Engineering Smart Houses

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Preface

This document is a part of the Master's thesis that was created on the department of Informatics and Mathematical Modelling on the Technical University of Denmark. The work was carried out in a period from 02.02.2004 to 12.07.2004.

This thesis is intended for readers with basic technical and engineering background. It would be helpful to have basic knowledge about concepts of programming, networking and security, which are crucial for presenting different features of Smart Houses. Additionally it is assumed that the readers are familiar with various house technologies that are used in the houses nowadays.

I would like to give my special thanks to Christian Damsgaard Jensesn the Associate Professor at DTU, supervisor of my thesis for the invaluable help and guidance throughout the period this thesis was carried out. I would also like to thank my girlfriend, my family and my Colleagues Tomasz Cholewinski, Bojan Pajkovski and Jakub Walaszczyk for all their support and help.

Abstract

The concept of Ubiquitous Computing has over the years become more popular in research projects world wide. The technology is continuously progressing making the computing devices more powerful, of lower price and less energy consuming. As a result the computing can be introduced to different places and activities that never involved computation before.

The goal of the project is to investigate the application of Ambient Intelligence technologies also known as Smart Houses in home environments. A large body of research into Smart Houses has been conducted by research groups from different disciplines of information technology. As a consequence no common understanding of Smart House technology has emerged and no common terminology has been defined. In order to better understand and compare the contributions of individual projects, we have defined a taxonomy for smart houses, which focus on the aspects of who (or what) controls the Smart Houses.

The result of this investigation is in part presented by this report and in part on a website intended for an audience with a technical background. The website contains enough information to give a person with technical background a picture of Smart Houses and in particular Intelligent Houses technology.

For the purpose of the website a series of animations presenting different ambient intelligence technologies have been created. In order to facilitate the creation of such animations, we have developed a tool that provides some basic building blocks of smart house technology and a simple way of combining them. The basic set of functions and graphical objects are created in a way that allows for its reuse and easy extensions. The tool's specification with guidance of its usage and extension capabilities have been written and placed both in the theoretical part of the thesis and on the Smart House website. Both the website and the tool is available on the attached CD.

KEYWORDS:

Smart Houses, Intelligent Houses, Ambient Intelligence, Ubiquitous computing,
Human Computer Interaction

Contents

Chapter 1

Introduction

In his paper "The Computer for the 21st Century" [1] Mark Weiser presents the vision of Ubiquitous computing that in his opinion "will gradually emerge as the dominant mode of computer access over the next twenty years". The idea of small computers embedded in every device, piece of furniture or an item is currently quite unreal because of a number of aspects. Still, in the near future all the requirements could be possibly fulfilled. Also the need for the ubiquitous computing would arise.

The progress of computers in the last decade shows how fast the technology can improve. The processing power of personal computers is getting better and better, the memory is getting larger, the size of devices is getting smaller and finally the price is getting cheaper. Also the protocols and software components for using the hardware are made more efficient, reliable and secure. It is easily to predict that the requirements for the very small and cheap ubiquitous computers will eventually be satisfied.

Another issue worth mentioning is the need for ubiquitous computing. It can be seen nowadays how many people are using notebooks, PDAs and advanced mobile phones. One can also observe how house technologies have become crucial for people, as they tend to carry those devices with them practically everywhere. It is very likely that the possibility of having the functionality of those devices hidden in the background would gain a lot of interest.

The ubiquitous computing is not only about such a fundamental change as the disappearance of portable computers. According to Mark Weiser it is more about "making everything faster and easier to do, with less strain and mental gymnastics." The small improvements in our houses, offices and in many public places are the key for the propagation of Ubiquitous Computing.

House environments are an area where the continual progress of technology will be easily noticeable. In the modern times, the families have less and less time to spend with each other. In typical family both husband and wife work full time. Often there is a need to work overtime and there are different duties that people have to do after work. This results in the tendency that people return home tired and their free time they spent mostly on doing different house keeping activities. This creates a great need for the technological improvements in the house-keeping activities that could make them easier, less time consuming or sometimes even to relieve people from doing those activities.

The goal of this project is to investigate the particular applications of Ubiquitous Computing and Ambient Intelligence in the domestic environments. The study of different technologies is to be performed and the information about different kinds of technologies and various research projects needs to be gathered and presented in the theoretical part. The information should be put on the Engineering Smart House website that needs to be created during the project as well. Finally several animations to illustrate the usage of Intelligent Houses technology should be created.

The theoretical investigation was performed during the project and as a result the taxonomy of Smart House was created. Each category was described in details focusing on the advantages, disadvantages and the possible improvements that the technology can bring to people's lives. Moreover various research projects carried out on universities and by industry were presented with the focus on the technologies that they are researching. The group of Intelligent Houses was presented in more details. Different components of those houses were described and the technologies that are available on the market were listed and described.

The Smart House website was designed, created and described in a thesis. Additionally the tool prototype for creating Intelligent House simulations was created in Flash MX technology and several animations were created using that tool and placed on the website. All the important issues of the development of the prototype consisting of goals, analysis, design, implementation and testing were described together with the usage of the tool and with the possibilities of tool's extension.

In the next Chapter, the Technology of Smart Houses will be presented. This includes the taxonomy as well as a detailed description of the technologies and research projects. The third chapter consists of a detailed description of the Smart House website together with the description of the tool prototype that was created. Finally the conclusions will be presented, where all the issues from all the chapters are going to be summarised.

Chapter 2

The houses of the future

2.1 Introduction

Looking on the evolution of houses in the past it is worth to have a closer look on a period from the times when the first automation appeared in the houses. Equipment such as fridge, cooker or washing machines became commonly used in almost every house. They brought a huge improvement in the house life and become an inseparable part of every home. The benefits from the automation of houses were significant and the production and development of home-use equipment became a very important field of the market. Later the electronic devices appeared in people's lives. Equipment such as TV, VCR, radio or Hi-Fi became very popular source of entertainment and finally became an inseparable part of every home. The appearance of those entertaining devices was just an addition to the house, but the way that equipment evolved is a very interesting example to study.

People watch TV or listen to the music to relax, to spend their leisure time resting and enjoying the movie or their favourite band. The only problem that existed in the past was the need to get up in order to change some settings directly on the device. Soon the remote controls were introduced and now people cannot imagine operating for example TVs in any other way, in fact many features of modern TV sets can only be operated by using the remote control. Such a change is an example of technology that gained such a success only because it made people's lives much easier. Now when people relax in a sofa, watching a movie, they can easily adjust all the setting without changing their comfortable position. It is easy to conclude that making people's life easier is the driving force for the progress of the technology inside the house and if people are going to buy it, the manufacturers will produce it.

New trends in simplifying the usage of the house and its equipment can be seen in houses nowadays. There are more devices that can be controlled remotely like lights or window-blinds and there are some integrated remote controls combining TV and VCR or DVD functionality. In several sections of this chapter the houses of the future will be presented in the hierarchy that is formed by the logical evolution of technology. There will be a differentiation between several types of houses and each type will be described in details.

Issues such as motives behind each group of houses, requirements for the technology or advantages and disadvantages of particular technological approach will be presented. A number of projects carried out by Universities or Industry that we have identified will be presented in a thesis as well. Their goals, their results and the information that they make available on Internet will be addressed and all those information will be located at the end of each section of the second chapter.

2.2 Model of Smart Houses

Smart houses technology has come to mean different things in different environments. Simple but clever location of the switches that control major house subsystems (heating, lighting or air conditioning) or electronic appliances are an example of technologies called "smart". Also houses that apply artificial intelligence technology to support people inhabiting the house and facilitate their everyday tasks belong to the "smart" technology category.

In an attempt to establish a common basis for studying smart house technology, we have developed a taxonomy of smart houses, which divide the houses into several categories. Afterwards we studied the categories of the houses and rearranged them into the evolution model. We focused on the requirements of each kind of houses together with the improvement that each type of houses brings to people's lives. These elements allowed to create a logical sequence of houses and resulted in the evolution model. Both taxonomy and evolution model of Smart Houses are presented and described in the two following sections.

2.2.1 Taxonomy

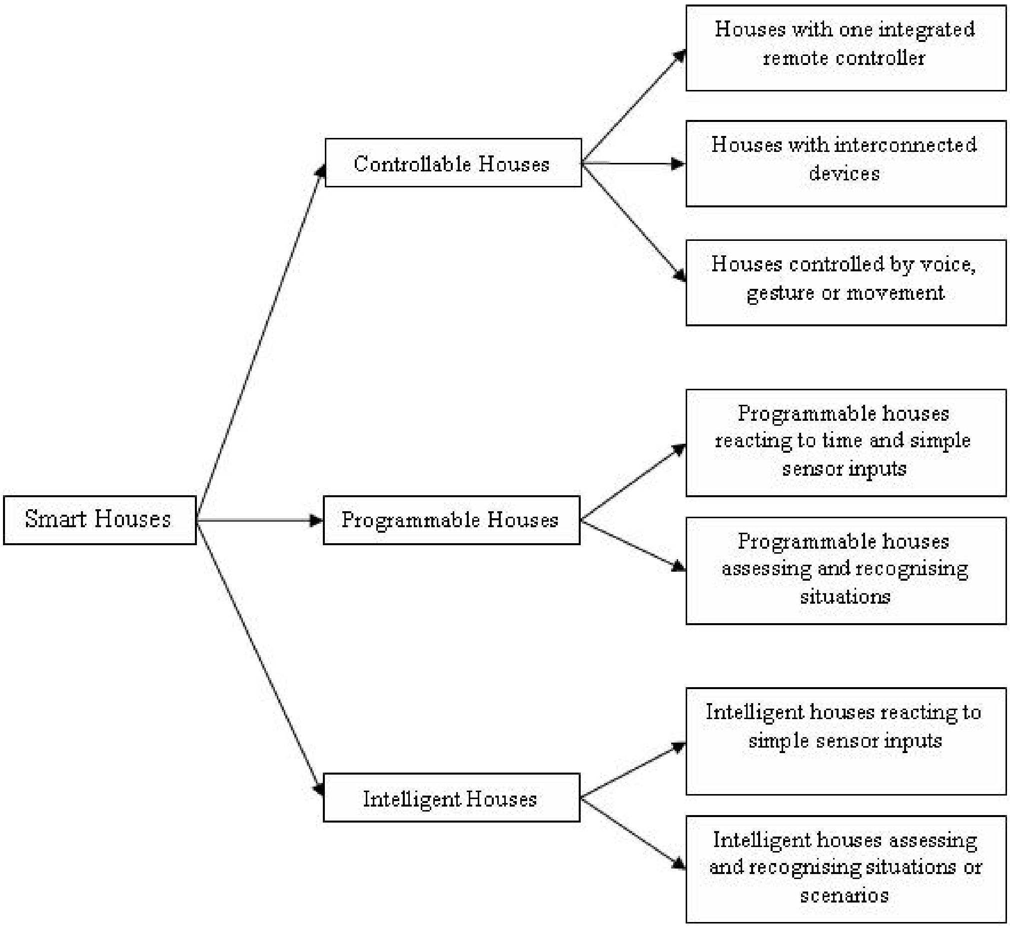

Figure 2.1: Taxonomy of Smart Houses

As it can be seen on the drawing above, Smart Houses can be divided into three main categories:

- **Controllable Houses** is the first category. This type deals with the improvement of the way, in which different equipment in the house is being controlled. It is a house, where an inhabitant can control different devices in more advanced and more efficient way than it is done in normal contemporary houses. We have identified three distinct classes of such houses:

  – **Houses with one integrated remote control**. In such a house a number of subsystems and appliances can be controlled from one remote control or a panel. There are no technical challenges in implementation of such an infrastructure. Simple remote or wired communication has to establish between devices and the control unit. An example of this technology is an integrated remote controller for the VCR and TV or a Bang & Olufsen [2] Master Controller.

  - **Houses with interconnected devices**. Different electronic devices like TV sets, VCRs, radios, computers and additional speakers, displays, microphones or cameras are connected with each other. Such infrastructure allows for media exchange between those devices and allows for more accessible entertainment or easy communications between people in different rooms in the house. There is a broadband network required within the house, but both wired and wireless technologies are commonly available for this purpose. Also the functionalities of previous type of houses are required, as there is a need for an easy control over all interconnected devices. Examples of this technology are KiSS [3] DivX/DVD players that gives the possibility to play movies in DivX format that are stored on the computer or streamed from the Internet. They also allow for wireless connections between the TV screen and players.

  - **Houses controlled by voice, gesture or movement**. Such infrastructure could be similar to the house from the first subgroup. The only difference is that a visible controlling unit is replaced with an invisible one that reacts on people voice, movement or gesture. There is no problem with the hardware to support such type of house, opposite to the software, which is a difficult part. The reason for that are the voice or gesture recognition capabilities, which need to be really reliable. Described here technologies would be similar to the voice dial functionality of modern phones or communication with the computer on the star ship Enterprise from the TV series Star Trek.

- **The Programmable Houses** are the second category of Smart Houses. Such infrastructure allows programming the house so it would switch on, switch of or adjust some devices in particular conditions. We have identified two subclasses:

  - First group are **Programmable Houses reacting to time and simple sensor inputs**. Time allows some devices to be turned on or off at a particular time, another example of sensor input is a simple thermostat, which switches on or off when the temperature somewhere in the house reaches a certain level or a dusk sensor that switches on the lights when it gets dark outside the house. Basically it is a data from one reliable sensor that triggers other devices to change their state. There are no technical problems with an implementation as different sensors with high reliability are commonly available on a market.

