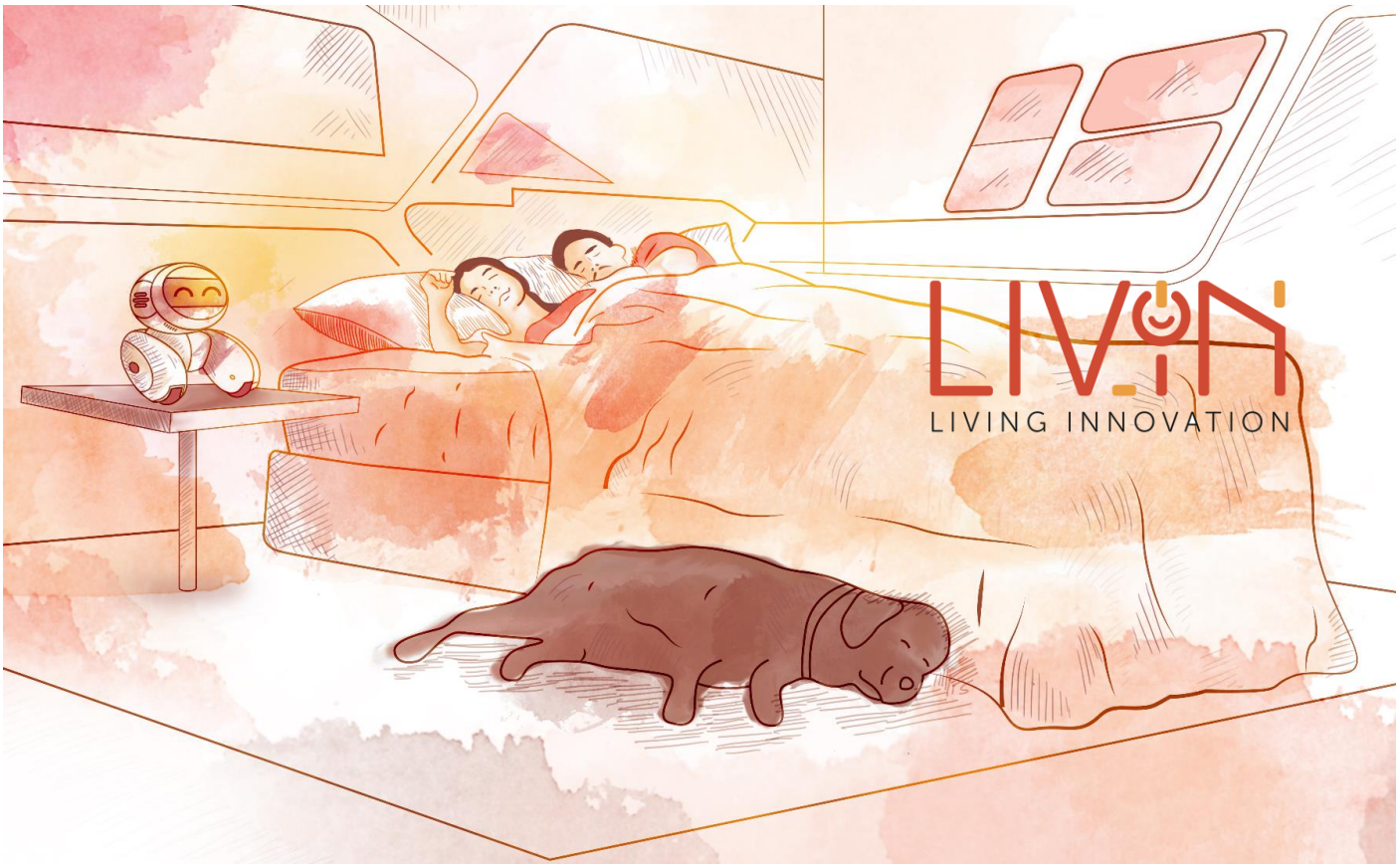

Smart Bedrooms – A compendium

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1. Introduction

Although the concept of smart homes has been in existence for more than a decade, the story of smart homes has only developed in the current decade. Automation, as well as the 'Internet of Things', are current trends that contain an enormous potential to enhance our daily lives. Sensor technology is boosted further and is enabling, in conjunction with machine learning and Big Data processes, the development of connected and interactive houses. This connectivity offers many opportunities to individualize homes by personalized programming. Moreover, smart homes will help to monitor vital body signs of residents, and therefore support overcoming problems connected to our aging population and their needs. Smart bedrooms will contribute to the accomplishment of this topic, in particular. Nevertheless, it must be taken into consideration that smart homes and bedrooms not only have advantages, but also disadvantages regarding data protection and safety issues, such as hacking.[1]

