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**Design and Implementation of an
Integrative System for Configurable Exergames
Targeting the Senior Population**

MASTER DISSERTATION

Teresa da Conceição Madureira Paulino

MASTER IN COMPUTER ENGINEERING



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SUPERVISOR

Mónica da Silva Cameirão

CO-SUPERVISOR

Sergi Bermúdez i Badia

Abstract

Exergames have been proposed as a solution for the promotion of physical activity in the senior population. The diversity of needs and limitations of the target users demand that the exergaming systems allow the configuration and adjustment of game parameters according to each user profile. Such systems are ideal to use in nursing homes, senior gymnasiums, or even rehabilitation centers. Health and sports professionals are then the main interacting users with the interface of such exergaming systems. Configuration can be difficult and time-consuming when considering complex systems with a significant amount of parameter choices. Since professionals working on such places already have time constraints, if they face long-time configuration of these systems they might give up of using them. Therefore, there is an evident need for systems that assist professionals in two ways. First, providing management support for training sessions and plans with exergames. Second, providing automatic decision-making processes that assist in game selection and parameters configuration to fit the user needs.

The acceptance and effectiveness of such systems can only be achieved if the main prospective interactors with the system are involved in the development process so that the system can fulfill the users' needs and expectations. This thesis reports on the design, implementation, and usability evaluation of an integrative system using some of the most-known human-centric techniques, such as interviews, card sorting, and paper prototyping.

Results of a usability study of the UI and the main functionalities of the system showed a considerable acceptance and interest by the professionals. The usability study revealed to be a great resource to find aspects of the system that should be further considered for improvement in future iterations. Furthermore, the high results of the USE (Usefulness, Satisfaction, and Ease of use) questionnaire confirm that this system is a promising tool that sports professionals may be willing to use in their daily practice.

Keywords: exergames; active aging; human-centered design; software design; integrative system.

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Resumo

A literatura suporta que os *exergames*, ou jogos que requerem exercício físico, constituem uma opção válida para promoção da atividade física na população idosa. A diversidade de necessidades e limitações do público-alvo exige que estes *exergames* sejam configuráveis de forma a permitir ajustar os parâmetros do jogo de acordo com o perfil de cada indivíduo. Estes sistemas personalizáveis são ideais para a utilização em lares, centros de dia, ginásios específicos para idosos ou até mesmo em centros de reabilitação. Os profissionais de saúde e de desporto são, assim, os principais utilizadores a definir as configurações destes *exergames*. Neste contexto, escolher as definições ideais para cada perfil pode ser um processo difícil e demorado, tendo em conta que a interface destes sistemas apresenta normalmente uma quantidade significativa de opções. Considerando que estes profissionais já têm constrangimentos de tempo na sua prática diária, se forem confrontados com uma interação longa e complexa com estes sistemas, podem acabar por desistir de usá-los. Neste sentido, existe uma clara necessidade de sistemas que auxiliem os profissionais a incluir os *exergames* na sua prática diária com a população idosa. Este sistema deverá assistir os profissionais de duas maneiras. Primeiro, que permita gerir sessões e planos de treino com os *exergames*. Segundo, que disponibilize processos de decisão automáticos de forma a auxiliar na escolha dos jogos, bem como nas configurações ideais para cada perfil de utilizador.

A aceitação e a eficácia destes sistemas podem apenas ser alcançadas se os profissionais forem envolvidos no processo de desenvolvimento desde o início. Tal permitirá que este possa ser desenhado tendo em conta as suas necessidades e expectativas. Esta dissertação descreve as técnicas aplicadas no desenho, implementação e avaliação de um sistema integrativo para *exergames*, com base em algumas técnicas bem conhecidas na área de interação homem-máquina, como por exemplo entrevistas, *card sorting* e prototipagem em papel.