  - **Programmable Houses assessing and recognising situations**. Such houses have a possibility to recognise simultaneous input from several sensors as a particular scenario. For example the inhabitant, tired after long hard work, returns home and lies down on a couch to take a nap. Then the house could turn off the lights and play some soft music for a while. Such scenario has to be defined and programmed in advance. The house does not react to the changing environment and has to be reprogrammed every time some changes occur. With the functionalities of the programmable house, there is a need for reliable software that would analyze the situation correctly. Additionally there is a need for the careful programming of the house so the scenarios stored in the processing unit would be identical to the real ones.

- **The Intelligent Houses belongs** to the last category of Smart Houses. Such a group is very similar to the previous one, with one small exception - there would be no need to program any functionalities as the house would do it by itself. The ambient intelligence in the house would observe the inhabitants in their everyday life, searching for repeated actions. After a pattern has been identified the house will program itself, so that the next time the scenario is recognised, the house automatically switches on or off certain equipment. There are two subcategories that are identical to those of Programmable Houses. Those that are **reacting to simple sensor inputs** and those that are **assessing and recognising situations or scenarios**. Their properties and requirements are identical to the ones in the Programmable Houses group.

2.2.2 Evolution model

The advantage of the evolution model presented on the figure 2.2 is the possibility to identify areas of R&D that will allow us to progress to the consecutive group of Smart houses.

This model was created focusing on the improvement that each type of house brings to people's life. For example it is very easy and convenient to control various devices using voice, but it is even easier to program the house once, so there would be no need to control any devices, as they would be controlled automatically by the house. Such scenario is of course too idealistic, but in the following sections of the chapter all advantages and disadvantages of different technologies will be addressed in more details. All the houses together with the technologies they consist of will be presented in the following sections according to the evolution model that was presented above. Additionally all the relations of different types of Smart Houses that lead to their place in the evolution model will be highlighted.

The last issue about the evolution model that need to be presented in this section is the position of the contemporary houses in the evolution. The modern houses considered as whole, belong to the first category in the model - "Modern Houses where some devices can be controlled remotely". Still if separate technologies are considered it is possible to find functionalities of more advanced kinds of houses. Examples mentioned earlier such as integrated Master Controller by Bang & Olufsen [2] or KiSS [3] players shows that the functionalities of Controllable Houses are already present in some of our houses. It is possible to find some features of programmable houses nowadays as well. The lights that are switched on, when a motion sensor detects any movement or when a dusk sensor detects imminent night are good examples of the sensors that lead to switching on or off some home use devices. Also the security systems where, the video camera starts recording or an alarm is switched on when some security sensors are triggered are good examples of programmable technologies. With time they will get more popular and will be used in the ordinary houses.

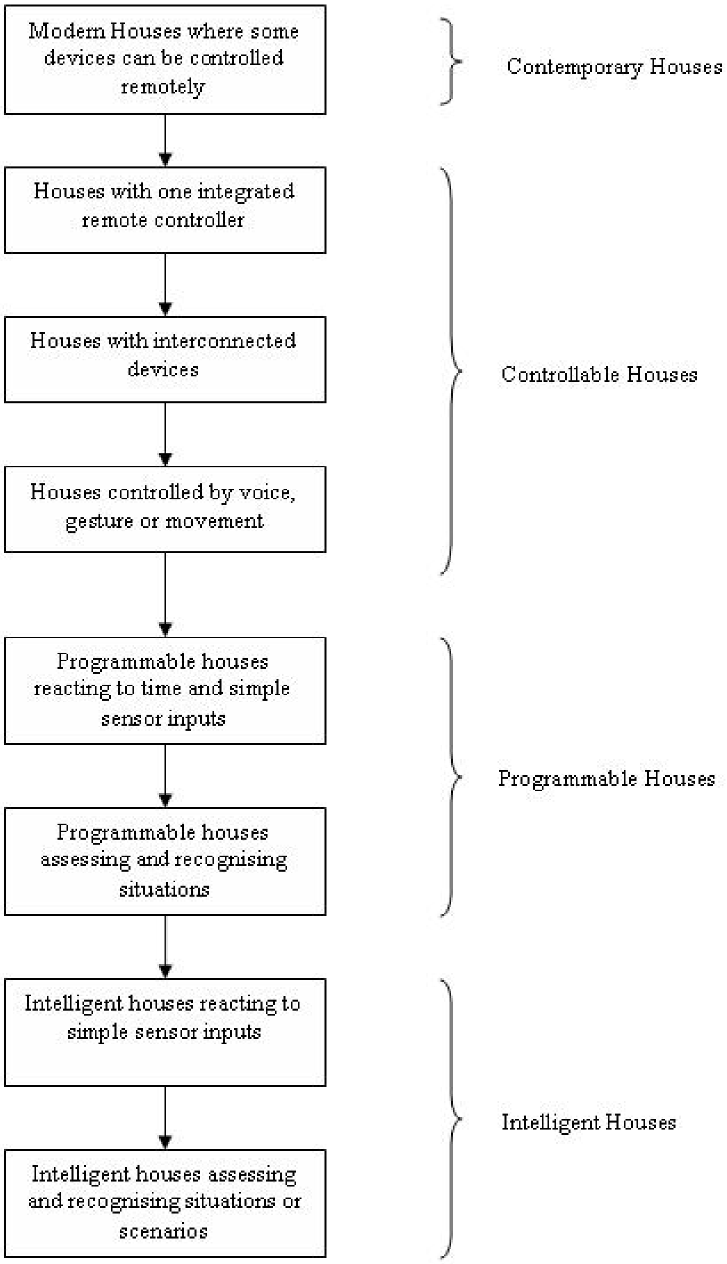

Figure 2.2: Evolution model of Smart Houses

2.3 Controllable Houses

Nowadays there is an increasing amount of equipment in the houses that can be controlled remotely. Still there is one obstacle preventing those devices from becoming widespread. It is the way they are controlled. It is easy to create a remote control similar to those people use for TV, but houses would end up full of different remotes laying everywhere. Hence together with the expansion of automated equipment in the houses there is a need to integrate all the controlling devices into one consolidated appliance. The most popular solutions are panels located in various places in the house. Usually, there are medium size touch screen with a simple interface and are placed in the main points in the house, like at the entrance or in the kitchen. There exist a limitation of such solution it can be used for setting the temperature, lights or alarm, but it is not a convenient method for operating TV or Hi-Fi as this is done usually from the armchair. Hence still the ordinary remote controls are necessary.

Second approach to such a problem is a portable remote panel, usually in the form of a laptop screen or a PDA. It would be possible to use a standard PDA or a mobile phone equipped with Bluetooth for this purpose. Such solution seems to be much more usable, still it has some limitations as well. A 14 inches touch screen would be capable of providing intuitive and easy to use interface, but the size of such a device would be too big for carrying it around easily. The mobile phone or a device of that size due to its small screen would not be a convenient solution for a controlling device as well. Small screen size would not be capable of presenting the house and all its components in a usable way. Hence the best solutions would be a PDA or a device with a similar screen and similar size. It would be an intermediary solution combining the features of a portable handy device and a clear and usable interface.

With the existence of a usable way for the remote control, another progress is possible within the living spaces. Practically every piece of equipment in the house can be made automatic. Then various things like doors, windows, garden lamps, air conditioning, temperature, water heating can be controlled from one place in the house. Also electronic devices can benefit from the possibility of controlling from the distance. It is possible to interconnect all media devices like computer, TV, DVD, VCR, Hi-Fi and additionally install some more screens and speakers all around the house and profit from them. It would be possible to watch TV or listen to the music in various places of the house, not only in the room were the particular equipment is located. It could make activities like cooking more enjoyable as it would be possible to watch a movie while working in the kitchen. Activities like watching TV even more relaxing, as it would be possible to watch a favourite program, movie or stream from internet while for example taking a bath. Additionally activities that people do on the Internet everyday, like checking the news, checking emails, watching movie trailers or searching for some information, would become less time consuming and they could be done while doing other activities.

There is one more improvement to such connected house that can be seen in the research projects on Internet. By installing some microphones and possibly video cameras, people can communicate easily with other inhabitants in the house. They could answer the intercom from any place in the house, and if they are absent, the guest can record himself on the camera at the front door. Again it seems like a good concept that makes living in the house easier for its inhabitants, but it has actually some negative sides. It is easy to observe a trend where visionaries, companies or research groups are trying to make something that is possible to do or challenge something that is very difficult to do without considering its actual need. It is often forgotten mostly in infrastructure mentioned above, that all development should be human centred. For a project to enter the market it has to address the needs of a large group of people not just individuals dazzled by the vision of a futuristic house. Additionally such house infrastructure could isolate the members of the family which conflicts with one of the goals underlining the development of the automated house - the concept that the house automation should save time so that the inhabitants could spend it with their families.

Another feature that could be controversial in its usefulness is the possibility to control the house from outside using the Internet. The controlling infrastructure within the house makes such a solution very easy to implement, as there is already one processing unit that control all equipment. Hence it would be just one device that would need to be connected to Internet. Still additional requirements concerning technology, security and privacy arise with such functionalities. So is such a control of the house a feature that people actually need? It is possible that such technology could actually bring more risks than advantages to the users. And again such development would be far from being human centred.

Besides of such few unnecessary features, the infrastructure of houses mentioned above is still worth researching and developing. A lot of its functionalities could highly improve the quality of life within the living spaces. Additionally the connection between various devices within the house gives a possibility for more advanced automated houses to show their real potential. Hence in Various projects on the Internet the features of controllable houses can be found and those research projects are going to be described in following section.

2.3.1 Controllable House projects

There are various projects that deals with the infrastructure of houses described in the previous section. One of the reasons for such a popularity is that it is relatively easy to fulfil requirements. There are already technologies that are cheap and convenient for both wired and wireless communications between different devices. The bandwidth provided by existing networks is capable of streaming high quality video and audio. The equipment such as touch screens, speakers, microphones are generally available and are relatively cheap. Additionally as many electronic devices are associated with infrastructure of controllable houses, big corporations that manufacture electronics would profit from popularity of such technologies. This results in those companies carrying out or supporting research projects. And with sufficient market power they could greatly contribute to the introduction of such technologies into the market.

Most of the projects and research carried out by different universities focus on advanced, challenging technologies and only few deals with the capabilities of the houses mentioned above. Still there are various functionalities of a controllable house that are included in the projects the research groups are creating. Differently, the hardware and software manufactures focus mainly on the group of technologies mentioned in the previous section. One of the projects that are worth mentioning is the "House of the future" made by Microsoft [16]. It is a flat with a surface area around 750 square meters, which is created in one of the buildings on Microsoft's campus in Washington and it is not actually a true research place. It is a place full of electronic that forms a vision of how possibly the living spaces could look like in the future. It does not try to dictate the future, but rather to present some possible scenarios. The house, which by its visitors may be called a "Disneyland style demo", is presenting a lot of advanced technological solutions. The electronic devices are interconnected with each other. The house gives the possibility to check emails on the TV screen. A projector in the Kitchen allows displaying different media on the wall and there is a place with huge screen that is a centre for the home entertainment - music, movies or videos. Also the touch screen outside the main entrance to the house can record a message that later could be shown in various places inside the house. For the controlling purposes there are pocket PCs that are embedded in the walls in different places of the house. It is possible to control the media devices in the house and additionally other equipment, like all the lights.

Besides the House of the Future, which is just a presentation of capabilities of the technology, Microsoft has two other projects that focus on actual implementations. One of them is a virtual media centre called "Freestyle" [17], which allows watching movies and listening to music on the computer with a remote control and a convenient interface similar to those in ordinary TV or Hi-Fi equipment. Another interesting project is an extension of the monitor called "Mira" [17]. It is an wireless touch screen that allows working with the computer from any place in the house and the handwriting recognition from the Pocket PCs is supporting the interaction with the computer. Both projects gained an interest from the electronic manufacturers that work on hardware to support those Microsoft technologies.

Phillips also carries out research into automated houses [4]. The project that focuses on the functionalities described in the previous section is called WWICE, which stands for World Wide Information, Communication and Entertainment [5]. The project deals with the connection within the house. The key element is a portable screen that can easily link to all the devices present and serve for both control purposes and for exchange of multimedia. Any media displayed or played on any screen or speaker in a room can be transferred to the portable and vice versa. Also a number of the devices within the house are connected with each other and allow the inhabitants to use the resources provided by any piece of equipment in any room in a house. Additional functionality is the concept of connection between different houses. So friends can watch the same movie or listen to the same music while having a video chat.

Another project worth mentioning is PHENOM [6]. Even though it focuses on more advanced concepts, its infrastructure relies on connection between different devices in a house. So for example a photo album could be displayed in any place in the house. Additionally there is a portable touch screen device that can be used for managing the display of different resources. Both projects mentioned above are being tested in a place called "HomeLab". It is a laboratory, where Phillips is testing their projects. There are some volunteers that live in a house for a given period and the researchers can observe their interactions with the system. This makes the projects human centred and allows answering the most important question of automated houses - are humans going to actually benefit from the technology and what would be the influence of the house automation on people.

Other companies that deal with automated houses are Ericsson and Electrolux, which created the e2Home company [8] for research and development of electronic household services. The company offers various applications that are controlled by a central terminal located usually in the kitchen. From such touch screen it is possible to control lights, alarms, electronic locks, energy usage and other parameters of the house. Also there is a feature of easy communication with services outside of the house for example booking common areas in the neighbourhood like a laundry. Additionally it is a possibility to access the home services when an inhabitant is for example at work by using a mobile phone or Internet.