1.1 Background information regarding the developing demand for smart sleeping facilities

Sleeping disorders are part of many people's lives. On average, some type of sleeping disorder affects every fourth person.[2] This "trend" has been affecting more and more people over the past ten years. For example, in 2007, only 6% of people faced problems falling asleep, while almost a third stated to have this issue in 2017. An even greater number of people have problems sleeping through the night. 51% of people in 2017 (26% in 2007) experienced these nocturnal sleeping disturbances (based on an Austrian statistic – but consistent with other reports in the DACH region).[3] Altogether, more than 100 differing kinds of insomnia are known globally. Regarding age categories, elderly people are more often affected by sleep illnesses due to less deep sleeping stages and more frequent short waking phases.

In addition, sleeping behaviour is normally changing, as one gets older. In the literature review, it was mentioned often that sleeping sicknesses are mostly hastily medicated. Triggers vary from being overworked to direct sleeping sicknesses. Moreover, it is evident that the human psyche is directly connected to a human's sleeping behaviour. Depression, for example, is strongly linked to sleeping illnesses and disturbances. Hence, the occurrence of depression has a direct impact on the risk of facing sleeping problems and vice versa. Daytime sleepiness and nightly disquiet are the most occurring forms of sleeping disorders in connection to mental illness. An analysis of DAK has also shown that sleeping disturbances lead to a higher number of sick notes at work.

Astonishingly, it is not common to seek medical attention regarding sleeping problems. These varying factors lead to a rising demand for sleep assisting products, which will inevitably make smart sleeping products more relevant for those affected. One of the recent profiteers has been the developer team of Smartsleep, who recently received an investment of 1.5 Mio. € for their sleep supplement, which promises to enable an especially restful sleep.

> IN 2007, ONLY 6% OF PEOPLE FACED PROBLEMS FALLING ASLEEP, WHILE ALMOST A THIRD STATED TO HAVE THIS ISSUE IN 2017

[1] https://www.int.fraunhofer.de/content/dam/int/de/documents/EST/EST%200216%20Smart%20Home.pdf

[2] https://www.minimed.at/medizinische-themen/gehirn-nerven/schlafstoerungen/

[3] https://www.meduniwien.ac.at/web/ueber-uns/news/detailseite/2018/news-im-maerz-2018/oesterreicher-leiden-haeufiger-an-schlafproblemen-als-frueher/

2. Needs and demands covered by current technology

In the literature, smart bedrooms refer to the enhancement of sleeping behaviour. A majority of products try to cover this topic by screening sleeping behaviour and influencing the way in which people awaken. Features, Apps, and Gadgets do this by analysing the sleeping stages and aligning the alarm times appropriately. This procedure can be explained by the varying sleeping stages of a human. The deep sleep phase is the most relaxing and deepest sleeping stage. Waking up in this stage can cause severe stress and discomfort, lower energy levels, and premature tiredness can result from it. However, differing types of technology also cover other needs.

2.1 Optimizing one's sleeping behaviour through sleep monitoring

Sleep-tracking is one of the most developed technologies within the smart bedroom. Smart beds overcome sleeping inconveniences by estimating the lightest stage of sleep and aligning one's wake up time accordingly.

> THE SLEEPING STAGES ARE MEASURED BY USING SLEEP-TRACKING TECHNOLOGY IN THE FORM OF SENSORS THAT MEASURE FACTORS LIKE RESPIRATION, HEARTBEAT, SLEEP RESTFULNESS, BODY PRESSURE, BODY MOVEMENT, ETC.

Through the evaluation of this data, a smart bed is able to analyse sleeping behaviour, which can be used to positively influence the rest gained from sleep, and to identify the optimal wake up time. The data transmission normally functions via Bluetooth.

