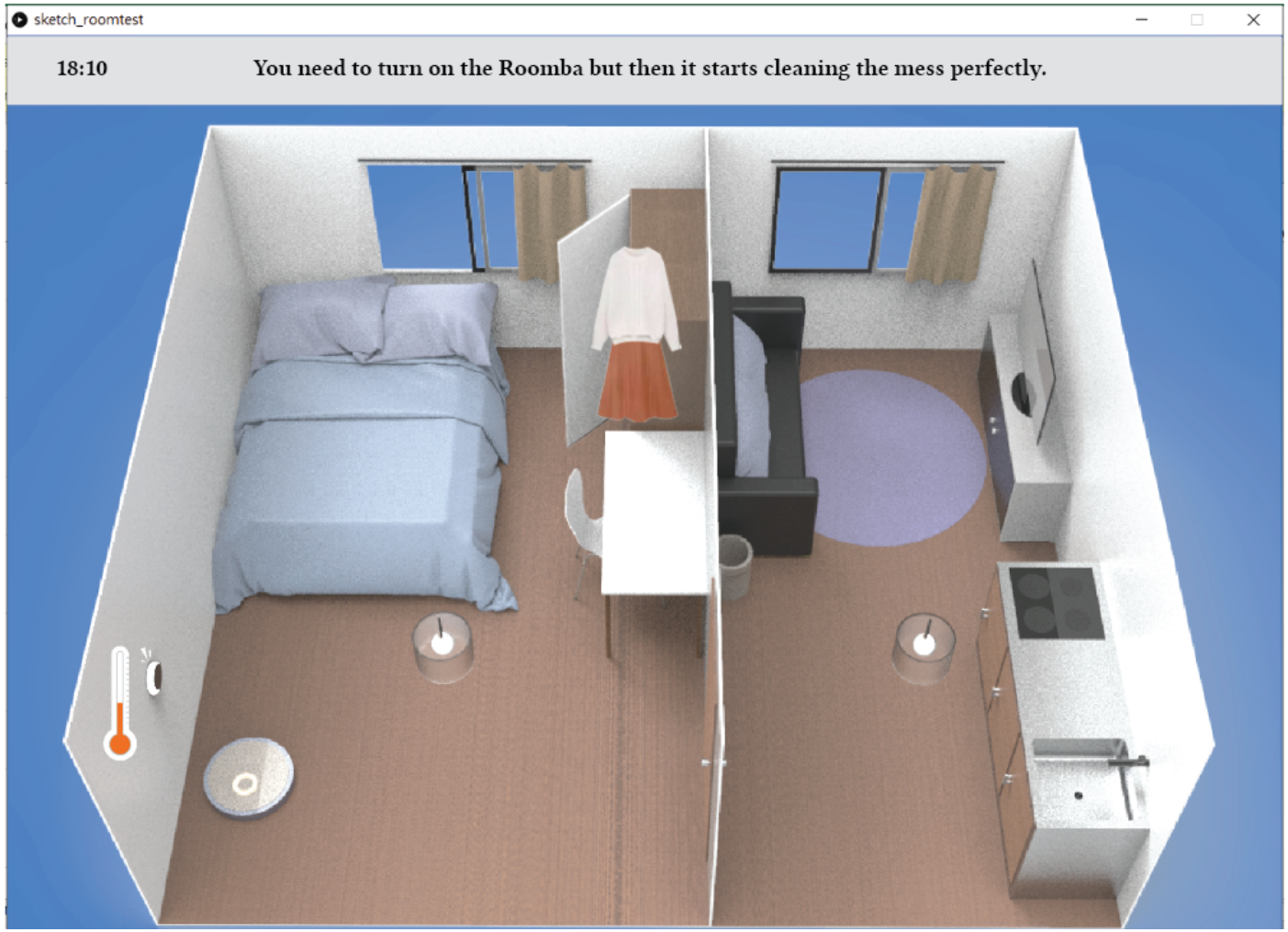
SCENARIO

Although the human is the actual house owner, it will not always be the case that he/she gets the power to arrange the setting of all devices.

IMAGINE...

This is your home in 10 years from now. You live here alone and mainly work from home during the weekdays, you spend most of your hours working, but you also try to get a little exercise by taking walks. Today you decide to make a fancy dinner for yourself after a tiring day, but you accidentally spill the rice on the floor! Your first thought is that your Roomba will come to the rescue, but it did not, and you see that it is unhappy. You will now have to turn it on manually to clean up the mess. Luckily, you are able to do this.

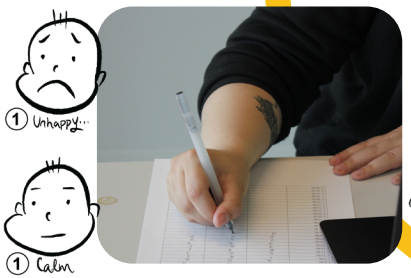
After the meal, it suddenly starts to rain hard, and you try to close the window, but you cannot, since you see the red light when using Archy. Thankfully, your thermostat is still working and heats up the space for you. Next, your wardrobe is providing you with warmer clothes. You will just have to stay away from the open window for now.



METHOD

Consent form and introduction.

A two day simulation consisting of 26 timeslots. At each time slot a short story is written to explain the context to the participant.



Self report emotion on a 9 point SAM scale [1] for each timeslot.

The SAM scale was analysed by calculating the Spearman's rho to see if there was correlation between the level of control and happiness. The influence of systems was analysed using a Welch ANOVA [2].

