A Sustainability and User-centered Approach towards Extending the Life-cycle of Mobile Computers

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Abstract. The aim of this article is to provide an understanding of cognitive and physical barriers concerning extending the lifecycle of mobile computers. Reference to Triandis´ theory of interpersonal behavior, 1) attitudes; 2) contextual factors; 3) personal capabilities, and 4) habits will be discussed to overcome these barriers. A survey among 449 subjects, complemented by an expert interview, was conducted to find out motivators and resistors for retaining computers though renewal processes. Results were structured and presented using a Computer Life-Cycle Extension Model. The emphasis on "Emotion" indicated that a pragmatic view by understanding what practical things to do and what knowledge to seek for is not enough. To motivate end-users to prolong the life of their computers, emotional incentives are equally important to extend the life-cycle of their mobile computers. For example, personalized design can also make users feel more attached to their computers, and thereby facilitate an emotional connection. This connection can make users more inclined to keep their computers longer. Moreover, a need has been observed to break away from stereotyping computer culture and usage.

Keywords: Sustainable Computer, Retainment, Triandis.

1 Introduction

In modern, mature economies, it is a challenge to adopt a sustainability lens towards the use of difficult degradable products. Based on the 5 R´s of "Circular Economy" [1], value is created by encouraging users to extend the use of these products. Concerning mobile computers, recycling does not entirely compensate for the initial environmental impact of producing them [2]. As such, a focus should be placed on renewal strategies by encouraging users to increase the life-cycle of their computers. However, because of rapid advances in technology according to Moore´s Law [3], users appear to be helpless, when it comes to what they can do themselves to prolong their effective usage.

One of the key reasons is that computer anxiety is still prevalent, even though mobile computers are becoming a more common assistive tool to complete day-to-day tasks. Studies showed that this anxiety is correlated with users´ self-fulfilling prophecy of not being well-versed with computers [4]. Consequentially, these users treat computers as "untouchable" black boxes.

This article aims to understand cognitive and physical barriers concerning extending the lifecycle of mobile computers. Triandis´ theory of interpersonal behavior [5] will be discussed to understand better: 1) attitudes; 2) contextual factors; 3) personal capabilities, and 4) habits to overcome these barriers.

In the discussion section, an integrated approach dealing with aspects of emotion, knowledge and practice to conquer computer anxiety will be elaborated.

2. The Concept of Retainment in Sustainable Computing

Retainment is a central idea in a circular economy that goes beyond the "take, make and dispose" mindset [1]. However, retainment is often a foreign concept in the world of computers which is characterized by rapid development. In fact, according to the conducted survey amongst 449 subjects, several subjects believe that nothing can be done to facilitate laptop retainment because of Moore's Law [3]. When asked the open question *"What do you think would help you in keeping your old computer longer?"* some subjects responded with "Moore's law slowing down" and *"If Moore's law stopped"*. Additionally, the computer industry is rarely negatively targeted when it comes to environmental concerns. *"How much computing can mankind afford?"* is a question not often asked in tech environments [6]. Despite this, computing is on par with aviation when it comes to CO_2 emission. Therefore, it is crucial to shed light on sustainability concerns in relation to the tech industry. Even though sustainable computing is a topic not often talked about, research has still been done on the matter. Not only that but some companies, such as Dell, have started taking an initiative to recycle and reuse computer parts. *Table 1* shows past research and newer efforts divided into categories based on the five R´s of circular economy.