The field of sleep-tracking is well researched and, because of that, there are many suppliers in the market. Sleep Number, ReST Smart Beds, Eight Beds and HiCan Smart Bed are only a few of several providers. Price ranges vary from slightly below $1,000 to several thousand, for example, a HiCan' smart bed costs about $30.000-. It has to be mentioned that HiCan's bed features gadgets for the whole bedroom with temperature control, light bulbs, blinds and a complete multimedia system.[4]

2.2 The form of waking up

Waking up is a whole process in itself. Gentle music, relaxing aromas or even the simulation of natural light can help in reducing the stressful moments of waking up. This type of technology is mostly used in connection with the before mentioned sleep-tracking system, as the perfect sleeping stage has to be determined in order to shape this process appropriately. All of these technologies function in mostly the same way: Through the pre-determined analysis of one's sleeping stage and the aligned wake up time, the system times the waking up process within a certain range of time. Smooth natural light, aromas or music start the process of awakening several minutes before the actual alarm.[5]

Specifically, the lighting systems are based on a empirical research. While the human eye is more light-sensitive in the morning than during the rest of the day, the daylight-alarm simulates the early sunrise to stimulate a natural rhythm. Varying products exist in the market with individual features and additional gadgets. Philips, for example, offers a basic version of a lighting-alarm starting at a price of 100€. However, more expensive gadgets can also be found. Withings offers an "aura-alarm system" that is directly connected to one's smart phone. Besides having an infinitely variable lighting system, users can also track their sleeping data with an additional sensor.

[4] https://www.lifewire.com/smart-bed-4161313

[5] https://www.faz.net/aktuell/technik-motor/technik/smartes-schlafzimmer-morgens-weckt-das-blaue-licht-13914139.html

Furthermore, an environment analysis can be done with the system, tracking the room temperature, noises and brightness.

2.3 The impact of light

Lighting systems, such as that by Phillip's, have gained in relevance due to an increased number of light sources close to our beds. Supported by varying studies, blue light has a strong negative impact on our health in the evening (during the daytime it boosts attention, reaction times and the mood) and is possibly connected to diseases, such as cancer, depression, prediabetes, heart disease and obesity. These effects occur due to suppression in the secretion of melatonin. Blue light is strongly emitted by electronics with screen, as well as energy efficient lighting. Smart lighting systems can help overcome these symptoms. By installing a pre-defined time routine, the system can vary the amount of light intensity and colours (by e.g. lowering the amount of blue light in the evening) and can help in adapting one's energy levels (e.g., more blue light in the morning to enhance the state of wakefulness and vice versa during the evening/night time).[6]

The price range of smart lighting bulbs vary from $15 – $200+. The first system started back in 2012 (Philips Hue) and is still regarded as one of the best smart lighting products on the market. However, other suppliers and bulbs are available on the market and are marketed by Ikea Tradfri, Lifx, C by Ge, Sengled Element and Nanloeaf.[7]

2.4 Light Therapy – Brighten up your life

Even more innovative inventions exist in the market, such as some that can even fight illnesses. The symptoms of winter blues include sleep problems, overeating, depression, anxiety, etc. It is caused by a lack of bright light in winter, which negatively influences our daily rhythm through reduced hormone production. 30 minutes of bright light, (at least 2000 lux) can help reducing the uncomfortableness caused by a lack of bright light.

> TEST SUBJECTS WERE UNSATISFIED WITH THE ADDITIONAL CABLING IN THE ROOM. IT WAS DESCRIBED AS A FEELING OF UNCOMFORTABLENESS.[8]

Lumie has developed a smart lighting system including lightboxes of up to 10.000 lux, which allow for a reduction in treatment times and enlarging the distance between the light and the person. It can be used during daily activities like working in the office or in the bedroom while watching TV. Being exposed to the light for a certain time per day can fight and prevent symptoms of winter

[6] https://www.health.harvard.edu/staying-healthy/blue-light-has-a-dark-side

[7] https://www.the-ambient.com/reviews/the-best-smart-lights-bulbs-platforms-209