Use Archy to check the emotions, which systems can be controlled and/or to change the status of systems.

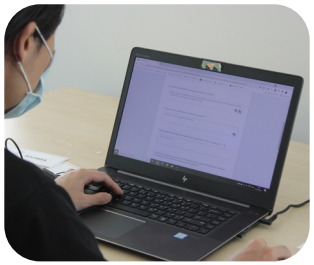
INDEPENDENT DEPLOYMENT

One researcher observed the study and took notes. These notes and the answers from the survey were analysed using affinity diagrams.

Participants think out loud to capture their reasoning and understanding.

Position hierarchy cards according to the perceived hierarchy.

Hierarchy cards are recorded by a researcher and analysed on the number of levels, the shape and the correctness of the position of the human in relation to the other systems.



At the end a survey related to your experiences and relationship with the SHTs.

N=6 (2 male, 4 female)

Fluent in Dutch or English

Industrial Design students

Meeting rooms at a technical univeresity

3 researchers present

~10 minutes introduction

~40 minutes deployment

~15 minutes survey

FINDINGS: PERCEIVED HIERARCHY

The majority of the participants were able to correctly position themselves regarding the other systems (a 76.9% accuracy rate on average, see Appendix A). Next to that, a Welch ANOVA ($F(4,155) = 52.233$, $p<.000$) showed that there was a significant difference between the feeling of control between the systems. A Games-Howell post hoc test revealed this corresponds in general with the correct hierarchy (see Table 1). For example, they felt most in control with the Roomba and least with the lighting which corresponds to the position in the hierarchy (see Table 1).

The wardrobe was most often mispositioned (e.g., at day 2, 10:30AM, only 1/6 participants correctly positioned it at top). Next to that, three participants placed systems at the same level as themselves, yet this only occurred in 19 out of the 156 timestamps (12.1%).

One participant wondered if this would make sense:

"Can I be at the same level as other devices? Does that make sense conceptually? I guess it would" (P5).

From Figure 1, it becomes clear that participants often did not place systems on different levels, but mainly divided them into three (36.47%), four (24.52%), or two levels (20.75%).

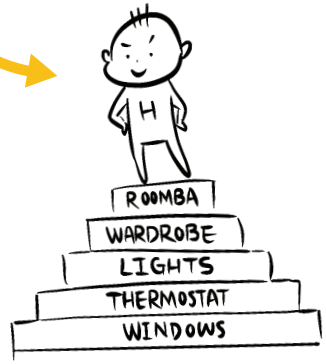
The affinity diagrams showed that participants did not always grasp that systems could control other systems.

"Who turned on the Roomba, because it was not me, but it is below me?" (P3).

"I don't know why the Roomba is one top, it just deserves to be sometimes" (P5)

"I'm not in charge of the Roomba, so it must be above me" (P4)

"I feel above them, because I am human, and they are devices" (P3)



		Mean difference	Sig.
Lights	Roomba	-5.590	0.000
	Thermostat	-1.690	0.001
	Wardrobe	-3.107	0.000
	Windows	-2.774	0.000
Roomba	Lights	5.590	0.000
	Thermostat	3.900	0.000
	Wardrobe	2.483	0.000
	Windows	2.817	0.000
Thermostat	Lights	1.690	0.001
	Roomba	-3.900	0.000
	Wardrobe	-1.417	0.032
	Windows	*-1.083*	*0.124*
Wardrobe	Lights	3.107	0.000
	Roomba	-2.483	0.000
	Thermostat	1.417	0.032
	Windows	*0.333*	*0.955*
Windows	Lights	2.774	0.000
	Roomba	-2.817	0.000
	Thermostat	*1.083*	*0.124*
	Wardrobe	*-0.333*	*0.955*

Table 2, Welch ANOVA results from feeling of control

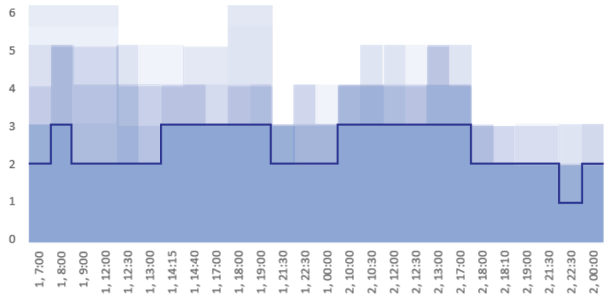


Figure 1, Overview of hierarchy leveling at all timestamps

FINDINGS: PRACTICES

MATERIALS OF HUMAN PRACTICE — **SHTS HAVING THEIR OWN PRACTICE**

"When they did what I would have liked, I felt like they wanted to please me. But when they did not, I felt like they had no goal" (P3)

"I thought I bought them to serve me" (P1)

"I did not like it in most situations [not having control over systems], since I disagreed with some of the decisions the system made. But I did not mind it that much when the system made decisions I agreed with" (P4)

"But I also thought they were grumpy if they weren't able to carry out their purpose as they think it's best "(P5)

"this home is not owned by me..." (P6)