Resultados de um estudo de usabilidade da interface do sistema integrativo demonstraram uma considerável aceitação e interesse por parte dos profissionais. O estudo de usabilidade revelou ser um bom recurso para encontrar aspetos do sistema que devem ser considerados para melhoramento em futuras iterações. Além disso, os resultados promissores do questionário USE (Utilidade, satisfação e facilidade de uso) confirmam que os profissionais poderão estar interessados em usar este sistema na sua prática diária.

Palavras-chave: *exergames*; envelhecimento ativo; desenho centrado em humanos; desenho de software; sistema integrativo.

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1. Introduction

1.1. Motivation

The percentage of the senior population is rapidly increasing worldwide. The loss of motor and cognitive ability typically associated with aging is highly related to health problems. Sedentarism in older adults has emerged as a new health risk which may lead to cardiovascular diseases such as heart attack or stroke. Therefore, there is a need to develop solutions to promote active aging and to support the population affected by chronic diseases associated with aging. In this context, the AHA-Augmented Human Assistance¹ project combines innovation and research aiming at developing new technologies that have the potential to support a healthy lifestyle, promote active aging, and assist those with motor deficits. In the scope of this project, a set of configurable exergames was designed and developed in collaboration with the senior population and sports professionals.

Although several commercial exergames combine fun and enjoyment while promoting physical exercise, they are not adapted to special populations. The diversity of capacities and health needs makes each older adult unique. Thus, the AHA project exergames are highly configurable enabling the adaptation for each different profile. Each game targets mostly one or few physical aspects such as cardiorespiratory endurance, muscular strength, agility, balance or flexibility. One of the objectives of the AHA project was to integrate a set of exergames into a mobile platform to be used in environments such as senior houses, hospitals or senior gymnasiums. The professionals who are working in those places will be able to select the games and adjust parameters according to each end-user profile. However, as a result of the diversity of needs and capacities, it may turn to be a trial and error adjustment process until finding the best configuration settings. Additionally, users may evolve their skills over time, so exergame parameters should be progressively adjusted to provide not only a good gameplay experience but the desired exertion outcomes as well. For that reason, a software system was envisioned to manage training sessions and plans and intelligently automate the exergames selection and configuration based on the end-user profile.

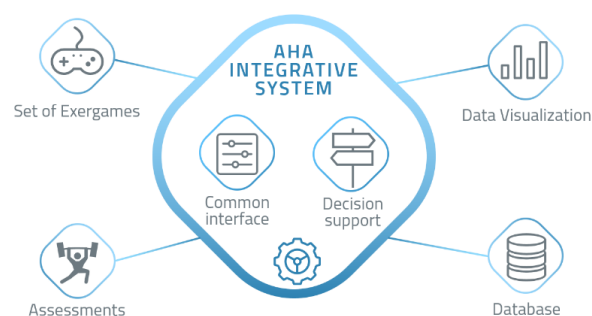


Figure 1-1 Generic diagram representative of the envisioned integrative system.

¹ Project reference CMUP-ERI/HCI/0046/2013

1.2. Objectives

Considering the above, the main objectives of this thesis are:

1. design the envisioned software system following human-centric techniques in collaboration with the main interactors of the system: the sports and health professionals;
2. implement the main features of the system based on the user-centered design;
3. evaluate the usability of the implemented software with the target users.

1.3. Document structure

This thesis is organized as follows: for a better understanding of the topic of this thesis, chapter 2 provides a literature review focusing on exergames for the senior population and presents existing similar systems. Three main stages comprise the design of the system: the requirements engineering, the software design, and the User Interface (UI) design which consisted of a set of known human-computer interaction methods such as card sorting, and paper prototype evaluation, as illustrated in Figure 1-2. These stages are presented in chapters 3, 4, and 5 respectively.