[8] https://www.smart-wohnen.de/gesundheit-fitness/artikel/withings-aura-fuer-einen-erholsamen-schlaf/

blues. In order to complement its product, Lumie has invented a Bodyclock, which is based on the same technology like sleep-tracking systems described before.[9]

2.5 The sleeping environment

Many other, mostly unconscious, factors have a great influence on sleeping behaviour and subsequently also on a person's power level throughout the day. The sleeping environment can be adjusted in order to create the optimum requirements for a restful sleep. By influencing the air humidity (50-60%), darkness inside the bedroom and the room temperature (recommended to be between 16 and 18 degrees), one's sleeping behaviour can be positively influenced. Of course, preferences vary between individuals, which complicates the process of full automation, but machine learning could further enhance this process.[10]

A solution to the configuration of the ideal sleeping environments offers the smart system control of MyGekko. An individual sleeping mode can be adjusted and activated to connect sensors measuring air humidity, heating systems and air handling systems. After the manual instruction of the system, MyGekko automatically matches the varying devices to generate the perfect sleeping conditions. Additionally, MyGekko allows for the installation of particular scenarios to further automate the process. Eventually, the system connects the whole house.[11]

2.6 The optimization of one's sleeping position

The sleeping position is another pivotal point when it comes to satisfying one's sleeping needs. Back and neck pain, hip problems or a hollow back can be caused by sleeping in the wrong position. Furthermore, poor mattresses, slatted frames and pillows can even worsen, and sometimes even cause, these symptoms. The demand for adjustable beds was primarily that of the medical field.[12] Hospital patients, but also an increasing number of elderly people, are in need of them in order to prevent or fight the before mentioned inconveniences. Prevention was of lower relevance. However, automation processes could help to implement these prevention arrangements. An automatic adjustment of the mattress while sleeping would have the benefit of improving one's sleeping behaviour.

As suggested before, the initial technology is normally used in hospitals, elderly homes and even in private housing when necessary. The original technology had to be adjusted manually, which can be a disadvantage for elderly or ill people with special needs, and is not feasible for changing sleeping position throughout the night.[13] The Kingsdown Sleep Smart (unveiled in 2013) measures the impact of the user lying on the bed and includes the following factors: weight, position, pressure points, movements, etc. The data can be visualized on the user's mobile device and manually adapted to further increase the quality of sleep. The "care centre", which is the control unit of the smart bed, senses where the user may feel uncomfortable and adjusts the settings of the bed accordingly.[14]

Another example for an automatically adjusting bed is the already mentioned 360 bed from Sleep Numbers. Pressure monitoring is used to measure varying movements and to determine whether adjustments are necessary. The adaption of the place functions via "Responsive Air". The air automatically adapts to one's optimum sleeping position to support sleep quality. In addition, the 360 bed features the possibility to adjust for both people lying in bed simultaneously.[15]

[9] https://at-lumie.glopalstore.com/collections/light-therapy-sad?utm_campaign=cat_r&utm_source=https://www.lumie.com&utm_medium=wi_proxy&utm_content=en_GB&utm_term=a

[10] https://www.lanline.de/smart-home-technik-soll-gesunden-schlaf-foerdern/

[11] https://www.my-gekko.com/de/anwendungstechnik-slide/18-0.html

[12] https://www.healthcarefacilitiestoday.com/posts/Smart-beds-can-improve-safety--3809

[13] https://economictimes.indiatimes.com/magazines/panache/this-smart-bed-can-adjust-itself-and-help-you-sleep-like-a-baby/articleshow/62393616.cms

[14] https://www.beds.org/mattress/kingsdown-sleep-smart.php

[15] https://www.sleepnumber.com/360

2.7 Snoring-related problems

Another disruptive influential factor can be attributed to peoples' bedfellow. Snoring has been identified as a severe relationship-killer and can even increase the risk of heart attacks, strokes, etc. (the unhealthy type of snoring, so called sleep apnoea, is a more non rhythmical type of snoring, while typical snoring is somewhat permanent).[16] Surgery procedures, separated bedrooms, or sleeping masks have been used in order to fight this problem. However, adapting the sleeping position can often help to overcome normal snoring, while sleep apnoea could at least be screened/predicted by traditional smart beds and fought afterwards.