While developing all the above mentioned functionalities e2Home is focusing on the aspects that they find most important. Those are the user friendly interface, security, privacy and the relevance of the services. And what is particularly interesting in the e2Home efforts is the fact that it succeeded in the real life implementations. Besides of the typical houses for testing the e2Home products, a Ringblomman condominium in Stockholm, was created. The condominium consists of 59 IT apartments, each of them equipped with the control panel providing the functionalities offered by E2Home Company. Hence the inhabitants have control over their house or can for example check their emails from the terminal. There is a great focus on communication with the condominium itself for example booking the common areas like laundry or sauna, contacting the administrator or ordering some food. The investment was really popular and all the flats were sold out long before the end of the construction.

The last project worth describing in this section is a Japanese TRON [9] which stands for The Real-time system Nucleus. This project is being carried out on the University of Tokyo and focuses on such concepts as ubiquitous computing, small size of devices, natural human interfaces or security. The researchers deal with both software and hardware, providing mostly the interfaces and design guidelines for their creations. Nevertheless they also create different implementations. One of them is a TRON Intelligent House [10] created in 1989 in Nishi Azabu in Japan which existed for three years. It was a blending of traditional wooden architecture with the computer technology. All the media received from outside like TV or phone together with the internal data from intercom or security sensors were put together in the display units available in each room. Additionally there was a central control panel and a general purpose remote control. Hence the house had the exact combination of features described in the section above with no unnecessary gadgets. Still during its existence period it got some negative opinions from the press, showing how sceptical people are to the idea of the technology that would surround them everyday.

2.4 Voice, Movement, Gesture

In the previous section it was shown how the usage of various equipment in the house can be simplified. Still there is a great potential to improve it even more. Hence there is a subgroup of Controllable Houses that show more advanced approach to the control over the house devices. Those are houses capable of voice, movement or gesture recognition. It would be natural and intuitive to say a command in order to switch on/off or adjust any device. There would be no need to approach any terminals or carry and look for any controlling devices. This advantage is consistent to a very important goal underlining development of Smart houses - that the technology should be not intrusive, should be invisible. People would like to live in an ordinary house, not a house full of different electronic equipment. The house environment should stay natural and contains natural interfaces to control the house.

There exist several technical requirements for such a type of houses. A lot of those deal with difficult and challenging technologies that do not have any professional solutions on the market. The most basic requirement is a communication network in a house. Such infrastructure is very similar to the one described in the previous section where there was one control panel in a house. In this case instead of a panel there is an invisible processing unit that makes the decisions and control the house equipment. Such a central computer has to be connected by a network of a higher bandwidth with several sensors like microphones, movement sensors or video cameras.

Above mentioned equipment is commonly available and relatively cheap. Also the capabilities of detecting and capturing data are on a satisfactory level. The problems arise with processing of the data from microphones or video cameras. There exist different technologies that deal with voice or gesture recognition, but the reliability is not always at the satisfactory level. The voice recognition is in much better situation. As it provides very intuitive way of controlling different devices, hence the Human Computer Interaction science deals with such issues. Additionally it gives very convenient way to control various popular devices like mobile phones. Thus, there is a need for the voice recognition technology on a market and for that reason many companies are involved in its development process. Still a successful implementation of voice recognition software for different devices does not imply the reliability of use of such technology in the houses. While giving a voice command to a mobile phone, the mouth of the user is located close to the microphone or the user is located in a car, where there are no other interferences. Differently in the house, where potentially the sounds of other people, radio, TV or other equipment would interfere with the users command and would make the recognition very difficult and less reliable. Additionally there is a problem when an inhabitant is speaking with other people in the house. It could be very difficult to determine whether a key word was a command to the house or whether it was an ordinary word in a sentence. Such problems could lead to the scenario, where an inhabitant would need to follow a certain procedure in order to give a command to the house. Also the way of speaking would require certain patterns like saying command very loudly. Such requirements would result in a less natural way of communication and would be far away from being convenient. It can be concluded that the voice recognition technology has several achievements, but still there is a certain progress to be done before reaching a sufficient level of reliability.

Another way of controlling a house is by movement or gesture. Such solutions have some disadvantages comparing to the voice recognition technology. The video cameras are much more expensive than ordinary microphones. Also there are more devices needed to capture gesture than to capture voice. For example on microphone is enough to capture voice from all over the room, in the same time it is necessary to have multiple cameras to capture the gesticulation of a person moving freely all over the room. Still there are some advantages of visual recognition solution. First of all, there is less external interference with the desired movement. Different intensity of light or different colours of clothes can make the recognition more difficult, but not as much as noises can disturb the voice commands. Additionally it is easier to control some devices, as context is also available. By the location of an inhabitant or by a direction of the gesture the right equipment can be recognised. The last advantages of using gesture recognition are the additional functionalities of video cameras. They can be used to identify the person by some face recognition algorithms and they can be used for intrusion detection purposes. As for person recognition it would give more capabilities to a controllable house, as it would be possible to identify who is giving a particular command. Still some problems can be noticed from the experiences of security systems for example on airports. It appears that it is quite easy to deceive a face recognition system by wearing a hat, sun glasses or a beard. Then the functionality of such system would have great capabilities but the reliability would be not sufficient to make the use of such system in the house convenient.

The main problem with the gesture recognition is the form in which hands need to move to be classified by the system. For achieving high reliability of the system some certain requirements have to be fulfilled. The camera needs to have a clear view on the hands of the inhabitant. Additionally it would be appreciated if the background would have a contrasting colour to the hands of a user. This leads to a particular compromise between natural and easy way of controlling the house and the reliability. It is very easy to detect and reliably classify movement, wide gesticulation or gesture performed in special places. But such constraints would make the usage of the house more annoying and difficult rather than easier and more comfortable. On the other hand making the controlling process very easy by small gestures anywhere in a house would greatly decrease its reliability. The solution to improve those scenarios could be to use both voice and gesture recognition. As a result a system would get the advantages of both technologies and should achieve quite good reliability with a quite convenient controlling mechanism.

Additionally the problems of lack of reliability or unnatural ways of control are caused by the real time requirements. For the usage of the system to be convenient, all the commands should be recognised and classified instantly. That could be a requirement difficult to achieve. The reason is that the people move, gesticulate and speak simultaneously. Hence a system has to analyze a large portion of data from different video cameras and microphones searching for the key patterns. This could result in less powerful and precise algorithms.

All those technical problems will be eventually solved in the near future, but still there would be one disadvantage of controllable houses that would persist, which is the unhealthy way of living that such a system promotes. Already in western civilised countries there is a problem of people spending too much time in front of TV and becoming so called "coach potatoes". The possibility that people could adjust setting of surrounding equipment by easy gestures or voice commands would take away the rest of their exercises. Of course it is not the technology that is to be blamed but people who choose such a life style. Still the technology is influencing our day to day life and makes some changes in people's life style.

2.4.1 Projects dealing with voice or gesture recognition

Similarly to the houses described in the previous section, houses providing voice or gesture recognition functionalities have many references on Internet. The fact that the requirements for such type of houses are not easy to fulfil is actually the reason for a great interest in this field. The universities or different research groups are interested in the challenges of the technology that need to be overcame. The need for improvements in different technologies gives potential topics for the PhD thesis or for large research projects. Nevertheless projects carried out by the industry are dealing with the gesture or voice recognition house infrastructure as well.

Various projects like TRON [9] or e2Home [8] that were mentioned in the previous section deals with the issues of Human Computer Interactions. Still they limit the voice or gesture recognition issues to be mentioned just in general concepts. There have no research or implementations in this area. There are many similar projects, but there are also ones that address the voice or movement control in more details. For example projects that are carried out by the Agent-based Intelligent Reactive Environments (AIRE) group [19] in the Massachusetts Institute of Technology.

The AIRE research group on MIT Computer Science and Artificial Intelligence Laboratory creates software components for various applications. Majority of them deals with intelligent spaces and their equipment. They try to cover all the important fields of the intelligent spaces development like the human computer interfaces, resource management, knowledge representation, computational needs, communication, distribution, parallelism etc They mostly focus on work spaces rather than living spaces. Still the technologies they create are not limited to the office use only. Among their projects a very interesting one is an Intelligent Room prototype space [20]. The purpose of its creation is to study different types of human-computer interaction. The most important mean of controlling the room is the voice. For the best audio quality the users have a small wireless microphone attached to their clothes. Hence a user can speak in any point of the room, but there is a special procedure that needs to be performed. The computer processing the speech is initially in the sleeping mode. For activating the computer a user has to stop speaking and say a keyword "computer". Then all what is said is being processed, searching for a known command. After a wile the computer is going to sleep mode again. Theoretically the Intelligent Room can recognise naturally spoken language. Still there is a trade of between the performance and the variety of grammar structure that the system can recognised. Hence there is a need to use specified grammar structures for controlling the room. Also there is an improvement using context recognition functionality. For example when a video is being displayed at the moment, the computer tries to use the set of grammar that involves controlling the video stream and the display.

Additionally to the voice commands there is a functionality that is similar to gesture recognition. The system in a room can recognise when a user is pointing on a display. This is system is rather used for interaction with personal computer instead of using traditional mouse. Still the technology can be used in other purposes as well. During the tests of Intelligent Room it was noticed how changes in placement of sensors, changes in ambient lights and shadows can influence the reliability of the visual recognition. Hence the technology was reliable only in fixed configuration and was not a promising one.

Another important project carried out by the AIRE group is the Oxygen project [13]. The key elements of its implementations are the devices embedded in the houses, cars or offices or the handheld devices with identical functionality. The Oxygen project focuses mostly on combining speech recognition with recognition of facial expressions, lips movement and gaze to support it. All the software and the hardware is similarly to the Intelligent Room, described or created on other projects of the AIRE research groups.

Another project worth mentioning is the Aware Home Research Initiative (AHRI) project [14] on Georgia Institute of Technology. The AHRI group is trying to address future domestic technologies. In their 470 square meters home they focuses on various functionalities of Smart Houses. The technology for controlling various equipment in the house relies on the gesture recognition. To make its usage natural and convenient a special gesture pendant was introduced. The pendant is a device that contains a wireless camera. An inhabitant of the house has to carry the pendant with him all the time and all the gesture has to be performed just in front of it. Because of this requirements a high reliability of the system was achieved. And a pendant with a good design and small size would not disturb people using it.

Very interesting project is also being researched by Phillips Company. It is called "Easy Access" [7]. The project deals with the interaction between people and a large database with multimedia resources. In the particular implementation that was carried out by Phillips, the database contained large music library. The interface allowing a user to choose a song was implemented using voice recognition technology. In particular a "query-by-humming" functionality was created. The system is capable of recognizing the song using a short sample that was hummed by the user. Event though such functionality is very narrow in its usage, it is interesting as it deals with much complicated voice analyse then regular speech recognition. And the project, being successful reached the "Internet-connected audio jukebox" implementation.

Another paper that is worth mentioning is called "Scenarios for Ambient Intelligence in 2010" [18]. It created in May 2004 by the Information Society Technologies Advisory Group (ISTAG) with cooperation of 35 European experts. The scenarios were not meant to predict anything, but rather to inspire people and cause some interest in the area of Ambient Intelligence. The paper presents several scenarios together with their social and political factors, business and industrial models and finally the technical requirements. The scenarios are dealing with ubiquitous computing in various places, from the houses, offices, to the restaurants and hotel rooms. The range of technologies covers various functionalities of smart houses. One of those functionalities is a voice recognition technology. It is stated in the paper, that the technology is very important as it will allow for miniaturisation of electronic devices. The paper does not contain any results of any implementations of technologies, but it presents many valuable aspects of ambient intelligence that are important in its development process.

The last project worth presenting is the Microsoft House of the Future [16] that was mentioned in the previous section. As the house has a presentation purpose and consists of different technologies, it also contains the voice recognition functionality. The place where it is used is a kitchen where an inhabitant can get help from the computer about the recipes. All communication with the computer is carried out using voice. The speech recognition implementation is not a reliable one and Microsoft explains that the reason is that such technology does not have any professional implementations on the market. This fact highlights the pure presentation purpose of Microsoft House of the Future.

2.4.2 Emotion and thoughts

There is one more way how equipment in a Smart House can be controlled. The house system could recognise emotions or thoughts of an inhabitant. It could be used as a stand alone feature or to improve the functionality of for example speech recognition. The idea seems to be quite futuristic, but there are some examples of different projects that actually experiment with such technology with a certain successes. For example emotions can be recognised by studying the face of a human and recognizing the mimics corresponding to a particular state of emotions. Such a feature is used on the Oxygen project [13] on MIT as an addition to the voice recognition functionality.

The thought is an attribute much more difficult to detect and recognise. There are no references in any Smart House project to such a functionality, but in some papers the visionaries are mentioning such technology as possible to exist in the future. The vision is not so abstract, as there are some cases in the modern science, where some signals from human brain can be read. As an example the EEG Biofeedback training [22] can be presented. Such a training gives skills in forcing the mind to relax, to concentrate, to calm, to become active etc On the training a person is playing a simple computer game. There is no mouse or keyboard to play the game. Instead there are some sensors attached to the head that senses the brainwaves. By creating more brainwaves of one kind the computer is giving right commands to the game. As a result, a person can learn how to adjust the brainwaves and the same way can learn how to change the state of its mind.