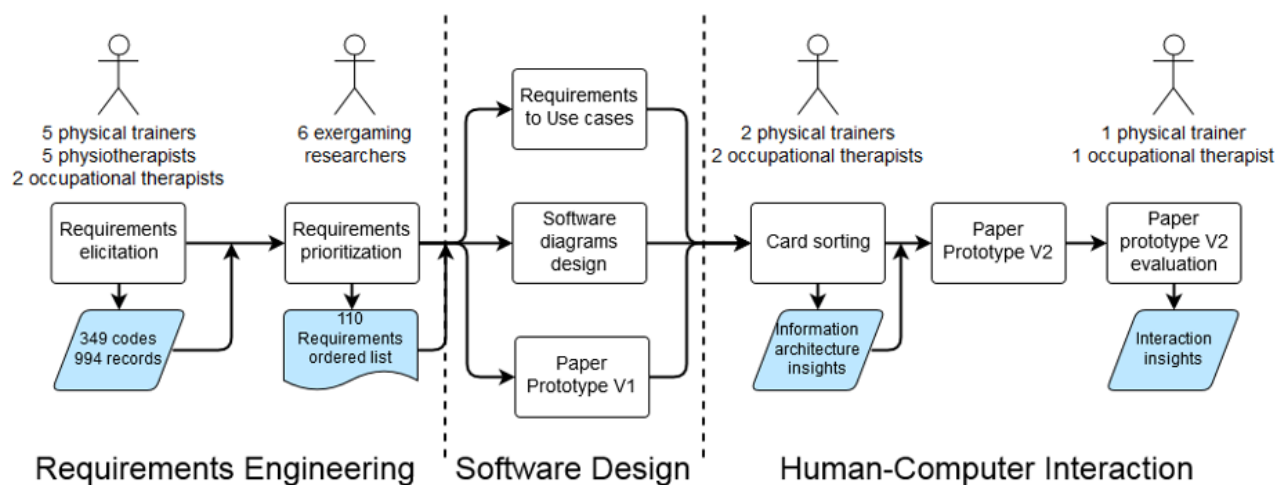


Figure 1-2 Diagram representing the different design stages of the system.

Chapter 6 describes the different packages developed for the exergames towards the integration. The implementation of the software is analyzed in chapter 7. Chapter 8 explores the automation of decisions and introduces a concept to implement decision support on the integrative system. Chapter 9 shows an overview of the system capabilities illustrated by different screenshots of the UI of the system and establishing relationship with the respective requirements. The methodology and results of a usability study are presented in section 10. To summarize, this thesis is wrapped up in the conclusion presented in chapter 11.

2. State of the art

2.1. Introduction

This chapter presents a literature review that contextualizes the research and describes existing similar systems. Specifically, section 2.2 gives a brief overview of aging and sedentarism. In section 2.3 are presented physical activity guidelines specific to the senior population and how older adults perform fitness training traditionally. Exergames as a new approach to fitness training are explored in section 2.4. Similar systems to the one presented in this thesis are described in section 2.5. Before concluding, existing systems are discussed and contrasted in section 2.6, illustrated by a table of comparison of the presented systems.

2.2. Aging and sedentarism

The percentage of people above 60 years old is growing globally, and it is expected to continue in the coming decades (Figure 2-1). “The number of older persons in the developing regions grew from 214 million in 1980 to 652 million in 2017—an increase of 205 percent—and it is projected to grow by 154 percent between 2017 and 2050” [1].

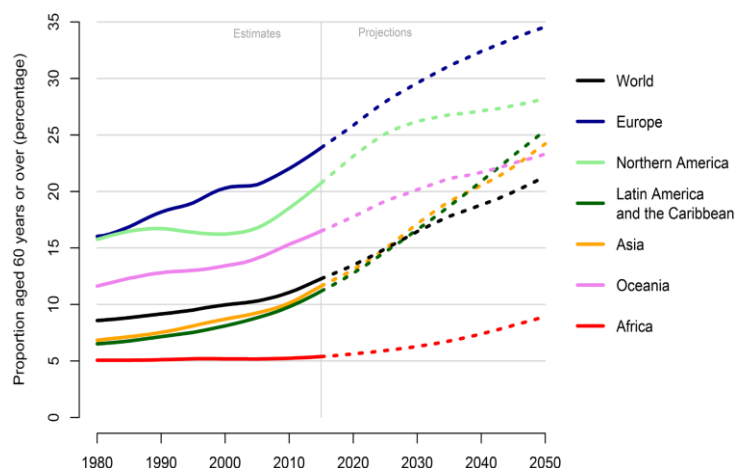


Figure 2-1 Percentage of population aged 60 years or over by region, from 1980 to 2050 [1].