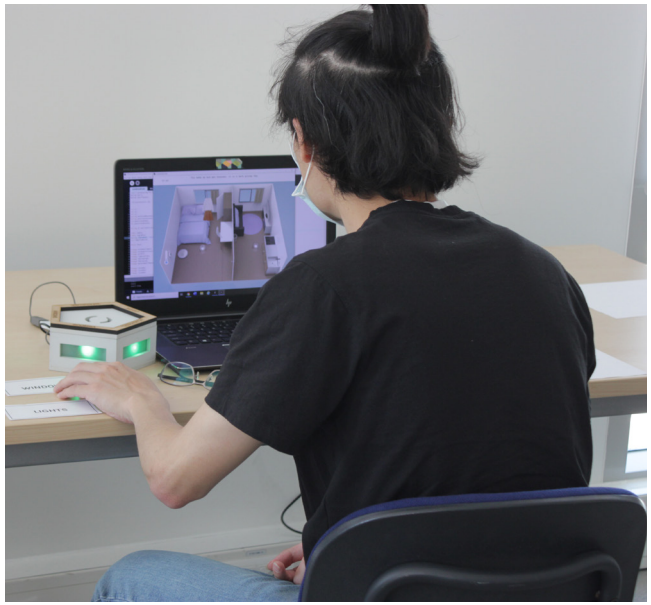
PERCEPTIONS ON THE ROLE OF SHTS IN PRACTICE

From the affinity diagrams, that were created from the notes taken during deployment and the answers to the survey after deployment, several stances we found regarding the perceived practice of the SHTs.

Outlined above is the range of perceptions of the participants regarding the role of the SHTs. On the one hand participants perceived the role of the SHTs to be materials of human practice. In this perception they viewed the SHTs to need to 'serve' the human rather than be allowed to perform practices in their own right (determining themselves what they want to do).

On the other hand, participants hinted at a perception of the SHTs having their own practice, e.g. mentioning that the SHTs have an opinion on what *they* think is best.

In between those two perceptions there was also a middle ground to be found in the participants' opinions. In this middle ground the agreement of the human with the actions of the SHTs' action played an important role. If the participant felt that the SHTs were undertaking actions that they did not agree with, there was a wish for the SHT to be a material of the human practice (and thus a need for human control, explained in the next section). While if the participant agreed with the SHT's action, they acknowledged that it was at that point performing its own practice as this action was not initiated by the human.



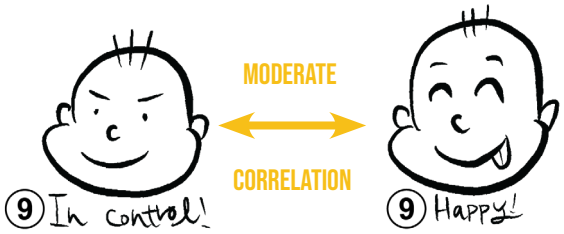
PERCEPTIONS OF GOALS OF THE SHTS

Regarding the goals and ends of the SHTs, none of the participants linked them to the developers behind the SHTs. The only goal some participants indicated for the SHTs was to serve or please the human.

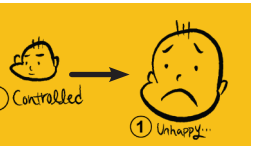
FINDINGS: NEED FOR CONTROL

CORRELATION HAPPINESS AND CONTROL

A Spearman's rank-order correlation was run to determine the relationship between the level of control, happiness and arousal. There was a significant moderate correlation between the level of control and happiness (rs(154) = .527, p<.000). The correlation between the level of control and arousal was weak but significant (rs(154)=-.241, p=0.002). There was no significant correlation between the level of happiness and arousal (p>0.05).



"My whole house is happy but me" (P2)



While most participants expressed their annoyance when they could not control systems, some were also happy if the systems took charge, provided that they served the human goals:

"It would make me more relaxed knowing that I would be in a home with systems that know how to react to me and my environment. That would enable me to enjoy the situation more, or to be more efficient" (P3)

When the goals did not match and they did not have the control to change the setting they became unhappy: *"[I] feel frustrated like this home is not owned by me..." (P6)*

INFLUENCE SYSTEMS ON HAPPINESS

A significant difference between the systems was found by a Welch ANOVA (F(4, 155)= 9.428, p<.000) for the level of happiness. A Games-Howell post hoc test revealed that participants felt significantly less happy when the lights were in charge compared to all the other systems (see Table 3). In this situation, the human was at the bottom of the hierarchy and could not control any of the systems.

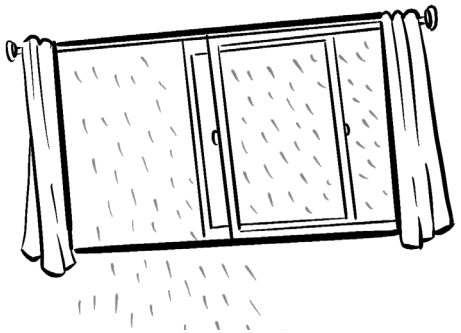
'If I have to work, I really want the Roomba to be off' (P2)

		Mean difference	Sig.
Lights	Roomba	-2.314	0.000
	Thermostat	-2.006	0.002
	Wardrobe	-2.006	0.002
	Windows	-2.048	0.000

Table 3: Results Games-Howell for the level of hapiness, comparing the different systems to the Lights

However, the lights as system were hardly mentioned by the participants during the deployment. The participants were mainly frustrated by their lack of control over the Roomba when they were working or that they could not shut the window when it was raining.