2.5 Programmable Houses

In the previous section it was shown how the process of controlling various equipment in a house can improve. Different technologies were described offering more and more convenient solutions. Still there is always some need and effort to control various house appliances. Hence there is another improvement that can be made. Such improvement is offered by the Programmable Houses. The motivation under such a technology is very simple. Instead of performing some activities all the time, the house could be programmed so that those activities could be done automatically. As an example, the heating can be shown. People set different temperature when they are at home, different when they leave, different when they sleep, different when the window is opened, etc A simple thermostat that is keeping one temperature level all the time is not good enough, thus people often have to adjust the heating anyway. It would be nice to be able to have a house programmed in such a way, that all the preferences related to different pieces of equipment were stored and applied when needed. Such technology would relieve people from doing various activities and would greatly save their time. Of course, such a technology can be applied only to everyday activities. Still those activities are the ones that consume the most of people's lives.

There are few more advantages of such a functionality of the house. One of them is the ability to control a house in such a way, that it was not possible before. In many cases like with temperature, air conditioning or water heating, all adjustments need some time until they affect the actual state of the house. Hence when people return to the house or get up in the morning, they have to wait some time until the adjusted settings will give the right effect. In case of Programmable Houses there is a possibility to set the parameters in such a way, that the desired state will be achieved exactly at the desired moment. This also provides a very powerful feature of conserving the energy. A lot of energy consuming system can be switched off and they would be switched on automatically in advanced to reach the desire state at the time that a particular resource would be needed. This feature is very important as saving energy saves the money. This could compensate the energy that is used by all the sensors and electronic devices that are part of the Programmable House system. Even the cost of buying and installing the technology can be eventually compensated.

The second advantage is assuring that some activities are always performed. Adjustment that conserve energy, turning on the lights outside the house when it gets dark, activating the alarm and closing the door when the last person is leaving the house are the activities that are very important and it is crucial that they are always performed. As humans can always forgets about something it would be a great feature if the house could make sure that those activities are performed.

The disadvantages and problems with Programmable houses depends on the complexity of the system. There could be a simple type, where the house is reacting only on simple sensor inputs - for example when the temperature is exceeding a certain level or when it is getting dark. Then some actions are performed by the house. The functionality is easy to implement, reliable and the sensors can be even integrated together with the devices so the whole decisions and actions would be performed inside a single device. Another type of Programmable Houses is much complicated and at the same time more powerful. It is a house that can analyse inputs from various sensors or more advanced sensor inputs like the images captured by the video camera. This allows to recognise some situations and to perform some actions in more specified cases. For example it is possible to assess not only that somebody entered the room, but also where the person has been before. It is also possible to recognise which inhabitant is currently in a room.

With such extended functionality there are more requirements to fulfil. The more advanced system would require of course more advanced infrastructure, but the biggest problem is with the situation assessment technology. It is very crucial to make the system reliable, so no unexpected actions are performed by the house. And in the same time it is very difficult to create such an advanced system that would be perfectly reliable. Basically there would be a trade off between the house performing some unwanted actions from time to time or the house that sometimes does not perform some tasks it is suppose to perform.

Still such problems can be solved by some usability tests or simply by implementations of only reliable functionalities. The biggest problem of Programmable Houses lies in the need to program the house. The process of programming the house and adjusting for every family arises. Such a process, until a system achieves a desired reliability level would be time consuming and tiring. Additionally the system would not be able to reprogram itself. Hence it would be necessary for the inhabitant to have some advanced programming skills or a specialist had to be called every time when one of the functionalities is not longer needed. Still the advantages of a good implementation of such a system would be greater than any inconveniences.

2.5.1 Programmable House projects

As can be seen nowadays, there are various pieces of equipment like thermostats or dusk sensors that provides some basic Programmable House functionalities. So it is easy to predict that in many research project at least small part of technologies belongs to the Programmable Hose category. For example in mentioned before E2Home [8] houses made by Ericsson and Electrolux there are the features of lights and heating that can be programmed. Another example is a TRON [10] house where all the doors in the house are opening automatically when somebody approaches it.

Other simple features of the programmable houses are the preferences of a person that are programmed in advanced and used if necessary. For example in the paper "Scenarios for Ambient Intelligence in 2010" [18] made by the ISTAG group there are many usages of stored preferences. One of the applications is a personal device that is filtering the calls and emails according to the user preferences. Another one are the preferred adjustment of house parameters and house habits, so for example a hotel room can easily adapt to the guest preferences. There is an issue of identification which is done by some special ID tags that a person posses.

Different way of the identification is made by the Microsoft House [16]. For entering the front door there is a biometric scan. This itself is a programmable feature, but also it allows identifying a person that is entering the house. As a result the previously programmed preferences can be used to adjust any device or any parameter of the house if needed. The features that are adjusted as preferred are mostly the favourite TV programs or favourite music but there is also a functionality of adjusting of lights.

Another interesting project is the Intelligent Room prototype space [20] created by the AIRE research group [19]. The great focus that is put there is to recognise a person and to assess the situation. This is done using the video technology. Advanced algorithms are applied to track the person and to assess the context so some actions like for example turning on the lights on the object of interest can be performed. The Intelligent Room that was implemented, tested and developed is focusing more on the office use. Still there is a second version of the Intelligent Room that is being researched. This version focuses on the living spaces with extended programmable functionalities. The highlighted capabilities of the house would be to recognise the situation and to apply previously programmed preferences. This would concern basic functionalities like the choice of music, the intensity of light or the temperature.

Other interesting project is the mentioned earlier the Aware Home Research Initiative [14] at the Georgia Institute of Technology. Among the technologies that they are researching, there is great focus on recognition of context and person tracking. The project is rather focusing on the ability to recognise a situation and identify and track a person, rather than what activities can be performed when the right situation is recognised. Still the recognition is the most important problem and thus the project is an interesting one. They are dealing with video cameras that provide the images for being analyse, they deals with the ID tags to identify the person, but they also research quite original technologies. The interesting one is a Smart Floor [12] that they introduce. This technology is based on the recognition of the force that the footsteps are putting on the floor. This allows for an easy and highly reliable of identifying the position and identification of a person. Of course all the footstep models have to be programmed before the people can be recognised.

Last project worth mentioning is the House_n project [11] on the Massachusetts Institute of Technology. The main goal of the project is to create a living space to study the interaction of people and the technology that surround them. The biggest focus is put on the influences of the technology on health of inhabitants. For this reason the project is unusual and interesting in the same time. It provides the most important data about the technologies. What is their influence on people, how people would react after a long of using particular technologies. The house is capable of recognition different activities and has some simple programmable issues. For the purpose of identification of the activities different sensors were introduced. For example thermometers, humidity or C02 sensors, microphones or touch sensors in doors and furniture were introduced. As the project focus on people the development is then human driven. For that reason functionalities that were introduces are the simple one, that are in the same time very important for people like control of the temperature or air conditioning.

2.6 Intelligent Houses

The final group of Smart Houses that we identified during the project are Intelligent Houses. There is a similarity to the previous houses but there is one crucial difference between them as well. The difference is in a way the house is being programmed. In case of Programmable House technologies it was a human that needed to program or reprogram the house. In case of Intelligent Houses it would be done automatically by the house itself. This is achieved by the capability of the house to observe the inhabitants in the search for patterns. After the pattern is found the house would start performing the activities automatically every time the pattern would be noticed again.

As the capabilities of Intelligent Houses are very similar to Programmable Houses thus the advantages like conserving the energy or assuring that some activities are being performed are adequate in case of this technology as well. Also there is a differentiation between the systems reaction on simple sensor inputs and system recognizing and assessing situations. The different is that the Intelligent Houses are much better choice for the complex types of houses that can recognise scenarios. The problem that was introduced in the previous section was with the trade off between the house doing some unwanted activities or the house not performing activities that were expected. Finding the right parameters that would solve that problem would be a very long task that would require hundreds of adjustments. It is practically impossible in case of Programmable houses, when a specialist has to be called every time. There is no such a problem in case of Intelligent House, as the ambient intelligence that is assessing the situations and scenarios is present all the time focusing on its improvements.

Other advantages of the Intelligent House are capabilities of intrusion or accident detection. As the house is observing the inhabitant all the time and all their usual activities are stored, then it is possible to easily detect an unusual activity. In some circumstances it could be a sign that an intruder entered the house in others especially in case of elderly people is that a person for example fainted. In such cases the neighbours, police or health care can be informed.

The real difficulties are in the implementation of the learning algorithm. First of all the powerful infrastructure for the system is required. The house intelligence needs to be able to collect all the data from all the sensors, needs to store it and needs to be able to analyze them all the time. This requires a bigger storage and higher computational capabilities. Secondly to write an efficient learning algorithm is not an easy task. There are many research projects about Artificial Intelligence or Neural Networks. None of them have any extraordinary achievements. The only achievement is the possibility to create an efficient learning algorithm for a particular implementation, but such a task is extremely difficult and requires a lot of development.

2.6.1 Intelligent House projects

There are not so many research projects dealing with the Intelligent Houses technology. The technology is most advanced and most difficult to implement. Still some of its functionalities can be implemented quite easily and some references to them can be found in the projects. For example in the PHENOM project [6] carried out by Philips, the system tries to identify some preferences of the user itself. Of course the preferences are simple ones like how fast a user changes the photos, still the idea of the system that learns by itself is important. Different projects that deal with the advanced sensors and implements the Programmable House functionalities are aware of the improvement that the Intelligent Houses can bring. Hence some plans or small researches are conducted in this area. For example the Intelligent Room [20] project made by AIRE group [19] or the Aware Home Initiative [14] on Georgia Institute of Technology.

From the more advanced features, the interesting one is the support for elders. The possibility of the house monitoring the habits of elders and searching for any unusual behaviour is a promising one and has some interest. The simple approach is proposed by Microsoft House [16], which is focused mostly on the accident detections, which would result in informing the family or other relevant people. The more interesting approach is proposed by House_n consortium [11]. The house system is looking even for small changes in the activities of elders that can be indicators of the beginning of some health problems. In such a case all the problems could be recognised in advanced and then treated much easier and with greater effect.

The project that is in general related only to the Intelligent House technology is the Adaptive House project [15] carried out by Michael C. Mozer on the University of Colorado in Boulder. In the concepts of the project it is highlighted that the house is intelligent and that it has many advantages over a programmable house. The functionalities of the project focus on the most basic and profitable need for the intelligent in the houses which is the energy consuming. The implemented house completely covers the control over heating, ventilation, air conditioning, water heating and interior lights. The goal of the house is to minimise the use of those resources, but in the same time to preserve keep the inhabitants satisfy. All of the decisions are made by the house system that is implemented using neural networks. The decisions are of course made in a proper manner, so the inhabitants are observed and the scenarios of them controlling heating or ventilation are recognised. As a result the house starts controlling the house parameters according to the preferences of inhabitants. The house had a real live implementation which resulted in all those basic system working very well. Now the project works on the extensions of the house capabilities. One of those is the prediction of when the inhabitants are going to return home in order to switch on heating at the right time. And finally the lights in the house are intended to be controlled in such a way, that the proper light patterns would be set and the lights could be switched on and off automatically, when an inhabitant is going from one room to another. The successful implementation of the house resulted in a large collection of research papers on the project website. The papers deal with hardware, neural networks, learning algorithms and also deals with mathematical models or with psychological issues related with the Intelligent House. It is obviously a good place to start the investigation into the Intelligent Houses.

2.6.2 Key elements of Intelligent House implementations

There are various elements of the Intelligent House system that creates the overall functionality. Those are the sensors that gather the data from the house, the network technology that allows sending the date between sensors and a central computer and between the central computers and the controlled equipment and finally the software capable of learning habits of inhabitants. There are different properties of each solution and in the following section those properties will be addressed shortly. Additionally some references to the sources, where more information can be found will be provided.

Sensors

The sensors that are available on the market are in most cases quite cheap and can be bought in most of the specialised hardware shops.

The most important sensors for the Smart Houses are the movement sensors. They result in the valuable data about the location of the person and they are reliable. By the proper placement of those sensors so that their ranges overlap it is possible to find the exact location of any person. There are different kinds of such sensors on the market and the most popular are passive infrared sensors. Such sensors have usually the range between 12 and 15 meters and the angle of 90 degrees. Still there are models that offer different ranges or angle. There are also some improved types like dual sensors that decrease the probability of environmental conditions triggering the sensor. There are also other movement sensors like ultrasonic, microwave, video imaging and piezometric sensors. Still there is no need for any advanced movement sensors as normal infrared sensor has a desired reliability for the house applications.

Second kind of sensor that could be very helpful is the video camera. Such a sensor can be for example used instead of a movement sensor. Such sensors can track the position of a person with great precision, can identify a person and finally it can also recognise the situation or the activity that the person is performing. The capabilities of the sensor itself can be high enough, the problem with the reliability is rather related to the software that process the data form the camera. It has to be both capable of complex computations and has to contain a sophisticated algorithms that would perform the analyse process. As it can be known from different projects, the recognition can be achieved, but the reliability is not always at the satisfactory level. On the other hand also the cameras that are used in different experiments are usually internet cameras or some standard surveillance cameras that does not have a perfect image quality as well.

There are many other sensors that are available on the market, are reliable and can extend the functionalities of an Intelligent House. Those are for example dusk sensors, thermometers, humidity sensors or pressure sensors. The last ones are very interesting as they can cooperate with movement sensors and video cameras or even replace them and provide complete person location functionalities. Such sensors can be placed in the sofas or armchairs, but also like in a Smart Floor project [12] carried out by the AHRI group [14] the whole floor can consist of pressure sensors.

Network

The next element of the implementation of an Intelligent House is a network technology that would connects all the sensors and devices with the central processing unit. Again different technologies can be chosen for this purpose.