Table 1: Past research and initiatives in relation to the 5 R's of circular economy [22]

Retain	Rent	Renew	Recycle	Reuse
	Assets resale and recycling [7]	Computer rental for businesses [11]	Free computer help from computerhope.com [15]	Assets resale and recycling [7]
	Donating old computers to schools [8]	Computer rental for businesses [12]	Computer Help from [16]	50 000 liters of water are required make a single laptop [20]
	Donating old computers to schools [9]	IBM letting anyone try their online quantum computer [13]	Free computer help from techguy.com [17]	Computers becoming more difficult to recycle [2]
	Get computer equipment as donations [10]	Donate computer power to research [14]	Free computer help from geekbuddy.com [18]	Recycling does not refund environmental impact [21]

Most research has been conducted about the 5th R "recycling". A crucial finding is that recycling does not entirely make up for the initial environmental impact of

creating a computer. Recycling 10% of the computer only saves 0,43% of life-cycle energy. Reselling or upgrading 10% of the laptop saves 8,6% and 5,2% respectively [21]. Laptops are more integrated than simpler materials. It is entirely different to recycle a plastic bottle than a computer with a complex structure that needs to be taken apart. Also, most of the energy required in creating a computer does not come from manufacturing the individual components, but rather in combining these components [21].

These facts are mainly taken from William and Saski's research done in 2003. While technology might have made the recycling process more efficient today, computers are becoming increasingly difficult to recycle [2]. Devices are becoming more integrated. The computer industry is trending towards creating thinner laptops that are lighter to carry. Therefore, it is still plausible to say that recycling is not the final solution in managing the end-of-life of computers.

Table 1 shows a gap in research related to the first retainment (The first R). This study aims to lessen this gap by answering the research question: "*What new behaviors are required by users to prolong the life-cycle of a computer*?

3. Research Method

To investigate what new behaviors are required by users to prolong the life-cycle of a computer, a survey was distributed among 449 participants, as well as an expert interview conducted with computer repair shop workers. In total, the team gradually gathered 449 responses through the engagement with numerous Facebook groups. Interestingly, many of these groups were female-dominant. In order to not get an extremely skewed gender balance the survey was closed at 449 responses. The final gender balance was 76,4% female, 22,9% male and 0,7% other.
As a follow up. an interview was also conducted with Bitfix, a computer repair shop in Trondheim. The purpose of the interviews was to gather information whether computers could be retained through a renewal process or not.
During the interview with Bitfix it was investigated if there are any practical things consumers can do to extend the lifetime of a laptop. It turned out that there were certain services Bitfix offered that consumers also could conduct themselves. The first part of the analysis framework was therefore to map out what practical actions consumers could do to extend the life-cycle of their mobile computer.
To find out if high computer proficiency was correlated with positive retainment behavior, interview results were correlated with those from the survey to verify whether consumers were already doing some Do-It-Yourself activities. Moreover, responses were analyzed to check if there are other factors which influence positive retainment behavior. For example, whether there is a gender typicality, which affects how likely consumers were to repair their computers, instead of discarding it.

4. Results

4.1 Expert Interview

Key findings from the expert interview are summarized in Table 2. Typically, end-users are not very much aware of the possibilities concerning replacements and upgrades of sub-systems and elements to prolong the life-span of the computer.

Table 2: Key findings from expert interview

Finding Number	Description
1	If a laptop has HDD and not SSD, upgrading to SSD will significantly increase the speed of the computer. This change can be done by the computer owner, if they have physical access to the HDD-panel. If not, it can be done by a computer repair shop
2	Cleaning and defragmenting a laptop is beneficial in terms of performance
3	Most laptops are upgradable, especially if the screen is bigger than 13-inches
4	In Norway, there is a 5-year reclamation on computers, meaning that in theory they should last 5 years. This is something not many computer users are aware of
5	Keyboards can be replaced on laptops
6	Choosing the right computer in the first place is beneficial when it comes to keeping it as long as possible
7	Many people think that fixing a computer is too expensive, but it can often be more affordable than getting a new one
8	More knowledge about computers would help consumers keep them longer, like knowing that repairs can be made, and that laptops can be upgraded
9	Those who are emotionally attached to their computers, appear to do more to keep them alive
10	More RAM can be added to a laptop
11	Consumers often break their charging port, by tripping over the charging cable. Not doing that would also help in keeping the computer longer
12	Bitfix can even help computer owners with ransomware and other viruses
13	If the laptop is just getting a bit slow, there are things that can be done to renew it and make it run better

4.2 Survey

The key findings from the survey are summarized in *Table 3*.