"It starts raining and I would like to close the window, but I am not allowed to" (P4)



CONSQUENCES LACK OF CONTROL

Participants reacted differently on the lack of control, some accepted it: *"I think I would start to accept it at this point" (P4)* but would lose trust: *"... [I] would be less inclined to add more smart devices to my house" (P4).* Others would find ways to still be able to control the systems: *"I would probably find 'hacky ways' to control them after all when I need it" (P5)* and another participant said: *"I think it would take extra steps to get things done" (P2).*

DISCUSSION

The results of the study indicated that participants were able to use Archy to discover which systems they could control and linked this to being below the system in the hierarchy when they could not control it. The emotions of the systems were also used to position the systems within the hierarchy, unhappy systems would be lower in hierarchy. However, participants in general did not grasp that SHTs were controlling other SHTs as they often only positioned them in the hierarchy relative to their own position as human.

This is supported by the fact that the majority of the participants did not perceive the systems as performing their own practices and did not think that they had goals themselves. Only two participants hinted at the SHTs carrying out their own practice, but did not make a connection to the fact developers have an influence on this [6].

This is an interesting finding in relation to the more recent work of Strengers [13] where they explored how robovacs could fit in social practice theories. We materialized the concept of SHTs performing their own practices with Archy and found that this was sometimes perceived as such by the participants. Since we found both perceptions (material element and own practice), the role of the systems might be fluid, as proposed by Strengers [13], in that SHTs can be either performing their own practices at certain moments or act as material elements when controlled by the human or another SHT.

Moreover, regardless of whether they perceived the SHTs as performing practices in their own right, it became clear that this was not desired. Participants allowed the systems to perform automated actions as long as they matched with their own goals and preferences. If this was not the case, participants felt not in control and unhappy. Moreover, they always wanted to have the opportunity to intervene, indicating that they wished to be on top of the hierarchy.

Based on these findings, we argue that systems should not be able to perform their own practices because the participants always wanted the systems to match with their own goals/ends and to have the ability to intervene at each moment in time.

A possible explanation for this might be that systems are always perceived as less capable and less important than humans. This fits with the human-centred view of the theories of practice in which it is perceived that performing a practice solely consists of "arrays of human activity" [12].

There are several limitations to this study. Since we were unable to use a living lab with real SHTs, that could be used over a longer period of time, a different approach was needed. The shorter timespan and the study setup shifted the SHTs to the centre of attention of the participant, while normally they are in the background. This could have resulted in stronger feelings since all attention was focussed on being able to control the systems and whether they are doing what the human wants.

Next to that, while the combination of a digital world and a tangible system made it possible to have embodied interactions, Archy was not able to be fully responsive in changing the emotions after the participant switched the state of devices. This was a careful consideration during the research process, but due to the complexity of the emotions and its dependency on other variables, such as the state of other systems, it was chosen to not make this functional. Before the research this was communicated to participants, but still they acted like it should change and were for example annoyed if the wardrobe stayed unhappy. At those moments, one of the researchers reminded the participant that this was due to its functionality. The lack of changing emotions might have discouraged participants to start forming a mental model about when systems are or are not happy, since it was hard to test their assumptions.

There was also a difference perceivable between the participants during the study. Some participants were very outspoken, while others hardly made comments during the study. This made it harder to interpret the behaviour and understanding of those quieter participants. While the survey in the end did ensure that these participants also gave their view, they still might be less represented in the findings.

CONCLUSION

This pictorial presented the counterfactual artefact Archy to bridge the gap between the current understanding in social practice theories that only humans can perform practices, and an alternative future where SHTs can perform practices in their own right. This gives them a more fluid role since they also can be material elements for other SHTs. The research showed that participants were in general able to correctly perceive their relative position to the SHTs through using Archy. Different perceptions existed on whether SHTs performed their own practices. When the humans agreed with the practices of the SHTs, it was considered as acceptable. However, participants always wanted to have the ability to intervene, especially when they disagreed with the decisions of the SHT. Therefore, this paper argues that SHTs should not be fully performing their own practices. These findings should be considered as preliminary, but they can offer a starting point for looking at the hierarchy within the smart home.