The technology behind fighting someone's snoring problem is mostly based on changing the person's sleeping position. While smart beds normally adjust the air chambers accordingly to raise one's sleeping position (which is said to stop someone from snoring), smart pillows start vibrating to encourage the person to turn over which is also an effective way to stop someone's snoring. [17] Again, Sleep Number's 360 bed features this device, but also an Italian manufacturer has developed a $20.000 smart bed which promises to restore peace in the bedroom.[18]

The most prominent smart pillow technology belongs to REM-Fit ZEEQ's kick-starter project.[19] At a cost of 199€ the pillow does not only start vibrating when the user starts snoring, it also features varying innovative ideas. A different approach is used by the Smart Nora device.[20] When snoring is detected, Nora triggers a gentle movement that is intended to stimulate the throat muscle. This stimulation will eventually lead to a normalization of natural breathing without snoring.[21]

2.8 "Space battles" in the bedroom

In the same way that snoring can disturb someone's sleeping behaviour, sleeping together can involve certain "space battles" too.[22] Movements within sleep often lead to space problems. This sleep disturbance may pose a relationship problem and tremendously affects sleep quality. Not only can sleeplessness result from it and harm the relationship, but also the health of the people concerned. Separated beds are normally used to fight this inconvenience, which is said to be an unsatisfying solution. Imitating the conveyor belt logic, an automatic system developed by Ford promises to target this problem. While one side of the bed is left unoccupied, with a resulting

[16] https://www.the-hospitalist.org/hospitalist/article/124917/smart-bed-could-improve-efficiency

[17] https://www.snorenation.com/how-smart-bed-technology-helps-you-stop-snoring/,

[18] http://fortune.com/2018/01/12/magniflex-smart-bed-stop-snoring-sleep-number/

[19] https://www.forbes.com/sites/forbes-finds/2018/06/27/this-smart-pillow-will-stop-your-partners-terrible-snoring/#60c60ab671d9

[20] https://www.smartnora.com/

[21] https://www.cnet.com/reviews/smart-nora-preview/

[22] https://www.huffingtonpost.de/2017/07/21/paar-beziehung-bett-schlafen-tipps_n_17549402.html

shortage of space for the second person, the bed automatically tows the mattress system in order to create new space for the affected partner.[23]

This technology is currently not available and was inspired by lane-keeping assistants. It can be compared to conveyor belts. In terms of marketing, Ford's project has already been a huge success with a great amount of people demanding the serial production of the bed. However, Ford has currently said that they are not planning to produce the bed in the near future.

2.9 The usage of sensors for age-related care

Even though more relevant in the medical sector and hospitalizing of patients, the usage of medical beds, even in private households, is increasing. The continuous trend of our aging society goes hand in hand with various problems, especially with regard to the rising need for care. Dementia patients, for example, often have to be monitored while sleeping to know when they stand up, as they are often not able to evaluate their strength and condition, which leads to a greater risk of falling.[24] Smart bedrooms could satisfy certain safety needs by informing relatives or nursing assistants when the person is standing up. The need for these sensors is also rising due to the challenges European healthcare system face: rehabilitation days in the hospital are sinking, which strengthens the demand for recovery and monitoring facilities at home. This need could be satisfied by the usage of smart facilities in mostly, but not exclusively, the bedroom. The second usage of medical beds and smart bedrooms would be the screening of vital functions (e.g. pulse or blood pressure).[25]

Regarding the first described technology, a smart mattress is used, which alarms the care-taking person when the patient stands up. Pressure sensors are used in the smart mattress, which are laid on the floor in front of the bed. An alarm signal is sent as soon the patient puts pressure on the mattress. Caremat has recently produced this gadget and is popular for safety protection in the dementia care sector.[26]

2.10 The medical usage of a smart bed

The possibilities on how to use a smart bed have taken many forms. In 2011, a study in Aachen, Germany, took place, which tested the capability of a BCG system (ballistocardiography) implemented in a bed to measure cardiopulmonary vibrations. This data was successfully used to monitor and detect cardiovascular diseases, in general, and heart failure, in particular. These diseases belong to the most common hospitalization causes in the industrialized world.