One of them is the Bluetooth technology [24]. This technology for wireless transfer was introduced in 1994 by Ericsson, but it was quite recently that the technology gained the popularity. The technology was designed to provide the radio at the 2.4 GHz. The main properties are that the technology is cheap, has low power consumption, is of small size and additionally it is designed for the small ranges. The range is supposed to be around 10 meters which is completely enough for the inside the house exchange of data. The small range additionally has an influence on the security and privacy issues. The probability that someone outside the house could percept or generate a signal is very small while using the bluetooth technology. Additional advantage is that the technology is quite popular and widespread nowadays and many mobile phones, PDAs and notebooks are already equipped with Bluetooth and could easily be used to interact with a house.

Another quite similar technology is called HomeRF [25]. The Home RF Shared Wireless Access Protocol is a standard created by the Home Radio Frequency Working Group. The technology has similar technical properties like the Bluetooth technology as both operates at the frequency of 2.4GHz, are low cost and low energy consuming. The difference is that the homeRF technology is designed for use in the house environments what gives it a great advantage. On the other hand the standard was created in the main purpose of carrying the sound around the house and all the functionality was made to support it. This would make some features of that technology rather useless in the Intelligent House implementation. Still the technology could be used in a Controllable House where such features could be used. It is also important to state that the HomeRF Working Group does not exist any more, thus the evolution of the standard is not certain.

Yet another technology similar to the previous one is ZigBee technology [26]. This technology is also working in the 2.4 GHz freqenecy and is a low power consuming technology intended for the house applications. Any differences can be easily seen on the figure 2.3.

Another network technology for the houses is the Z-Wave [27] technology offered by Zensys Company. The technology is again a low cost and low power consuming one. It is intended to send just control commands or statuses as the bandwidth is only 9.6 Kbps. Still such a bandwidth is enough for most of the applications of the Intelligent house, as the information sent by for example movement sensor has just to distinct values - (detects or does not detect). What is particularly interesting is the fact that the Zensys Company is not only creating a standard for the network protocol, but also the actual equipment for various house applications in the house that are using the Z-Wave technology.

The nice comparision of the key providers of the house wireless network technologies can be seen in the fallowing table. This table is based on a similar table provided by the RyherdVentures [28].

Technology	Z-Wave™	ZigBee™ **802.15.4**	BlueTooth™ **802.15.1**
Primary Application	Residential Control Lighting HVAC security	Building Automation Lighting HVAC access control	Cable Replacement Audio
Key Features	Mesh Network	IEEE standard	Market Leader
Data Rates (bps)	9600	20K, 40K, 250K	11M(b), 54M(a/g)
Battery Life (days)	1000+	1000+	0.5
Network Size & Type	232	256	32
Frequency & Modulation	868/900Mhz FSK	868/900Mhz, 2.4Ghz DSSS	2.4Ghz FHSS
Range (meters)	30	10	10
Nominal Cost	<$5	<$5	$5

Figure 2.3: The structure of the website

Another technology that is quite different than the ones presented above is the IrDA infrared technology. [29]. It is a standard defined by the Infrared Data Association consortium. Such a communication in the latest version can transfer the data with transfers up to 1.5 Mbps. Such a speed is enough for a successful implementation but a problem lies with the range of infrared signal. To transfer the data reliably the range cannot exceed 1 meter. That makes the technology much less usable as one meter is a very small distance even in a small room. Moreover the infrared signal can be interfered by the ambient light, what makes the possible range even smaller. Still there are some advantages of such technology as well. One of them is the directional nature of the signal. Thus the signal would be received only by the piece of equipment that is intended to receive it. This would simplify the implementations and again would have a great security benefits, as the possibility to intercept the signal from outside the house would be practically impossible.

The other technologies that are worth mentioning here are the wired technologies. Those are much difficult to implement, as the wires has to be placed inside the walls. But eventually the new houses being build will have an extended set of cables inside the walls so there would be no problem with such issue anymore. First advantage of such technology is the lack of hundreds of radio waves around inhabitants that could potentially affect people's health. Second advantage is that the problem of security and privacy is solved. As there is no way that someone with the radio waves receiver could intercept some data.

An interesting example of a wired technology can be the X-10 technology [30]. Similarly to the Zensys Company, the standard for the network is just a small part of the X-10 technologies. The most important parts are the different pieces of equipment that are created. The devices range from the sensors, switches, lamp modules to the entertainment equipment. All of those with the functionalities of connection with the home network and with some simple programmable functionality are available to buy with a low price.

There are many others companies creating products that are similar to the ones mentioned before or that are not very convenient for the Intelligent House implementation. Moreover some technologies disappear while others enter the market. Hence there will be always a need to do a small research to check the current state of the market.

House Intelligence

Implementing the intelligence of a house in not a straightforward task. There are no products available on the market or standards that could be easily implemented. The area of Artificial Algorithms and Neural Networks that could be applied is still a work in progress that does not have any easy to implement results. Of course, this does not imply that creating house intelligence is an impossible task. It is possible to create some simple or more sophisticated learning algorithms, but still that is not an easy task and there are not simple solutions that can be presented in such places. Of course if someone is interesting in such subjects can check the papers about the learning algorithms and neural networks that are available on the website of the Adaptive house project [15] or check the NEuroNet website [31].

2.7 Summary

In this chapter a number of Smart House technologies were described. At the very beginning a taxonomy of the houses was presented as well as three main categories were identified. These are the Controllable Houses, Programmable Houses and Intelligent Houses. These categories were also reorganised to form another model which presets the evolution of the houses according to the improvements that each type is introducing to people's lives.

According to the evolution model, the house technologies were described with focus on their advantages and disadvantages. Additionally different research projects that were investigated were described and placed next to the corresponding technologies. Finally a section that gave an overview of different technologies that can be used in the implementation of an Intelligent House was presented.

Chapter 3

Engineering Smart House Website

During the project work, an Engineering Smart House website was created. The purpose of the site and the intended audience were identified and the relevant design was made. The information from the theoretical investigation of Smart Houses and related projects was chosen and placed on the website. Additionally several animation illustrating the usage of Intelligent Houses were created using Flash MX technology [23] and placed on the website. All above mentioned issues are presented, described in more details and summarised in this chapter.

3.1 Website design

It was essential to identify the purpose of the website together with the intended audience, so that the appropriate layout, structure, types of information and the language style could be chosen. The reasoning and the result of those tasks will be presented in the following subsections.

3.1.1 Intended audience

The site is intended to give a clear view on the area of Smart Houses and in particular Intelligent Houses. The properties of different types of houses together with descriptions of their technologies are presented. Additionally several projects carried out by different universities and industry are going to be shown and described. The amount of information covers the most important issues and describes them shortly. Finally a set of links providing much detailed information on covered topics was prepared and positioned in relevant places.

Even though that the website is not going to contain advanced technical information, still it is assumed that a reader would have a technical, engineering background. The terms and explanations presented in a text are used assuming that a reader has a basic knowledge about concepts of programming, networking and security. Still even for a person without engineering background it would be possible to understand the basic concepts of the provided information.

The website is of course intended for people with some interest in the Smart House technologies. It is assumed that the readers will have the experience of using modern house technologies and additionally they would be familiar with basic sensors like movement sensors, video camera or thermometers. Finally the information on the website and in the sources that the website links to should give a qualified engineer a clear view of how to implement an Intelligent House.

3.1.2 Structure

The graphical layout of the website was created using an html template provided by the IMM department. As the website is not presenting any commercial product and there is no need to attract clients with a fancy graphics and animations on the site. The only basic requirements are that the layout should be simple, elegant and clear. All of those requirements are fulfilled by the IMM layout. Additionally creation of advanced layout is not a goal of the project, thus there was no need for a special design. Due to the intended audience the language style chosen for the website is in majority semiformal.

The structure of the website can be seen on the following graph where each box represents a sub page and each arrow represents a link.

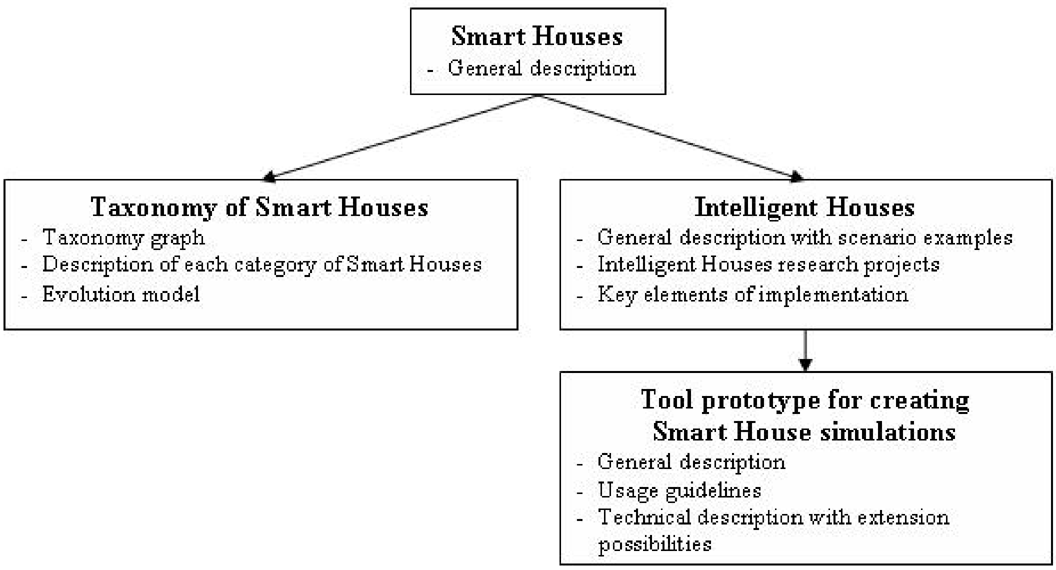

Figure 3.1: The structure of the website

- The main page, titled **Smart Houses** contains a general definition of Smart Houses. The information presenting the content and purpose the website follows and finally the links to all sub pages and the information that is located there are described.

- Next page, titled **Taxonomy of Smart Houses** consists of information about categorisation of Smart Houses. The taxonomy graph is presented there and each type of the houses is described. Additionally the evolution model with short explanation of its idea is presented on this sub page as well.

- The **Intelligent Houses** sub page contains more detailed information about this group of Smart Houses. Besides of the description there are four scenarios presented to illustrate usage of Intelligent Houses technology. All scenarios are described and there is a link to animations showing the particular scenarios (more information about the animations and their creation process can be found in the next section). Afterwards there is a section that presents the commercial and research projects that are carried on different universities and by industry. The description of the area of each research and of the resources available on the Internet is presented there. As an addition to each research project there are relevant links to the official sides and other related Internet resources. The last piece of information on this webpage is a description of key elements in the implementation of Intelligent Houses. The elements like sensors, network technologies, learning algorithms, are listed and described there. The descriptions quite short as there are links to Internet resources providing more information about particular aspects and technologies.

- The last sub page titled **Tool prototype for creating smart house simulations** consist of information about the tool prototype that was created during the project work (detailed information about the prototype and its functionality are present in the next section). On the page, the program is described and the source Flash MX file is linked. Afterwards a user guide, explaining the usage of the prototype is shown and finally small short description with guidelines for possible extensions are presented.

3.2 Tool Prototype for creating Smart House simulations

3.2.1 Overview

For illustrating some Intelligent House functionalities, several animations were created. The animations were created in a feasible way, by using previously created tool. The tool because of its simple functionalities and a great potential of extensions is addressed in this project as a tool prototype. The prototype contains a set of basic graphical object representing a floor plan of a house, furniture, sensors and equipment so they can be easily duplicated and placed in a desired position. Several animations are connected with each sensor and each piece of equipment to visualise that a sensor is detecting something or that a piece of equipment is working or changing its state. A simple mechanism of moving an inhabitant is also implemented to the prototype. Finally a set of functions is created so a user can create a simple script that would perform a desired animation of moving the inhabitant, triggering the sensors and switching the equipment on or off.

The tool prototype was created using a Flash MX technology [23]. The reasoning for that choice is presented in the next subsection. Afterwards the process of design, implementation and testing is presented. The functionalities of the tool with the usage guidelines are presented afterwards. Finally there is a section about the possibilities of extending a prototype with new objects and new functionalities.

3.2.2 Flash MX technology

The prototype was created using Macromedia Flash MX technology [23]. Flash was chosen because of its capabilities that perfectly meet the prototype needs. Flash is a development environment that is specialised in creating interactive graphical and animated content. It is very easy to create simple graphics and simple animations in Flash. As all the graphics are vector based, they can be easily reused, duplicated or transferred to other projects. Additionally the graphics can be converted to objects that can have animations, sound or other functionalities embedded inside it.

Flash technology provides the Action Script programming language. It is a simple, but powerful script language that was design to interact with the graphical objects and with animations. Hence it is very easy in Flash to create the functionality that could easily manage all the items and animations visible on the screen. That is exactly the functionality necessary for the tool that had to be created. It allows to create sensors and equipment as graphical objects and to write the functions that would easily trigger animations on the desired equipment and sensors.

3.2.3 Design

The first phase of the tool prototype creation is to create graphical objects that would be easy to use and duplicate. This is en easy task, as all the graphics can be converted to objects and automatically there are being placed in a library. The library is a container for all the distinct objects that are used in a project. Simply to use another object of a particular type it is enough to drag it to a desired screen location. Additionally the library allows for creation of directories what allows to sort all the object into categories like sensors, equipment, furniture etc... Additionally the screen where objects are placed can be divided into layers, so similarly to the library the objects can be sorted and for example all furniture would be placed on a "furniture" layer.

The next task is to plan the animation. Again flash offer a good and obvious solution. As all the graphical object can be a movie clips, hence it is very easy to embed the animation into each piece of equipment or a sensor. The possibility to edit every frame or a group of frames it is easy to change colour, size, shape or add additional elements to the animation.