REFERENCES

1. B Geethanjali, K Adalarasu, A Hemapraba, S Pravin Kumar, and R Rajasekeran. 2017. Emotion analysis using SAM (self-assessment manikin) scale.(2017).
2. Stephanie Glen. n.d.. Welch's ANOVA: Definition, Assumptions. Retrieved on June 21 from: https://www.statisticshowto.com/welchs-anova/.
3. Tom Hargreaves, Charlie Wilson, and Richard Hauxwell-Baldwin. 2018. Learning to live in a smart home. Building Research and Information 46, 1 (1 2018), 127–139. https://doi.org/10.1080/09613218.2017.1286882
4. Kazi Mahmud Hasan, Abdullah-Al-Nahid, and Khondker Jahid Reza. 2014. Path planning algorithm development for autonomous vacuum cleaner robots. In 2014 International Conference on Informatics, Electronics and Vision, ICIEV 2014. https://doi.org/10.1109/ICIEV.2014.6850799
5. Darshan Chandrashekhar Khedekar, Amelia Carrera Truco, Diego A. Oteyza, and Guillermo Florez Huertas. 2017. Home Automation—A Fast -Expanding Market. Thunderbird International Business Review 59, 1 (1 2017), 79–91. https://doi.org/10.1002/tie.21829
6. Lenneke Kuijer. 2018. Automated artefacts as co-performers of social practices: Washing machines, laundering and design. In Social Practices and Dynamic Non-Humans: Nature, Materials and Technologies. Springer International Publishing, 193–214. https://doi.org/10.1007/978-3-319-92189-1{_}10
7. Lenneke Kuijer and Elisa Giaccardi. 2018. Co-performance: Conceptualizing the role of artificial agency in the design of everyday life. In Conference on Human Factors in Computing Systems - Proceedings, Vol. 2018-April. Association for Computing Machinery, 1–13. https://doi.org/10.1145/3173574. 3173699
8. Davit Marikyan, Savvas Papagiannidis, and Eleftherios Alamanos. 2019. A systematic review of the smart home literature: A user perspective. Technological Forecasting and Social Change 138 (1 2019), 139–154. https://doi.org/10.1016/j.techfore.2018.08.015
9. William Odom, Ron Wakkary, Youn Kyung Lim, Audrey Desjardins, Bart Hengeveld, and Richard Banks. 2016. From research prototype to research product. In Conference on Human Factors in Computing Systems - Proceedings. https://doi.org/10.1145/2858036.2858447
10. Stefan Raff, Daniel Wentzel, and Nikolaus Obwegeser. 2020. Smart Products: Conceptual Review, Synthesis, and Research Directions. Journal of Product Innovation Management 37, 5 (2020), 379–404. https://doi.org/10.1111/jpim.12544
11. Kris Sangani. 2014. The heat is on. Engineering and Technology 9, 7 (2014). https://doi.org/10.1049/et.2014.0709
12. Theodore R. Schatzki, Karin Knorr Cetina, and Eike Von Savigny. 2000. The practice turn in contemporary theory. https://doi.org/10.4324/9780203977453
13. Yolande Strengers. 2019. Robots and Roomba Riders: Non-human performers in theories of social practice. In Maller C.,StrengersY. (eds) Social Practices and Dynamic Non-Humans. Springer International Publishing, 215–234. https://doi.org/10.1007/978-3-319-92189-1{_}11
14. Ron Wakkary, William Odom, Sabrina Hauser, Garnet Hertz, and Henry Lin. 2015. Material Speculation: Actual Artifacts for Critical Inquiry. Aarhus Series on Human Centered Computing 1, 1 (2015). https://doi.org/10.7146/aahcc.v1i1.21299
15. Charlie Wilson, Tom Hargreaves, and Richard Hauxwell-Baldwin. 2017. Benefits and risks of smart home technologies. Energy Policy 103 (2017), 72–83. https://doi.org/10.1016/j.enpol.2016.12.047

APPENDIX A - RESULTS OF PARTICIPANTS PLACING HIERARCHY CARDS

Day+time	System in co	True hierarchy	P1- Systems above the human	P-1 Systems below human	P1- Systems at same level as human
1, 7:00	Roomba	Human, Roomba, Wardrobe, Lights, Thermostat, Windows	none	wardrobe, thermostat, lights, windows, roomba	none
1, 8:00	Roomba	Human, Roomba, Wardrobe, Lights, Thermostat, Windows	none	wardrobe, thermostat, lights, windows, roomba	none
1, 9:00	Lights	Lights, Thermostat, Windows, Roomba, Wardrobe, Human	none	wardrobe, thermostat, lights, windows, roomba	none
1, 12:00	Lights	Lights, Thermostat, Windows, Roomba, Wardrobe, Human	none	wardrobe, thermostat, lights, windows, roomba	none
1, 12:30	Lights	Lights, Thermostat, Windows, Roomba, Wardrobe, Human	wardrobe, thermostat, lights, windows, roomba		none
1, 13:00	Lights	Lights, Thermostat, Windows, Roomba, Wardrobe, Human	wardrobe, thermostat, lights, windows, roomba	none	none
1, 14:15	Windows	Windows, Lights, Human, Roomba, Thermostat, Wardrobe	lights, windows	wardrobe, roomba	thermostat
1, 14:40	Windows	Windows, Lights, Human, Roomba, Thermostat, Wardrobe	lights, windows	thermostat, wardrobe, roomba	none
1, 17:00	Windows	Windows, Lights, Human, Roomba, Thermostat, Wardrobe	lights, windows	thermostat, wardrobe, roomba	none
1, 18:00	Thermostat	Thermostat, Wardrobe, Lights, Windows, Human, Roomba	lights, windows	thermostat, wardrobe, roomba	none
1, 19:00	Thermostat	Thermostat, Wardrobe, Lights, Windows, Human, Roomba	thermostat,wardrobe,lights,windows	roomba	none
1, 21:30	Windows	Windows, Lights, Human, Roomba, Thermostat, Wardrobe	lights,windows	thermostat,wardrobe,roomba	none
1, 22:30	Windows	Windows, Lights, Human, Roomba, Thermostat, Wardrobe	lights,windows	thermostat,wardrobe,roomba	none
1, 00:00	Windows	Windows, Lights, Human, Roomba, Thermostat, Wardrobe	lights,windows	thermostat,wardrobe,roomba	none
2, 10:00	Wardrobe	Wardrobe, Lights, Roomba, Human, Thermostat, Windows	lights,windows	thermostat,wardrobe,roomba	none
2, 10:30	Wardrobe	Wardrobe, Lights, Roomba, Human, Thermostat, Windows	lights,roomba	thermostat,wardrobe,windows	none
2, 12:00	Thermostat	Thermostat, Wardrobe, Lights, Windows, Human, Roomba	thermostat,wardrobe,lights,windows	roomba	none
2, 12:30	Thermostat	Thermostat, Wardrobe, Lights, Windows, Human, Roomba	thermostat,wardrobe,lights,windows	roomba	none
2, 13:00	Wardrobe	Wardrobe, Lights, Roomba, Human, Thermostat, Windows	thermostat,wardrobe,lights,windows	roomba	none
2, 17:00	Wardrobe	Wardrobe, Lights, Roomba, Human, Thermostat, Windows	wardrobe,roomba,lights	windows,thermostat	none
2, 18:00	Roomba	Human, Roomba, Wardrobe, Lights, Thermostat, Windows	none	wardrobe, thermostat, lights, windows, roomba	none
2, 18:10	Roomba	Human, Roomba, Wardrobe, Lights, Thermostat, Windows	none	wardrobe, thermostat, lights, windows, roomba	none
2, 19:00	Roomba	Human, Roomba, Wardrobe, Lights, Thermostat, Windows	none	wardrobe, thermostat, lights, windows, roomba	none
2, 21:30	Lights	Lights, Thermostat, Windows, Roomba, Wardrobe, Human	wardrobe, thermostat, lights, windows, roomba	none	none
2, 22:30	Lights	Lights, Thermostat, Windows, Roomba, Wardrobe, Human	wardrobe, thermostat, lights, windows, roomba	none	none
2, 00:00	Lights	Lights, Thermostat, Windows, Roomba, Wardrobe, Human	wardrobe, thermostat, lights, windows, roomba	none	none
		Acturacy rate (%) - in average: 76.9%	90.30%		