The BCG system based bed has not made it as a "smart bed" yet, but was sponsored by Philips research. It is based on the integration of highly sensitive medical sensors in the mattress or the bed frame. It produces outcome by monitoring specific vibrations caused by the heart activity and the respiration of the chest. The device was tested in varying daily tools and with differing sensors. The outcome has been more than positive. The system has been able to consistently and reliably detect cardiac arrhythmias.[27]

The sensor used in the smart bed could also be implemented in other household furniture like chairs or couches, but the accuracy has not yet been measured. In addition, the smart bed would fit the requirements perfectly, as a certain amount of time is needed to be spent in which the person has contact with the piece of furniture.

[23] https://diepresse.com/home/techscience/5579291/Smartes-Bett-schuetzt-vor-Revierkaempfen

[24] https://link.springer.com/content/pdf/10.1007%2F978-3-642-39470-6_24.pdf

[25] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6038300/

[26] https://www.pflegebetten-24.de/ratgeber/fixierung-und-bettgitter-am-pflegebett-wirklich-immer-noetig

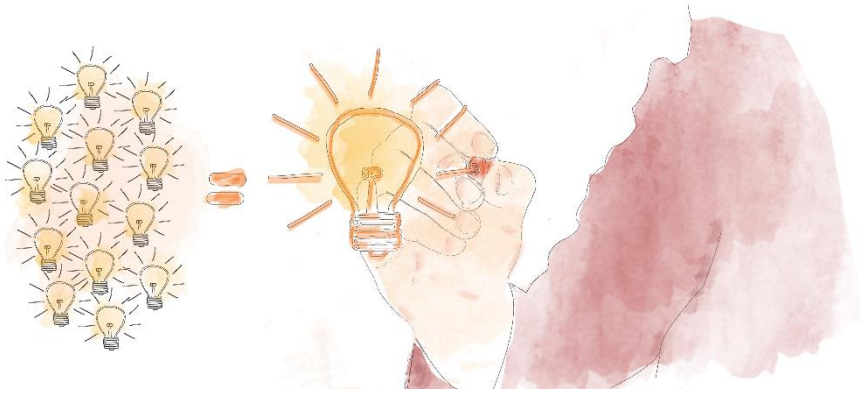
[27] https://ojs.cvut.cz/ojs/index.php/ap/article/view/1426

2.11 The most disruptive inventions

Of the many mentioned components of a smart bedroom, the pillow is perhaps the most underrated one. Beside its comfort, it includes a tremendous amount of features. The most advertised function is its ability to help a person avoid snoring. The pillow is equipped with a decibel-tuned microphone, screening for snoring noise, and is connected to a snore alarm. When reaching a specified height of decibels, the device starts vibrating gently to encourage the user to change positions and thereby stop snoring. Recent reviews mentioned that the microphone has not reached technological maturity yet, as it is not able to distinguish between snoring and changing positions.

The pillow also features a monitoring system, tracking how well a person has slept. A numeric analysis can be done, as the pillow offers a numeric sleep score too. However, it was also mentioned that traditional tracking devices are superior to the smart pillow's technology.

Different sleeping cycles can be disturbing in a relationship. The smart pillow ZEEQ will help to overcome these inconveniences. The partner-friendly alarm, for example, is helpful if ones does not want to wake their partner with their noisy alarm. By using a more than sufficient vibration, the device wakes one up while not affecting their partner. The audio-streaming gadget also allows one to listen to their music while their partner hardly hears anything. iTunes, Spotify, YouTube and even Audiobooks can be connected to the pillow and played until one falls asleep (a programmable turn-off function is included).[28]



Lucid dreaming describes the active knowledge of being in a dream.[29] Often, the person is even able to take some control over certain amounts of it (e.g. actively influencing the environment and some characters). Many methods and techniques have been developed to naturally reach lucid dreaming, but people often devote months, years or their whole lives to actively live them, without having a guarantee they will reach this stage. Studies have shown that gamma activity is present during a lucid dream, which is normally associated with consciousness.