Table 3. Key findings from survey

Finding Number	Description
1	In the optional question, 56 respondents gave suggestions about what others could do in order to help the respondent's computers lasting longer 27 respondents gave suggestions about what they themselves could do in order to help their computers last longer
2	53% stopped using their computer(s) because it got too slow to run the stuff they wanted
3	8,9% stopped using their computer(s) because it got a virus
4	9,6% stopped using their computer(s) because the screen broke
5	4,7% changed out their old computer because they just wanted something new
6	70% of males had at some point upgraded their hardware, compared to 20% of females
7	73,4% of males knew what a Core i5-6200U was, compared to 17,5% of females
8	7 respondents who showed high computer proficiency, by knowing what a Core i5-6200U was, wrote in the optional section (without any prompt to do so) that laptops cannot be upgraded
9	75,4% of respondents under 20 years of age, did not know what a Core i5-6200U was, compared to 49,2% of respondents over 20
10	20% of respondents said that they have not repaired a broken computer because it was too troublesome

5. Discussion

5.1 Computer Life-Cycle Extension Model

Figure 1 shows the computer life-cycle extension model. This model will be used as the basis for discussing how "Knowledge", "Practice" and "Emotion" may affect end-users´ decision-making strategies concerning prolonging the lifespan of their computer. *Sections 5.2*, *5.3* and *5.4* will elaborate on these categories.

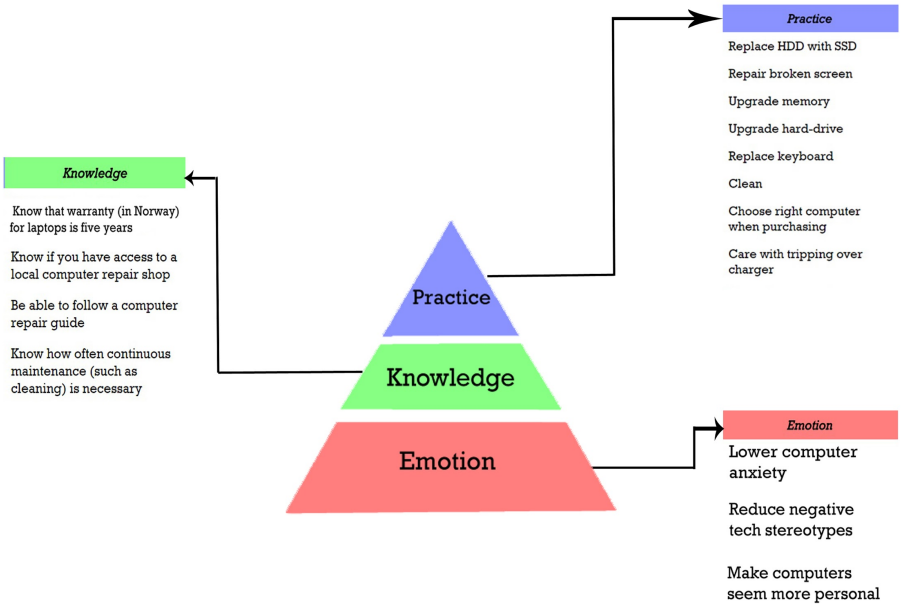

Fig.1. Computer Life-Cycle Extension Model

5.2 Practice

A key finding in the survey was finding number 2 in *Table 3*. Respondents mainly stopped using their old computer(s) because the computer(s) got too slow to run the stuff they wanted. A key finding from the expert interview was finding number 13, in *Table 2*. If a laptop simply is running too slow there are things that can be done to fix it. This is contrary to what some respondents believed in the survey, even when they showed high computer proficiency, as seen in finding number 8 *(Table 3)*. In addition, finding 10 of the same table shows that 20% of respondents simply did not repair their computers because it was too troublesome. This attitude might be caused because the computer is not easily fixable. Also, it might result from not having access to information about possibilities. According to the computer Life-

Cycle Extension Model a clear and easy to understand guide for usage and maintenance should be presented to extend the life-cycle a computer. In conjunction with the knowledge component of the model, more detailed information should be provided to the consumer prior to purchasing the computer, so that he or she can make a more well-informed choice.