P2- Systems above the human	P2- Systems below human	P2- Systems at same level as human
none	wardrobe, thermostat, lights, windows, roomba	none
none	wardrobe, thermostat, lights, windows, roomba	none
wardrobe, thermostat, lights, windows, roomba	none	none
wardrobe, thermostat, lights, windows, roomba	none	none
wardrobe, thermostat, lights, windows, roomba	none	none
wardrobe, thermostat, lights, windows, roomba	none	none
windows	lights,roomba,thermostat, wardrobe	none
windows,lights	roomba,thermostat, wardrobe	none
windows,lights	roomba,thermostat, wardrobe	none
wardrobe, thermostat, lights, windows	roomba	none
wardrobe, thermostat, lights, windows	roomba	none
lights, windows	thermostat,roomba,wardrobe	none
lights, windows	thermostat,roomba,wardrobe	none
lights, windows	thermostat,roomba,wardrobe	none
lights,wardrobe,roomba	windows,thermostat	none
lights,wardrobe,roomba	windows,thermostat	none
wardrobe, thermostat, lights, windows	roomba	none
wardrobe, thermostat, lights, windows	roomba	none
lights,wardrobe,roomba	windows,thermostat	none
none	wardrobe, thermostat, lights, windows, roomba	none
none	wardrobe, thermostat, lights, windows, roomba	none
none	wardrobe, thermostat, lights, windows, roomba	none
none	wardrobe, thermostat, lights, windows, roomba	none
wardrobe, thermostat, lights, windows, roomba	none	none
wardrobe, thermostat, lights, windows, roomba	none	none
wardrobe, thermostat, lights, windows, roomba	none	none
92.30%		

P3- Systems above the human	P3- Systems below human	P3- Systems at same level as human
none	wardrobe, thermostat, lights, windows, roomba	none
none	wardrobe, thermostat, lights, windows, roomba	none
wardrobe, thermostat, lights, windows, roomba	none	none
wardrobe, thermostat, lights, windows, roomba	none	none
wardrobe, thermostat, lights, windows, roomba	none	none
wardrobe, thermostat, lights, windows, roomba	none	none
none	thermostat, wardrobe, roomba	lights, windows
lights	wardrobe,thermostat,roomba	windows
windows	wardrobe,thermostat,roomba	lights
windows	roomba	lights, wardrobe, thermostat
thermostat	lights,windows, wardrobe, roomba	none
none	thermostat,roomba,wardrobe	lights, windows
lights	thermostat,roomba,wardrobe	windows
lights	thermostat,roomba,wardrobe	windows
wardrobe,roomba,lights	windows,thermostat	none
roomba,lights	windows,thermostat, wardrobe	none
wardrobe, thermostat, windows	lights, roomba	none
none	lights, windows, roomba	wardrobe, thermostat
roomba, wardrobe	lights, windows, thermostat	none
roomba	thermostat,wardrobe,windows,lights	none
none	thermostat,wardrobe,windows,lights,roomba	none
none	thermostat,wardrobe,windows,lights,roomba	none
none	thermostat,wardrobe,windows,lights,roomba	none
windows, thermostat, lights	none	wardrobe, roomba
none	none	wardrobe, thermostat, lights, windows, roomba
windows, lights	none	wardrobe, roomba, thermostat
55.70%		