The TACS (transcranial alternating current stimulation) method imparts mild electronic stimulation to the frontal regions in the brain, which helps in enhancing gamma activity. In a recent test run of the Lucid Dreamer, 77% of the participants succeeded and experienced lucid dreaming. The device can be controlled via an application and tracks lucid dreaming activity. Unfortunately, the Lucid Dreamer has not reached market maturity yet and it is unclear when, or if, a product will be sold. Other devices mostly work in the form of sleeping masks emitting light and noise signals. However, studies have proven that none of the induction methods were able to induce lucid dreaming reliably and consistently.[30]

[28] https://www.medgadget.com/2018/09/zeeq-worlds-smartest-pillow-a-medgadget-review.html

[29] https://www.luciddreamer.com/technology/

[30] https://www.sciencedirect.com/science/article/pii/S1053810012001614?via%3Dihub

3. Disadvantages and adaption barriers

As has been mentioned before, smart homes are connected to a variety of advantages. The most relevant factor considered is the enhancement of convenience within one's home. Through automation processes, the daily routine of users can be optimized. The trend of customization and individualism is also covered by this emerging technology. However, beside this positive influence, smart homes/bedrooms/beds are inevitably facing major drawbacks. In regard to the technology's development, no dominant design has been found yet. The lack of standardization increases the risk of relying on an entire system from one supplier.[31] Revolv Hub, for example, was bought and integrated by Google's automation system Nest. Within two years, after the expiration of warranty, Nest decided to close down Revolv Hub and its app, making the device useless.[32]

Another major disadvantage can be observed in the safety concerns. Due to the connection of all different parts of a smart home (starting from light bulbs to TVs and even coffee machines), the lack of security within one device threatens the stability of the whole system. A possible result is the hack of the smart system. Consequently, private households can be controlled externally or used to cause even greater damage. The power of such a hack was experienced in 2016 when a bot-network paralyzed a majority of the World Wide Web by using a huge amount of 'Internet-of-Things' goods to overstrain networks through countless requests.[33]

Regarding smart beds, Hunker has revealed a variety of disadvantages from the user's point of view. The sensor technology of less expensive beds can come with very thin foam toppers, making it very uncomfortable to sleep - especially for side sleepers. Also, trapped heat within air chambers is listed as a drawback. In addition, and often unconsidered, is the problem of sharing the bed with one's partner. Cuddling can be difficult, as a smart bed normally consists of two separate mattresses making it difficult to lie in the middle of the whole system. These effects can especially be seen in less expensive products leading to the last disadvantage: The price can be seen as a major barrier for the less wealthy population. Finally, the cabling of smart systems and the presumable need for a server are seen as a big problem.[34]

4. Conclusion

Smart bedrooms can be designed in varying ways. Most gadgets focus on lighting activities, sleep-tracking and health products, in general. Smart beds tend to include varying gadgets and are unsurprisingly seen as the central system in a bedroom. Two major tasks of smart bedrooms were identified within the process of writing the paper: The support of elderly people in order to deal with tasks regarding our aging society and the satisfaction of comfortability and sleeping demands in general. In regard to the technology, it has been identified that standardization processes have not started yet, with the dominant design expected to be established in the near future. Varying studies classify smart homes in the technology stage of "Crossing the chasm", which means they start marketing and selling High-Tech products to "mainstream" customers.[35] With regard to smart bedrooms, smart beds are the most developed gadget within "Crossing the Chasm". Other features are not as developed as the bed itself, but have a strong potential to gain popularity in the future. Many praised gadgets have not been marketed yet, but promise an exceptional future. Lucid dreaming, for example, could be realized soon, which can be seen as a disruptive innovation in the sleeping process.