5.3 Knowledge

In order to conduct the required practices to retain a computer, users need to have certain knowledge. According to findings 6 and 7 from *Table 3,* respondents who knew what a CPU was were far more likely to make computer upgrades. Most importantly, users need to believe that the life-cycle of a laptop is longer than two years. As discussed previously some computer users believed that Moore's Law caused computers to evolve so fast that they quickly become obsolete. Important knowledge to counter this effect is the awareness that warranty, in Norway, for laptops only lapses after five years [23]. This theoretically means that laptops are supposed to last for at least five years. Once users are informed of this law, they would have a different attitude towards computer longevity.

It gets more complicated for end-users, when it comes to knowing how to routinely maintain laptops and fix things themselves. Previous studies showed that high computer anxiety is correlated with poor performance on computer-related tasks [4]. Most likely, this means that the idea of not being computer literate becomes a self-fulfilling prophecy. If consumers experience strong computer anxiety they might be reluctant to seek out knowledge.

The survey also indicated that those who knew more about computers were more likely to have upgraded the hardware at some point. In turn, most probably users who upgrade their hardware increases their knowledge, and the cycle continues.

As shown in findings 6 and 7 of table 3, females were far less likely to have upgraded the hardware on their computers, and far less likely to know what a Core i5-6200U is. This justifies the observation of a gender gap in computing. Reasons for why the gender-gap in relation to mobile computer retainment exists is discussed in the next section.

5.4 Emotion

The first element of the Emotion category in the Computer Life-Cycle Extension Model is "Lower computer anxiety". If users had less anxiety when dealing with computers, it is possible that they would take more steps to acquire the knowledge needed to change their practice. Perhaps this is caused by the idea of how a typical computer-savvy person is supposed to be like. Stereotypically, in pop culture, "computer-wiz" people such as hackers and programmers are often portrayed as antisocial or neurotic [24]. It is possible that if people perceived themselves as more computer literate, that they would take active steps towards obtaining new computer knowledge and starting new practices.

The survey table also showed gaps between men and women when it comes to what each gender knew about computers, and whether they had attempted to make upgrades on their own or not. In the "Triandis model" this can be related to norms,

roles and how users view themselves [5]. If powerful hardware is mainly marketed and directed towards men, women may presume that it is "not their cup of tea" to, for example, upgrade computers. Similarly, people who are not considered to fall under the computer-wiz stereotype might not consider making upgrades. Computer-anxiety appears to be related to social norms, as well as how these norms are subject to change.

The next issue in the Triandis' model is attitude. Attitude comes from beliefs about, and evaluation of outcomes. In the computer life-cycle extension model, this can be related to believing that doing the required practices has a purpose. In order to make users believe that they can retain their computer longer, stereotypes about fast-moving technology and the practical implications of Moore's Law need to be challenged. If users believe that there is nothing they can do, because a computer is obsolete after two years, it is not likely that they will look for solutions to retain it.

There are most likely additional benefits when re-evaluating whether technology should stereotypically be branded as "inevitably fast-paced". Though this is true to some extent, many technologies have reached saturation and are far from obsolete in the near future. An example is the programming language Java. It was developed in 1995, and is one of the most popular languages of 2016, even though newer substitutes do exist [25].

The third element of the "Emotion" category of the model is "being moved emotionally", and according to Triandis cause "affect". As affirmed in an interview with Bitfix, "Affect" means that those who like their computers more, also wish to do more in order to keep the computer lasting longer. Possibly, men were more likely to have upgraded their computer at some point, because they feel more attached to it. To them the product carries elements of recognition, comprehension and association [25].

In conclusion, a pragmatic view by understanding what practical things to do and what knowledge to seek for is not enough, to motivate end-users to prolong the life of their computers. Emotional incentives are equally important to extend the life-cycle of their mobile computers.

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