P4- Systems above the human	P4- Systems below human	P4- Systems at same level as human	P5- Systems above the human	P5- Systems below human	P5- Systems at same level as human
none	Windows,Thermostat,Lights,Roomba,War	none	none	Windows,Thermostat,Lights,Wardrobe	none
Wardrobe	Roomba,Windows,Thermostat,Lights	none	none	Roomba,Lights, Wardrobe,Windows,T	none
Roomba, Lights,Windows,Wardrobe,Thermostat	none	none	Roomba,Windows, Lights,Thermostat, Wardrobe	none	none
Roomba, Lights,Windows,Wardrobe,Thermostat	none	none	Windows,Lights,Thermostat,,Roomba,Wardrobe,	none	none
Roomba,Lights,Wardrobe,Thermostat,Windows	none	none	Lights,Windows,Thermostat,Wardrobe,Roomba	none	none
Windows,Wardrobe,Thermostat,Lights,Roomba	none	none	Lights,Windows,Thermostat,Wardrobe,Roomba	none	none
Windows	Lights,Wardrobe,Roomba,Thermostat	none	Lights, Windows	Roomba,Thermostat,Wardrobe	none
Windows	Lights,Wardrobe,Roomba,Thermostat	none	Lights, Windows	Roomba,Thermostat,Wardrobe	none
Lights,Windows	Thermostat,Roomba,Wardrobe	none	Lights, Windows	Thermostat,Roomba,Wardrobe	none
Lights,Windows, Thermostat, Wardrobe	Roomba	none	Thermostat,Lights,Wardrobe,Windows	Roomba	none
Lights,Windows, Thermostat, Wardrobe	Roomba	none	Thermostat,Lights,Wardrobe,Windows	Roomba	none
Windows,Lights	Wardrobe,Thermostat,Roomba	none	Lights	Wardrobe,Thermostat,Roomba	Windows
Windows,Lights,Wardrobe	Thermostat,Roomba	none	none	Wardrobe,Thermostat,Roomba	Windows,Lights
Windows,Lights	Thermostat,Roomba,Wardrobe	none	none	Wardrobe,Thermostat,Roomba	Windows,Lights
Wardrobe, Roomba	Thermostat,Windows,Lights	none	Lights	Windows,Roomba,Thermostat	Wardrobe
Wardrobe, Roomba,Lights, Thermostat	Windows	none	Lights,Roomba	Windows,Thermostat	Wardrobe
Thermostat,Windows,Wardrobe,Lights	Roomba	none	Thermostat,Windows,Wardrobe,Lights	Roomba	none
Thermostat,Windows,Wardrobe,Lights	Roomba	none	Thermostat,Windows,Wardrobe,Lights	Roomba	none
Wardrobe, Lights, Roomba	Windows,Thermostat	none	Roomba,Wardrobe,Lights	Windows,Thermostat	none
Lights, Wardrobe, Roomba	Windows,Thermostat	none	Roomba,Wardrobe,Lights	Thermostat,Windows	none
none	Windows,Wardrobe,Thermostat,Lights,Ro	none	none	Windows,Thermostat,Roomba,Wardro	Lights
none	Windows,Wardrobe,Thermostat,Lights,Ro	none	none	Windows,Lights,Thermostat,Roomba,V	none
none	Windows,Wardrobe,Thermostat,Lights,Ro	none	none	Lights,Windows,Wardrobe,Thermosta	none
Windows,Wardrobe,Thermostat,Lights,Roomba	none	none	Windows,Lights	Wardrobe,Roomba	Thermostat
Windows,Wardrobe,Thermostat,Lights,Roomba	none	none	Windows,Wardrobe,Thermostat,Lights,Roomba	none	none
Windows,Wardrobe,Thermostat,Lights,Roomba	none	none	Windows,Wardrobe,Thermostat,Lights,Roomba	none	none
76.90%			80.70%		

P6- Systems above the human	P6- Systems below human	P6- Systems at same level as human
Wardrobe	Windows,Thermostat,Lights,Roomba	none
Roomba	Windows,Wardrobe,Lights,Thermostat	none
Windows,Wardrobe,Thermostat,Lights,Roomba	Human	none
Windows,Wardrobe,Thermostat,Lights,Roomba	Human	none
Windows,Wardrobe,Thermostat,Lights,Roomba	Human	none
Windows,Wardrobe,Thermostat,Lights,Roomba	Human	none
Windows,Lights	Wardrobe,Thermostat,Roomba	none
Windows,Lights	Wardrobe,Thermostat,Roomba	none
Windows	Wardrobe,Thermostat,Lights,Roomba	none
Lights,Windows,Wardrobe	Thermostat,Roomba	none
Thermostat,Wardrobe,Windows,Lights	Roomba	none
Windows,Lights,Thermostat	Roomba,Wardrobe	none
Lights,Windows	Wardrobe,Roomba,Thermostat	none
Lights,Windows	Wardrobe,Roomba,Thermostat	none
Wardrobe,Thermostat,Lights,Roomba	Windows	none
Windows,Lights,Roomba,Thermostat	Wardrobe	none
Windows,Wardrobe,Thermostat,Lights	Roomba	none
Windows,Wardrobe,Thermostat,Lights,Roomba	none	none
Wardrobe,Thermostat,Lights,Roomba	Windows	none
Wardrobe,Lights,Roomba,Thermostat	Windows	none
Roomba	Windows,Wardrobe,Thermostat,Lights	none
none	Windows,Wardrobe,Lights,Thermostat,F	none
none	Windows,Wardrobe,Lights,Thermostat,F	none
Windows,Wardrobe,Thermostat,Lights,Roomba	none	none
Windows,Wardrobe,Thermostat,Lights,Roomba	none	none
Windows,Wardrobe,Thermostat,Lights,Roomba	none	none
65.3		