The last issue concerning graphics is a floor plan. There are two options for that. The simplest one is to have a background image created in flash or in any external program.

This would have one disadvantage - from the programming point of view, there would be no difference between the interior of the room and the wall. Thus it would be very difficult to create the simulation where it would be impossible to cross the walls. On the other hand walls could be created in flash in such a way, that they would be separate objects. This would have a different disadvantage - it would be very inconvenient to use and would require some advanced knowledge and experience with Flash Environment. As the main purpose of the tool is to create animations, not some complicated validations, thus the simplest solution of using images would be the most appropriate.

The next task to accomplish in the prototype is the programming part. First problem is moving an inhabitant object to the desired location. The most appropriate would be to divide the route into small sections and move the object section by section every small interval of time. This can be easily achieved by using the setInterval() flash built in function, which executes any provided function sequentially in specified intervals. All necessary distances and intervals can be easily calculated as the position of the inhabitant object and the place where the mouse is being pressed is known.

The last and the biggest task is to create the script language functionality. The prototype is intended to have a set of functions that manages the items and animations on a screen. So a user could create an animation simply by creating a sequence of the function calls. As analysed in the previous paragraph it is possible to make a single function that performs some instructions over the period of time. The setInterval() function that is used is being run in background, so the next function could be executed strait away. This is because there is no wait functionality in Flash Action Script. So when a several function would be placed in a sequence forming a script, there would be a problem of every function not waiting for the previous one to finish. The easiest solution to implement is a so called "busy waiting" technique which is creating a dummy loop with big counter. Of course this is not the proper way to do it, because of usage of too many resources. The best solution that can be implemented in such a case is to use the onEnterFrame() function. This Flash Action Script function is being executed every frame of the application, so in case of ordinary application 25 times per second. This is a commonly used function in Flash and its execution is not using any special processing power. Hence by placing all the functions of the script in this functions and applying some appropriate status variables would solve the problem.

3.2.4 Implementation

Symbols' organisation

At the beginning all the items used in a tool were designed, created and sorted in a feasible way. The layers on the stage were created as visible on the following screen shots:

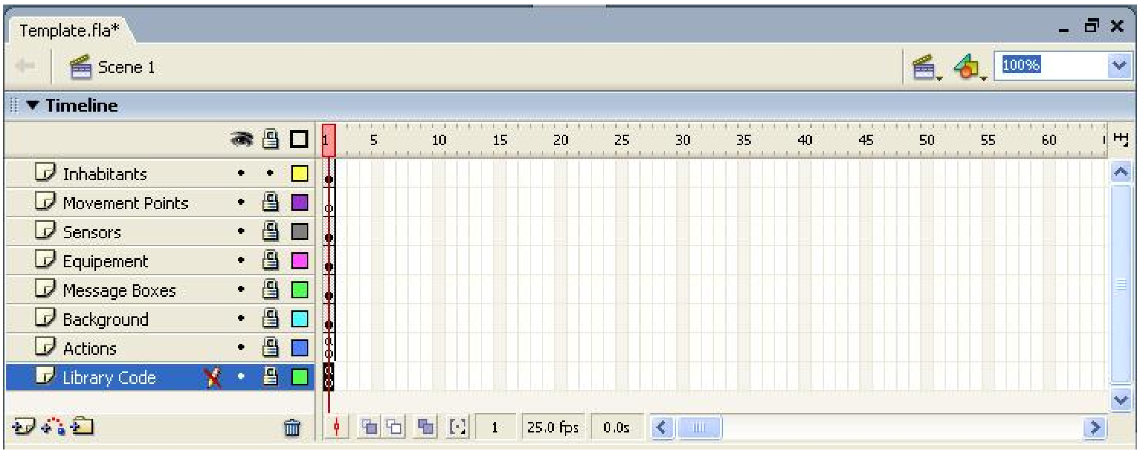

Figure 3.2: The stage layers in the prototype

As visible on the picture the 6 groups of items were created plus two additional layers that contain the Action Script code. The library consists of similar types of directories containing the appropriate symbols. The screen shot of the library can be seen in appendices. The special order of layers was created to preserve the proper overlapping of items. The groups of items that were created are described below:

- The **Inhabitants** is a group for the inhabitant symbols
- The **Movement Points** group is a small group consisting of just one kind of movement points that helps in moving the inhabitant during the animation
- The **Sensors** group contains all the symbols representing sensors
- The **Equipment** consist of all equipments and furniture symbols that can be places in the animation
- The **Message Boxes** group contains all message boxes that allows for displaying comments during the animations
- Final **Background** group consist of all floor plan images to be used during the animations

Two last layers are designed to contain Action Script code. The Actions layer is a place where a script performing the animations should be placed. The Library Code layer contains all the functions that are used in the script.

The symbols

The graphic that was created for the animations was made using simple and clear shapes. All the object like furniture that are not animated and have only background purposes are made in the grey scale. The equipment that is intended to be controlled by the house intelligence and can be control in animations is created in blue and black colours. Only few, the most basic items were created in a prototype. As the tool has capabilities of adding and using new object very easily, thus there was no need to add a large number of items.

For better explanation of symbols the legend was created in a flash format and placed on the website. All the symbols that were created in a prototype are present there. The legend can be seen on the following screenshot:

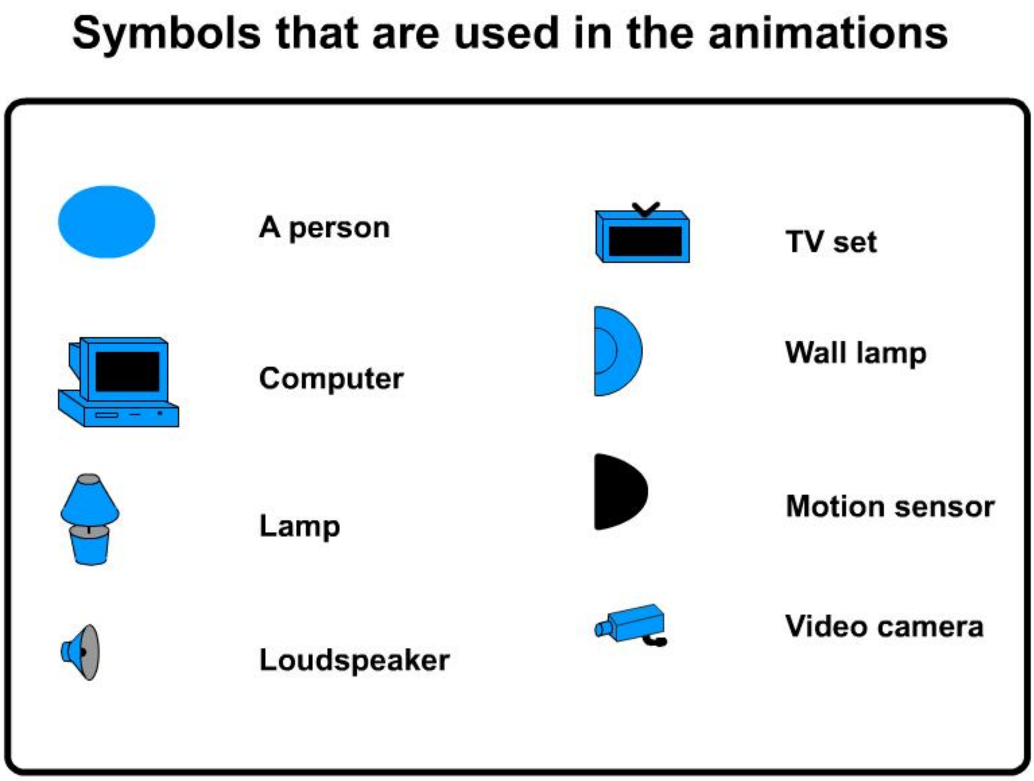

Figure 3.3: The legend

The next step of the prototype creation was to make the animations for the items. In some cases like TV it was enough to create just two states representing the TV switched off, with the black screen or switched on with yellow screen. In other cases a more fancy animations were created. The animations used the Flash mechanism of specifying the number of frames and editing one or more frames in the same time. The frames editing mechanism can be seen on the following screenshot:

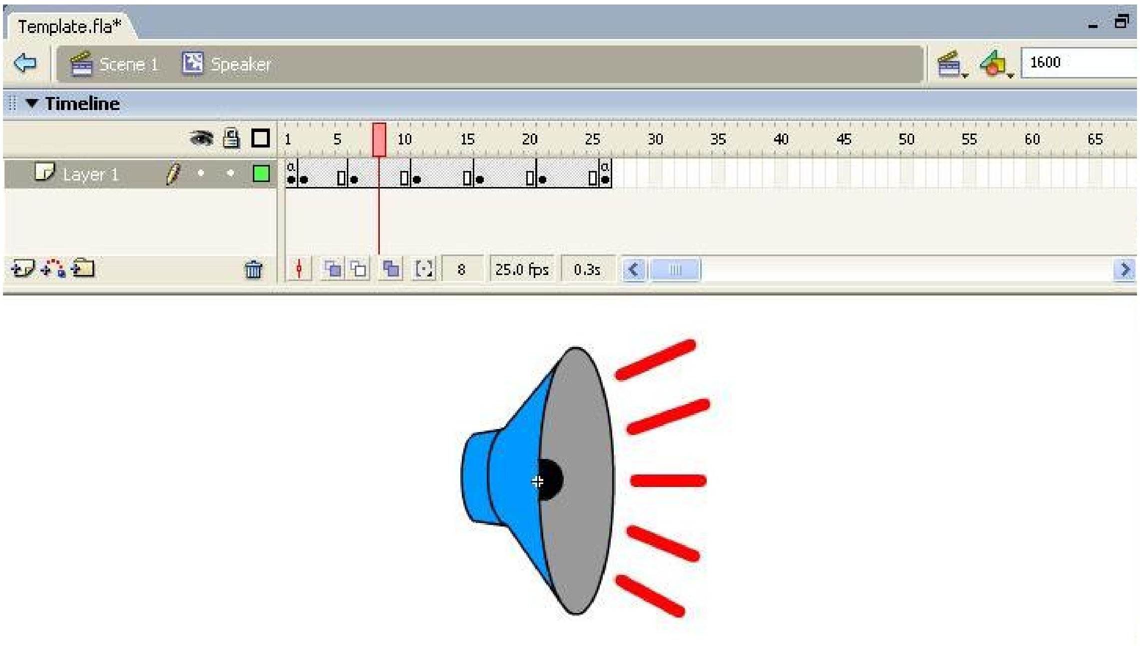

Figure 3.4: The frame mechanism of the flash object

On the scale above the speaker symbol, the right frame can be chosen and frame of animation edited. The animations were done in the same manner in all the items. The firs frame contain the simple picture of a switched off state of the piece of equipment. The second frame consists of the picture of the item switched on, or there the animation starts. This allows for creating just one function that switches on or off any item. Also every new item would be compatible with the prototype's functionality as well.

Sensors' representation is created in a little different and more advanced way then any other equipment. The sensors consist of a sensor base and a sensor area. A sensor base has the same behaviour like any symbol representing other pieces of equipment. The difference lies in the sensor area. It is a semi transparent light grey figure that can be easily reshaped to cover desired area. The area has functionality, that it is invisible in the actual animation or simulation. Using a defined naming convention for the sensor area and corresponding sensor base, the sensor animation can be triggered when an inhabitant symbol enters the sensor area. Hence it gives a great improvement to the animations, as there is no need to handle sensors, as they would be triggered automatically.

The example of the Flash working space with the graphical elements placed on the stage can be seen in the appendices.

Action Script

When the graphical part is ready the Action Script performing the movement of inhabitant and providing the scripting functionality needs to be implemented. First the movement needs to be implemented. For the simulations it is needed that an inhabitant would move to the place where the mouse is clicked. For this purpose the onMouseUp() function is used. The function takes two points into consideration - the point when the inhabitant symbol is located and the point, where the mouse was pressed. The appropriate calculations are made to divide the distance into very small sections. Next, using setInterval() functions the movement is made. The setInterval() function takes two parameters, one is the name of a function to execute and the second one are the milliseconds between each execution of a given function. This way the function moving an inhabitant's symbol one section is being execute many times. SetInterval() function executes until it is cancelled by the clearInterval() function. Hence a counter variable is implemented to cancel the Interval in the desired function call.

For moving an inhabitant form the script functionality, the movement points mentioned before were introduced. The movement point is a simple cross symbol that can be placed on the stage and it get invisible in actual animation. Its instance name can be used as a parameter to the movement function for providing the destination for the inhabitant symbol to move. Such a solution is the most convenient as it relieves a user from working with the coordinates, which are much less usable. So basically a user has to place the movement points on the stage, give them distinct instance names and then address them in the script.

The next step of implementation is to create those functions in such a way, that they can be placed one after another and each function will run not earlier then after the previous one is finished. As the setInterval() functions is executed in a background, thus there is no way besides implementing the so called "busy waiting". The solution to such problem is placing the script code in the onEnterFrame() function. This Flash function is being executed every frame of the flash program. So then all the functions of the script are being executed every frame, but the proper state variables would ensure that only the proper function would perform its functionality, and the others would be skipped. So there would be a variable inMove, initially equal to "zero". When a first function starts performing a movement of the inhabitant, the variable will be set to the value of "one". So every function would check at the beginning if the value of the inMove variable is equal to "zero". If not no action would be performed. So when the move of inhabitant finishes, the value of the inMove function is set back to "zero" allowing other functions to run. Additionally two variables - currentFunction and nextFunction would assure that when one function is finished the next one would perform its functionalities afterwards. By such a simple solution the proper functioning of the animation script is assured.