[31] http://www.digitaljournal.com/tech-and-science/technology/costs-advantages-and-disadvantages-of-smart-homes/article/497912

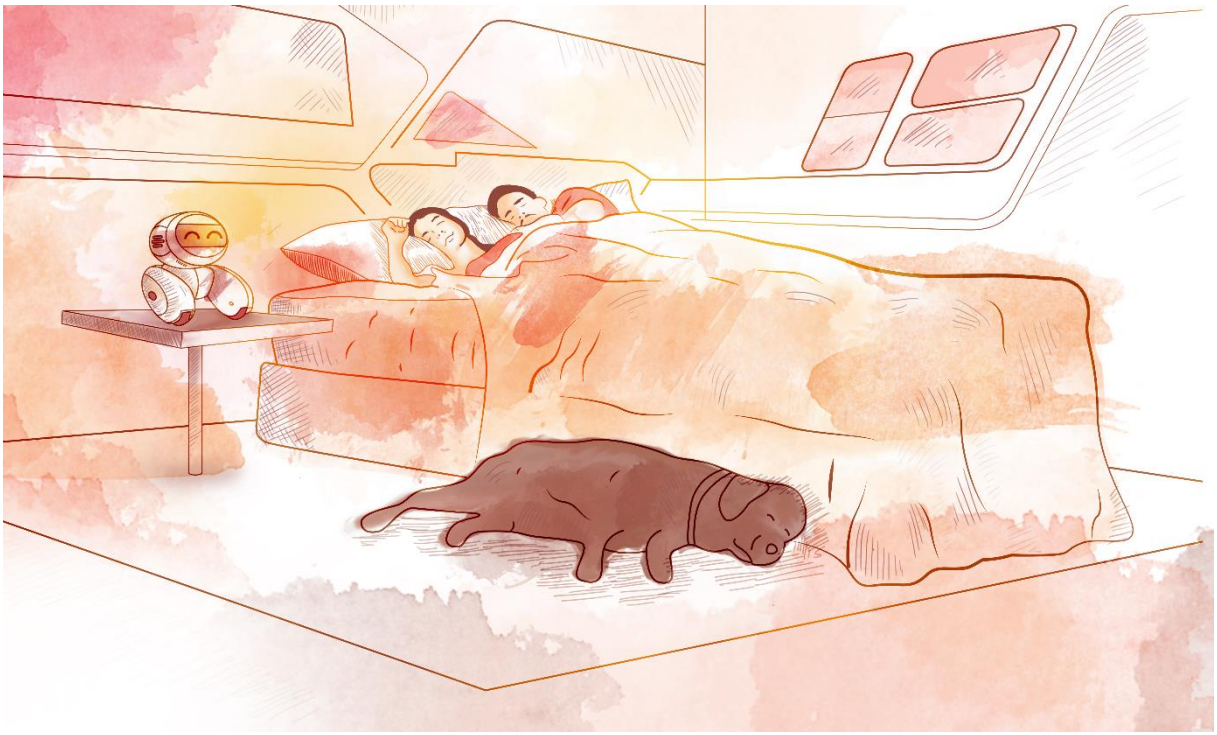
[32] https://www.theguardian.com/technology/2016/apr/05/revolv-devices-bricked-google-nest-smart-home

[33] https://www.welt.de/wirtschaft/article181408256/So-leicht-dringen-Hacker-in-ihr-Smart-Home-ein.html

[34] https://www.hunker.com/13710048/pros-cons-of-sleep-number-beds

[35] https://digit.hbs.org/submission/can-construction-tech-companies-win-the-war-over-the-smart-home-market/

It has to be stated that sleeping needs satisfied by smart technology are not decisive regarding sleeping well, as there are other external factors, like one's lifestyle and well-being, that have to be considered when enhance one's sleeping behaviour. Being actively involved in sports and eating a well-balanced diet are two major factors that affect the restfulness of sleeping.



Additional resources on sleeping disorder:

A report on the varying types of sleeping illnesses can be investigated under the following link (the other links are additional sources):

http://www.schweizer-gesundheit.ch/behandlung/stressbedingte-schlafstoerung-im-zusammenhang-mit-depressionen

https://www.ksm.ch/de/schlafkrankheiten/insomnie/symptome-und-ursachen-im-detail/index.html

https://www.smartsleep.de

http://www.spiegel.de/gesundheit/diagnose/schlafstoerungen-millionen-menschen-in-deutschland-betroffen-a-1152066.html

https://www.stern.de/wirtschaft/die-hoehle-der-loewen/die-hoehle-der-loewen--smartsleep---kann-man-sich-fit-schlafen--8220216.html

https://www.dak.de/dak/bundes-themen/muedes-deutschland-schlafstoerungen-steigen-deutlich-an-1885310.html