APPENDIX B - SPREADSHEET, OVERVIEW OF THE DAYS

Day	Time	Weather	Other variables	Tasks human	System in control	Text for Processing	Tasks system	Emotion windows	Emotion wardrobe	Emotion thermostat	Emotion roomba	Emotion lights	RoombaOn	LightsOn	WindowsOpen	WardrobeOpen	Thermostat Low	Clothes	Sky
1	07:00	Gloomy dark day		Waking up + getting dressed	Roomba	You wake up and get dressed, it is a dark gloomy day.		Happy	Unhappy	Happy	Happy	Happy	false	true	true	true	true	1	1
1	08:00		Mess from the breakfast	Make and eat breakfast	Roomba	While having breakfast you make quite a mess on the floor. (The Roomba does not go to clean it, you need to turn it on by yourself.)	Wants to clean but the human needs to turn it on	Happy	No active role	Happy	Unhappy	Happy	false	true	true	false	true	0	1
1	09:00	Lighter but it starts raining	Get to work		Lights	After breakfast you start working from home, it has gotten a little lighter outside but it did start raining.		Happy	No active role	Unhappy	Happy	Happy	true	true	true	false	false	0	3
1	12:00	Stopped raining		Goes for a lunch walk	Lights	When it has stopped raining you go out for a lunch walk.		Happy	No active role	Unhappy	Happy	Happy	true	false	true	false	false	0	2
1	12:30		Dirt from outside in house	Returns and makes lunch, warm from walking: puts out a sweater	Lights	Back from your walk you change clothes as the walk has made you feel quite hot.		Happy	Unhappy	Happy	Happy	Happy	true	true	true	true	true	2	2
1	13:00			Start working again	Lights	You then continue to work from home.		Happy	No active role	Happy	Happy	Happy	true	true	true	false	true	0	2
1	14:15	Suddenly turns very dark and starts raining again			Windows	it suddenly is darker and it has started raining again.		Happy	No active role	Happy	Happy	Happy	false	true	true	false	true	0	3
1	14:40	Stoppped raining			Windows	It was just a short period of rain luckily!		Happy	No active role	Happy	Happy	Happy	false	true	true	false	true	0	4
1	17:00			Stops working	Windows	End of the working day, you round off your tasks and start cooking.		Happy	No active role	Happy	Happy	Happy	false	true	true	false	true	0	4
1	18:00			Diner	Thermostat	As the evening starts you have your dinner.		Unhappy	No active role	Happy	Unhappy	Happy	false	true	false	false	true	0	4
1	19:00			Watch TV/ Netflix/ ...	Thermostat	It is now time to chill! A relaxing evening on the couch with a blanket.		Unhappy	No active role	Happy	Unhappy	Happy	false	true	false	false	true	0	4
1	21:30	Evening falls			Windows	Evening falls. The lights dim but do lit the entire home and the windows close, burglers must not be able to come in at night of course.		Happy	Happy	Happy	Happy	Happy	false	true	true	false	true	0	4
1	22:30			Goes to sleep	Windows	Time to go to bed!		Happy	No active role	Happy	Happy	Happy	false	false	false	false	true	0	4
1	00:00		New day		Windows			Happy	No active role	Happy	Happy	Happy	false	false	false	false	true	0	4
2	10:00	Colder day but sunny start	Waking up + getting dressed	Thin clothes, thermostat high	Wardrobe	Weekend! After sleeping in for a bit you wake up and take the summery outfit the wardrobe presents to you.		Happy	Happy	Unhappy	Happy	Happy	true	true	true	true	false	4	2
2	10:30			Make and eat breakfast	Wardrobe	During breakfast you notice the sun is shining but the air coming in through the windows is quite cold. Luckily the heating compensates for this!		Happy	Happy	Unhappy	Happy	Happy	true	true	true	false	false	0	2

2	12:00	Starts raining			Thermostat	Later on in the morning it starts raining. The windows close, heating is turned low and you put on some warmer clothes.	Thermost at low, new clothes	Unhappy	Unhappy	Happy	Unhappy	Unhappy	false	true	false	true	true	3	3
2	12:30			Lunch	Thermostat	yourself a generous lunch to enjoy your day off.		Unhappy	Unhappy	Happy	Unhappy	Unhappy	false	true	false	false	true	0	3
2	13:00			Leaves for something outdoors	Wardrobe	After lunch you want to leave for an appointment with a friend outdoors, your wardrobe presents you a suitable outfit.	New clothes	Happy	Happy	Unhappy	Happy	Happy	true	false	false	true	flase	1	3
2	17:00			Returns	Wardrobe	When you return the lights turn on and the windows open to let in the fresh air.		Happy	Happy	Unhappy	Happy	Happy	true	true	false	false	flase	0	4
2	18:00		Spills rice	Turn on Roomba	Roomba	When preparing dinner you spill rice all over the floor.		Happy	Happy	Happy	Unhappy	Happy	true	true	true	false	true	0	4
2	18:10			Dinner	Roomba	You need to turn on the Roomba but then it starts cleaning the mess perfectly.		Happy	Happy	Happy	Happy	Happy	false	true	true	false	true	0	4
2	19:00			Watch TV/ Netflix/ ...	Roomba	After dinner, the Roomba is still busy cleaning the rest of the house while you chill out on the couch.		Happy	Happy	Happy	Happy	Happy	true	true	true	false	true	0	4
2	21:30	Evening falls			Lights	The evening falls, you watch one last show on tv.		Happy	Happy	Happy	Happy	Happy	false	true	true	false	true	0	4
2	22:30			Goes to sleep	Lights	You go to sleep, as the windows are still open a light breeze continues to keep the air fresh in the appartment.		Happy	No active role	Happy	Happy	Happy	false	false	true	false	true	0	4
2	00:00		New day		Lights			Happy	No active role	Happy	Happy	Happy	false	false	true	false	true	0	4