The following functions were written to be used in the script language:

- **movePerson**(movement point) This function moves the inhabitant with the instance name "mcInhabitant" to the destination of the movement point provided as a parameter. The function using the setInterval() functionality calls the movePersonFunction() which contains the code to move the inhabitant by one small step.

When the counter variable goes down to zero, the movePersonFunction() is cancelling its further executions and is setting the inMove variable to the value "zero" so the next function could run.

- **moveItem**(object, movement point) This function is almost identical to the previous one. The difference is that it can move an object or inhabitant with any instance name. Also the function that is called using the setInterval functionality has a different name - moveItemFunction(). The mechanism of those function are identical to the ones above.

- **wait**(number of seconds) This function is altering the execution of any other functions for a given number of seconds. Again such functionality was achieved using setInterval(), which call waitFunction(). The waitFunction() perform no actions before its last execution, when it sets the inMove variable back to "zero" so the next function could be run.

- **switchDevice**(device, state) This function changes a state of a device. Both the device and the state are provided as parameters. This function does not have any special mechanism, as the action of changing a state is instant and the next function in the script is allowed to be executed strait away.

- **setMessage**(label, message) This function is displaying the string message given as a parameter on the label which is provided also as a parameter. The message is appended to the label from the top. So there is a history of messages available and a user can any time during the animation scroll the messages to read the previous one. Similarly to the previous function this function is also instant.

- **makeInvisible**(object) This function is the last one offered by in the script functionality. It makes an object given as a parameter invisible. Again such function is instant.

The set of the functions contains only functions providing basic functionality, because of the capability that allows for adding new functions in an easy way. There was no need to create a large number of functions, as a user can easily do it by himself. The functions can be seen also in appendices, where their source code is located.

For better understanding the usage of the functions and the script functionality, the following example of script language can be provided:

```
switchDevice(mcTv, "on");
switchDevice(mcSpeaker1, "on");
switchDevice(mcSpeaker2, "on");
setMessage(Label2, "1. Tom is watching TV.\n");
wait(2);
movePerson(mcPoint1);
movePerson(mcPoint2);
```

setMessage(Label2, "2. The TV sound was redirected to the speakers in the kitchen.\n");
wait(5);
setMessage(Label2, "5. The end of the scenario.");

The last functionality in the prototype that has been implemented is the ability to pause the animation. It was done by modifying the onMouseUp() function. So when the animation is in progress, clicking the mouse is altering the animation. The altering is not straight forward. If there is any movement in progress, the movement is allowed to be finished and then the script is paused. Clicking again is resuming the animation. When the script is finished and there is no animation to alter, clicking anywhere on the stage is simple making the inhabitant move to that point.

Testing

After the prototype was finished it had to be tested. There was a problem with testing of the application, because of it special nature. Still some test was carried out. As the amount of code was quite small and additionally it was divided into small functions it was very easy to perform a structural test. All if statements were analysed to see if all of them will be eventually executed. This part of testing was an easy one. The more difficult were the functional tests. The tests were created simply by using the program functionality which is to created animations. The scripts for several scenarios were created and the output which is the animation itself was analysed. The prototype finally passed all the tests, what with the small size of the project gives a very good chance that an application is error free.

3.2.5 Functionality and usage guidelines

Creating the house

The house is created by dragging the objects from the library onto the stage, onto a proper layer. For using own floor plans, first the image has to be imported to the library and then dragged on the stage. Afterwards the position, angles and sizes can be easily adjusted using the flash editing options. The next step is to give instance names to all the inhabitants, equipment and sensors. In majority, the naming convention is flexible, as long as the same instance names are used afterwards in the script. There are some exceptions in sensors and in the inhabitant instance name. The inhabitant should be call "mcInhabitant" (the mc stands for Movie Clip and is used according to naming convention proposed by Flash). This enables the functionality of moving an inhabitant by simply clicking on any place on a stage. The second exception are sensors. A sensor is placed using two objects. One is the sensor base and the other is a senor area. They should be named mcSArea# and mcSBase# respectively, where # is a number from 1 to 99 that has to be identical in both names. This way when a properly named inhabitant enters the sensor area, the sensor base will animate. There is one additional requirement for changing a shape of the sensor area. As the change is made inside the symbol, thus changing the shape of one sensor area is changing the shape in all instances of that object. To avoid this, each time the sensor area is needed it should be duplicated in the library first. Then every sensor area on a stage would be an instance of different object and there would be no problem in changing the shape of the area without affecting other sensors.

In this place a small simulation of a Smart House is already created. A user who is interested in implementing some Smart House technologies in his or her house can plan the placement of the sensors in a house. He or she can place the sensors in the desired way, adjust the sensor areas and check which sensors are triggered when an inhabitant is moving from one place to another.

Scripting functionality

The scripting functionality allows for easy creation of Smart House animations. The animations can be conveniently shown to the people on a presentation as the functionality of altering the animation is present. Additionally the functionality of message box, where all necessary description can be displayed during the animation allows for placing the animation on a website. Hence there is no need to explain the animations as all comment appear on the screen.

Before writing the script the house with all necessary objects has to be created on a stage and all the appropriate instance names have to be assigned. The scenario has to be planned, so all the movement points are placed in the desired positions and then the script has to be written. The script has to be placed in the "Action" layer in the following place in the small block of code presented here:

```
_root.onEnterFrame = function() {
  _root.currentFunction = 0;

  // the beginning of the script - write the commands below
  .
  .
  .
  .
  // the end of the script - switching the simulation mode
  if (currentFunction == (nextFunction - 1) && isInMove == 0) {
    nextFunction = -1;
    }
}
```

The function calls have to be written between the commented lines announcing the beginning and the end of the script. The rest of the lines are the instructions that are necessary for the script to work. It is worth to remember that the message displayed in the message box is being appended to it at the top. Thus there is a need to place \n sign at the end of each message. Additionally it is worth to put a number in each message so the messages would be clearer. The instructions of how to extend the prototype with new elements or new functions are placed in the next subsection.

3.2.6 Possible extentions

One of the features of the prototype is the possibilities of easy extensions. Various items can be added with just basic knowledge of Flash MX technology. Among such items are the floor plans and furniture. Both of those types of elements are just static graphics that are practically only a decoration. It is possible to create a simple shape by using the flash environment and then to convert the graphics into a symbol, so it would be placed in the library and could be reused later. It is also possible to create the image in any other program or download an image from the Internet as flash is capable of importing various formats of images.

Creating new equipment with some animations is a little bit more difficult task. The basic shape of the object has to be created in flash, then the object has to be extended to several frames and then the frames has to be edited to create the animations. There are few requirements for such an animation so it would be compatible with the scripting functionality. The first frame, which is a switched off state of the equipment has to contain the call to stop() function that would prevent the animation from playing all the time. The actual animation has to start from the second frame. In the last frame of the animation some instructions can be placed as well. If it is intended that the animation stops in this point, the call to stop() function has to placed as well. In case the animation is intended to loop, the instruction that makes the animation to go back to second frame (gotoAndPlay(2)) is needed. If the animation is intended to go bask to the switched off state, no code is needed.

The next step of the extensions of the prototype is the possibility of adding a new function to the script language. It is very easy to do it with the functions that perform its actions instantly. When there is no movement that is altering the execution of the next functions in the script. In such a way there is an clear template of such function which looks in the following way:

```
function nameOfTheFunction([parameter1, parameter2, ]) {
  _root.currentFunction += 1;
  if((_root.isInMove == 0) &&
    (_root.currentFunction == _root.nextFunction)) {
    // here write the actions to perform
    _root.nextFunction += 1;
    }
}
```

Just the name of the function needs to be created, any necessary parameters have to be named and of course the actual actions have to written. The other lines deal with all the variables that enforce the proper functioning of the script.

It is much more difficult with the functions that are intended to perform some actions over a period of time, and no other script functions can be executed in that time. Still there is a template for such type of a function as well:

```
function nameOfTheFirstFunction([parameter1, parameter2, ]) {
```

```
  _root.currentFunction += 1;
  if((_root.isInMove == 0) &&
  (_root.currentFunction == _root.nextFunction)) {
  // all necessary calculations
    _root.isInMove = 1;
    _root.nextFunction += 1;
    _root.intervalID =
    setInterval (_root.nameOfTheSecondFunction(), milliseconds);
  }
}

function nameOfTheSecondFunction([parameter1, parameter2, ]) {
  // perform all necessary operations
  counter--;
  if(counter == 0) {
    // perform all cleanup operations
    _root.isInMove = 0;
    clearInterval(_root.intervalID);
  }
}
```

Again the names of the functions and parameters have to be created and changed in the template. The first function that is the function called from the script is intended to have just initialisation purposes. There if it is necessary the exact number of milliseconds for the setInterval () function has to be calculated. Also other initialization has to be made in order for the second function to perform the task. The second function is a function that is run a defined number of times, until the counter reaches zero. There all the necessary operations that perform a desired task should be placed.

The last group of extensions that can be applied to the prototype are the ones that are adding completely new functionalities. There are no templates or limits in such extensions of course, but still there are some particular possibilities that can result in reasonable features.

The sensors areas placed on the stage detect the inhabitant and trigger the animations of the sensors. There is already a programmed code that performs some functionality when a sensor is triggered. So it is very easy to implement some features of the programmable house in such a place - for example to switch on the nearest lamp, when a sensor is triggered. It is also possible to implement Intelligent House functionality. A learning algorithm can be placed in the onEnterFrame() function that would search for some patterns. The code placed in the sensors' objects and additionally the code placed in the equipments' object would be just reporting its state, so the learning algorithm could store it and analyse it. The functionality of receiving the data by the learning algorithm is pretty simple, but it is the learning algorithm itself that is the most difficult. Hence implementation of such functionality would be a very difficult and time consuming task.

3.3 Summary

During the implementation phase of the project the website and the flash program were created. The website was structured to clearly present the most important properties of Smart Houses. For a better explanation of the Intelligent House capabilities several scenarios together with the animations illustrating them were presented. And finally the description of the prototype with its usage guidelines is available on the website as well.

The tool prototype was created according to the main goals - to provide a simple structure that would allow for easy usage and to make various extensions and additions possible. This goals were achieved and a prototype that allows for easy creation of different animations where more items and more functionality can be added in an easy way was created. Finally the tool's guidelines for its usage and extensions were documented and included in both the report and on the website.

Chapter 4

Conclusions

The first part of the thesis concentrates on the investigation of Smart House technologies, which resulted in defining the taxonomy and the evolution model of smart houses. It has been shown that each group of houses in the evolution model is better, more powerful than the previous one in the hierarchy. Furthermore, this implies that Intelligent Houses are the most sophisticated ones and have the greatest potential of improving people's lives. Several research projects have been identified, which had some success in implementing some Intelligent House's functionalities as well as functionalities of other types of Smart Houses. In either way, it would take a long time before such technologies will completely dominate our homes. What is much more realistic is that some chosen elements and functionalities can be widespread much sooner.

The evolution model was created focusing on the improvements that the technologies bring to people's lives. It was not a prediction of the sequence in which the technologies will be developed. What is actually the most probable is that the technologies will evolved in parallel and in the house of the near future elements of all technologies will be present. It is quite logical that the easy to implement functionalities will use the Intelligent House functionalities and the most difficult ones would be for example controlled by voice or from a panel.

The most important issue is that the progress of technology is only one important key to the development of Smart House technologies. The other one are human needs. It is necessary to let people use some functionalities to find out what is actually necessary, what are the influences of those technologies on people. Nevertheless it is obvious that the ubiquitous computing will enter people's houses and many activities will be done in a much different way than they are done now.

The Engineering Smart House website was a second part that one had to concider in this thesis. This website provides a very good solution for the convenient presentation of the information about smart houses. All the research projects that were investigated and described in this thesis are presented in some specified level of details. More details could be found on other web pages that this website links to. In this way, for readers that are interested in a particular research, it is very convenient to reach more information using the presented links. In addition, the advantage of such a website is that all descriptions can be illustrated by linking the Smart House animations. Such a possibility allows for very clear presentation of different technologies as the visual way is a much better mean of explanations.

The last part this thesis focused on, was the prototype tool that was created. The functionality of the one is extensible, hence this gives the small prototype a great potential to become a powerful tool. As a result, more advanced simulations can be created or a tool could help in the actual creation of a Smart House system.

This thesis, due to its diverse goals, allowed for working with different aspects of Smart Houses. The investigation allowed experiencing the technical parts of all different technologies that were concidered, together with the progress of their development. It allowed seeing which companies are interested in which types of technologies and finally and understand the reasons for that. Finally the project allowed experiencing the implementation side of the Smart House technologies and the animation's creation allowed experiencing the usage of those technologies in a real house.

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Appendix A

Tool prototype screen shots

A.1 The library

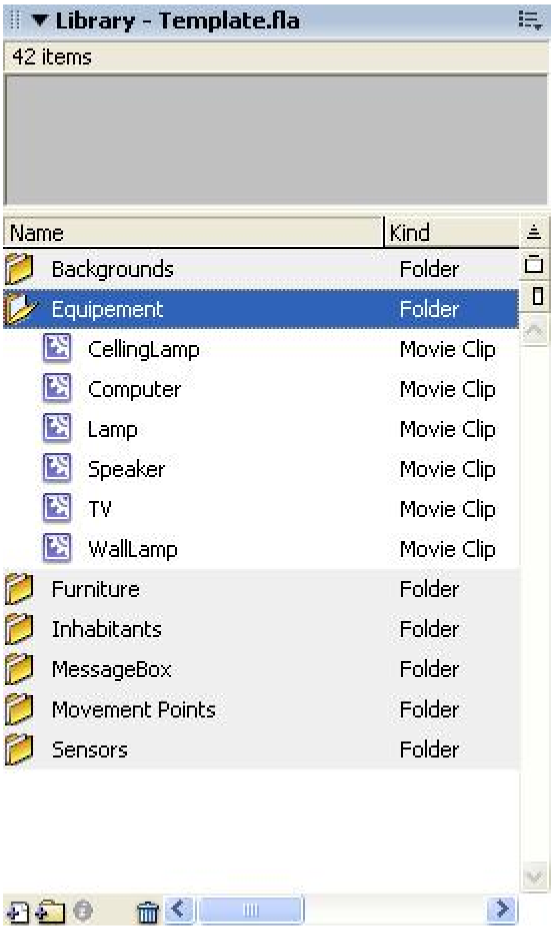

Figure A.1: The library of the flash project

A.2 An example of the house

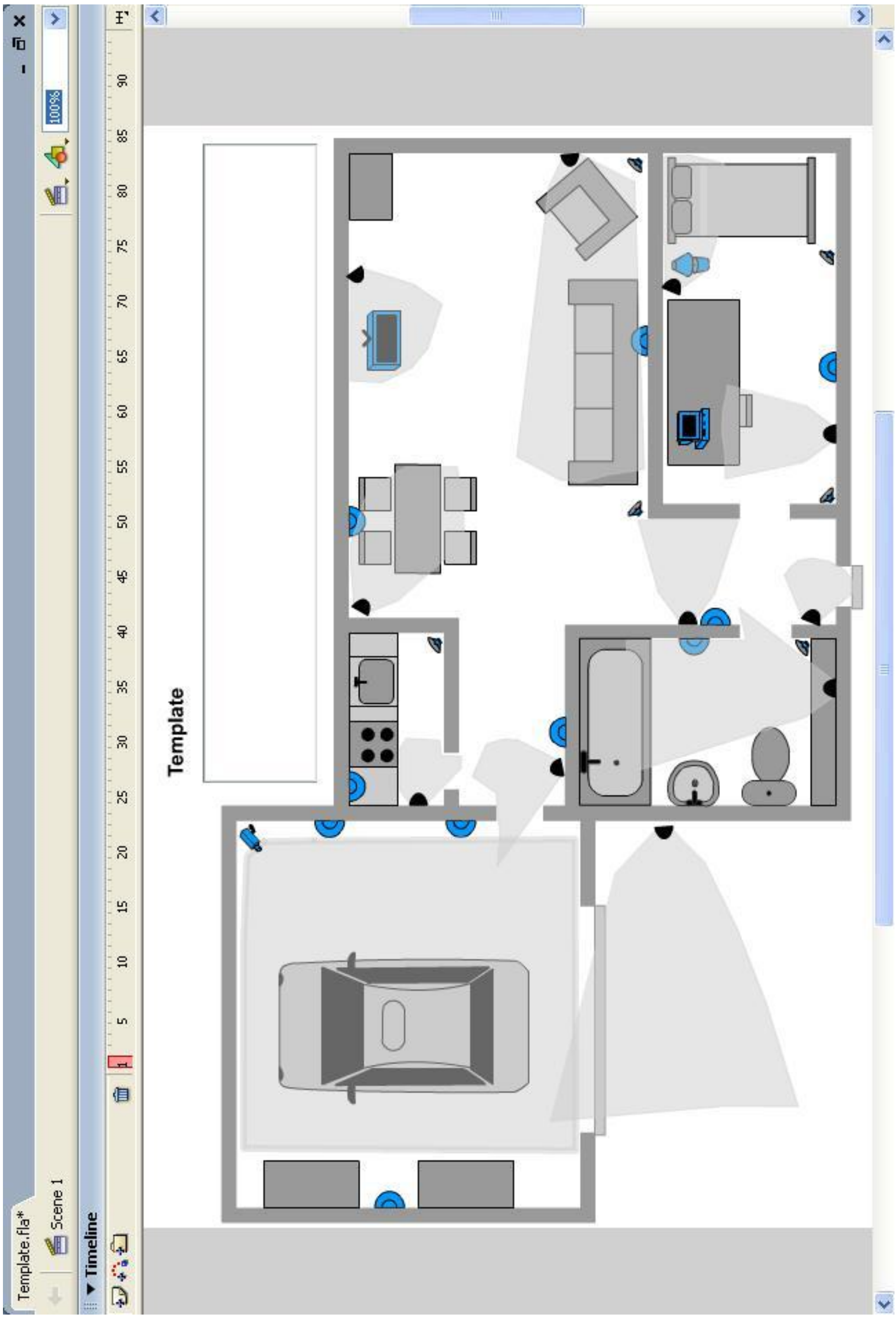

Figure A.2: An example of the house created using the prototype

Appendix B

Flash Action Script source code

```
// motion of an inhabitant variables
movementCounter = 0;
isInMove = 0;
moveInXDirection = 0;
moveInYDirection = 0;
sumofMoveInXDirection = 0;
sumofMoveInYDirection = 0;

// the script part variables
nextFunction = 1;
currentFunction = 0;

// pausing the script variables
isPause = 0;
lastFunction = 0;

// the function dealing with pressing the mouse functionality
_root.onMouseUp = function() {
  // the funtionality for pausing the animation during its progress
  if(_root.nextFunction != -1) {
    // pausing the animation
    if(_root.isPause == 0) {
      _root.isPause = 1;
      _root.lastFunction = _root.nextFunction;
      _root.nextFunction = -2;
    }
    // turning the pouse off
    else {
      _root.isPause = 0;
      _root.nextFunction = _root.lastFunction;
    }
```

```
  }
  // functionality to move the inhabitant with instance name
  // mcInhabitant to the point of mouse click
  // (if no animation is being played)
  else if(_root.isInMove == 0 &&
  !(Label2.hitTest(_root._xmouse, _root._ymouse, true))) {
    //calculating the lenght, direction and
    //numer of steps to move the inhabitant
    if(Math.abs(_root._xmouse - _root.mcInhabitant._x) >
      Math.abs(_root._ymouse - _root.mcInhabitant._y)) {
      _root.movementCounter =
      Math.round(Math.abs(_root._xmouse - _root.mcInhabitant._x));
      if(_root._xmouse > _root.mcInhabitant._x) {
        _root.moveInXDirection = 1;
      }
      else {
        _root.moveInXDirection = -1;
      }
      _root.moveInYDirection = (_root._ymouse - _root.mcInhabitant._y)
      / _root.movementCounter;
    }
    else {
      _root.movementCounter
      = Math.round(Math.abs(_root._ymouse - _root.mcInhabitant._y));
      if(_root._ymouse > _root.mcInhabitant._y) {
        _root.moveInYDirection = 1;
      }
      else {
        _root.moveInYDirection = -1;
      }
      _root.moveInXDirection = (_root._xmouse - _root.mcInhabitant._x)
      / _root.movementCounter;
    }
    // indicating that the movement is started and
    // calling the Interval function to perform actual movement
    _root.isInMove = 1;
    _root.intervalID = setInterval (_root.movePersonFunction, 27);
  }
}

// the interval function called by the movePerson() function
function movePersonFunction() {
  // sections acumulating the leangth of few steps if necessary
  // to avoid loss of the precision by Flash rounding mechanism
  _root.sumofMoveInXDirection += _root.moveInXDirection;
```

```
  if(Math.abs(_root.sumofMoveInXDirection) >= 1) {
    _root.mcInhabitant._x += _root.sumofMoveInXDirection;
    _root.sumofMoveInXDirection = 0;
  }
  _root.sumofMoveInYDirection += _root.moveInYDirection;
  if(Math.abs(_root.sumofMoveInYDirection) >= 1) {
    _root.mcInhabitant._y += _root.sumofMoveInYDirection;
    _root.sumofMoveInYDirection = 0;
  }
  _root.movementCounter -= 1;
  // the last step of movement part that
  // clears that stops future calls to this function
  if(movementCounter == 0) {
    _root.mcInhabitant._x += _root.sumofMoveInXDirection;
    _root.mcInhabitant._y += _root.sumofMoveInYDirection;
    _root.sumofMoveInXDirection = 0;
    _root.sumofMoveInYDirection = 0;
    _root.isInMove = 0;
    clearInterval(_root.intervalID);
  }
}

// the interval function called by the moveItem() function
function moveItemFunction(object) {
  // sections acumulating the leangth of few steps if necessary
  // to avoid loss of the precision by Flash rounding mechanism
  _root.sumofMoveInXDirection += _root.moveInXDirection;
  if(Math.abs(_root.sumofMoveInXDirection) >= 1) {
    object._x += _root.sumofMoveInXDirection;
    _root.sumofMoveInXDirection = 0;
  }
  _root.sumofMoveInYDirection += _root.moveInYDirection;
  if(Math.abs(_root.sumofMoveInYDirection) >= 1) {
    object._y += _root.sumofMoveInYDirection;
    _root.sumofMoveInYDirection = 0;
  }
  movementCounter -= 1;
  // the last step of movement part that
  // clears that stops future calls to this function
  if(movementCounter == 0) {
    object._x += _root.sumofMoveInXDirection;
    object._y += _root.sumofMoveInYDirection;
    _root.sumofMoveInXDirection = 0;
    _root.sumofMoveInYDirection = 0;
    _root.isInMove = 0;
```

```
    clearInterval(_root.intervalID);
  }
}

// function moving an inhabitant (with instance name "mcInhabitant")
// to a location specified by a mowie clip mc (possibly movement point)
function movePerson(mc) {
  _root.currentFunction += 1;
  if((_root.isInMove == 0) &&
  (_root.currentFunction == _root.nextFunction)) {
  // calculating the lenght, direction and numer of steps
  // to move the inhabitant
  if(Math.abs(mc._x - _root.mcInhabitant._x)
  > Math.abs(mc._y - _root.mcInhabitant._y)) {
    _root.movementCounter =
    Math.round(Math.abs(mc._x - _root.mcInhabitant._x));
    if(mc._x > _root.mcInhabitant._x) {
      _root.moveInXDirection = 1;
    }
    else {
      _root.moveInXDirection = -1;
    }
    _root.moveInYDirection = (mc._y - _root.mcInhabitant._y)
    / _root.movementCounter;
  }
  else {
    _root.movementCounter =
    Math.round(Math.abs(mc._y - _root.mcInhabitant._y));
    if(mc._y > _root.mcInhabitant._y) {
      _root.moveInYDirection = 1;
    }
    else {
      _root.moveInYDirection = -1;
    }
    _root.moveInXDirection = (mc._x - _root.mcInhabitant._x)
    / _root.movementCounter;
  }
  // indicating that the movement is started
  // and calling the Interval function to perform actual movement
  _root.isInMove = 1;
  _root.nextFunction += 1;
  _root.intervalID = setInterval (_root.movePersonFunction, 27);
  }
}
```

```
// function that can move any object
// to a location specified by a mowie clip mc (possibly movement point)
function moveItem(object, mc) {
  _root.currentFunction += 1;
  if((_root.isInMove == 0) &&
  (_root.currentFunction == _root.nextFunction)) {
    // calculating the lenght, direction and numer of steps
    // to move the object
  if(Math.abs(mc._x - object._x) > Math.abs(mc._y - object._y)) {
    _root.movementCounter = Math.round(Math.abs(mc._x - object._x));
    if(mc._x > object._x) {
      _root.moveInXDirection = 1;
    }
    else {
      _root.moveInXDirection = -1;
    }
    _root.moveInYDirection = (mc._y - object._y) / _root.movementCounter;
  }
  else {
    _root.movementCounter = Math.round(Math.abs(mc._y - object._y));
    if(mc._y > object._y) {
      _root.moveInYDirection = 1;
    }
    else {
      _root.moveInYDirection = -1;
    }
    _root.moveInXDirection = (mc._x - object._x) / _root.movementCounter;
  }
  // indicating that the movement is started
  // and calling the Interval function to perform actual movement
  _root.isInMove = 1;
  _root.nextFunction += 1;
  _root.intervalID = setInterval (_root.moveItemFunction, 27, object);
  }
}

// function that makes the action stop for a given number of seconds
function wait(seconds) {
  _root.currentFunction += 1;
  if((_root.isInMove == 0) &&
  (_root.currentFunction == _root.nextFunction)) {
    _root.isInMove = 1;
    _root.nextFunction += 1;
    _root.intervalID = setInterval (_root.waitFunction, seconds * 1000);
  }
```

```
}

// the interval function called by the wait() function
function waitFunction() {
  _root.isInMove = 0;
  clearInterval(_root.intervalID);
}

// function that change the state of a given device
function switchDevice(device, state) {
  _root.currentFunction += 1;
  if((_root.isInMove == 0) &&
  (_root.currentFunction == _root.nextFunction)) {
    if(state == "on") { device.gotoAndPlay(2); }
    else { device.gotoAndPlay(1); }
    _root.nextFunction += 1;
  }
}

// function adding a given message to a specified label
function setMessage(label, message) {
  _root.currentFunction += 1;
  if((_root.isInMove == 0) &&
  (_root.currentFunction == _root.nextFunction)) {
    label.text = message + label.text;
    _root.nextFunction += 1;
  }
}

// function that can make any object on the screen invisible
function makeInvisible(object) {
  _root.currentFunction += 1;
  if((_root.isInMove == 0) &&
  (_root.currentFunction == _root.nextFunction)) {
    _root.nextFunction += 1;
    object._visible = false;
  }
}
```