The aging process is typically associated with health problems, mostly resulting from the loss of capacities or chronic diseases characteristic of the older population [2]. Evidence has been found between sedentary behavior and risk of diseases, disabilities, and mortality in older adults [3]. As we are living longer, paying attention to our physical condition is becoming gradually more important [4]. World Health Organization identifies the practice of physical activity as one of the critical behaviors that can influence healthy aging, which they define as “the process of developing and maintaining the functional ability that enables well-being in older age” [2]. Among many benefits, a lower rate of mortality and cardiovascular diseases have been identified in older adults who maintain good physical exercise levels. Additionally, they exhibit higher levels of functional health and have a lower risk of falling [5].

2.3. Exercise guidelines for the senior population

In general, an exercise program for the senior population should consider the following criteria: the physical domain/parameter, the duration, intensity, frequency, and individual profile characteristics. It is recommended for older adults to have a structured training plan that addresses different aspects of physical fitness [4]–[6]. The Senior Fitness Test manual identifies five physical parameters as being the relevant components of functional fitness: muscular strength, aerobic endurance, flexibility, agility, and dynamic balance, and body mass index [4]. The American College of Sports Medicine and the American Heart Association recommends at least 30 minutes, five days per week, of moderate-intensity aerobic exercise for healthy older adults [6], this totalizes 150 minutes per week, which is also the recommendation from the World Health Organization [5]. Additionally, for a minimum of two days each week, it is recommended to perform muscle-strengthening and flexibility exercises. Concerning balance, older adults with reduced mobility should perform exercises that maintain or improve balance 3 or more days per week.

A myriad of exercise options is available to older adults, such as exercising alone, in groups, at home, outside, or at a fitness center. The best option is “the one that people will do”, the form of exercise should fit the personal and environmental needs of each older adult [4]. Walking, dancing, cycling, swimming, practicing yoga, tai chi or pilates, are just a few examples of exercises available for older adults to perform at home or when alone [7].



Figure 2-2 Older adults performing the exercise in a fitness center specialized for the senior population. (Ginásio Santo António, Madeira, Portugal)

In fitness centers, physical exercise is usually performed in group classes instructed by sports professionals who design the training programs accordingly with the guidelines mentioned in the previous section. Figure 2-2 shows a group of older adults in a fitness class led by a sports professional. In some circumstances, fitness centers provide special classes to train specific

physical aspects, for instance, agility and balance targeting older adults with low mobility or that are at high risk of fall².

2.4. Exergames for seniors as a new approach

Exergames are defined as video games or computer-based games that require “physical exertion or movements that are more than sedentary activities and also include strength, balance, and flexibility activities” [8]. Interaction in exergames happens using motion tracking technology which enables getting input to the game from the player movements and gestures. The fun and entertaining characteristics of these games make the exercise process look more attractive and motivating [9]. There are already a variety of exergames in the market, such as the Dance Dance Revolution³ (DDR) or the Just Dance⁴ which are aimed for fun and enjoyment. Other examples focus more on the fitness outcome: Shape Up⁵ or Wii Fit⁶.



Figure 2-3 Setup of the modified DDR system [11].

The variety of needs and abilities of the senior population demands that exergames should be highly configurable and designed considering the senior's characteristics [12]–[15]. Besides improvements in physical fitness, exergames can also improve cognitive functions suggesting that simultaneous cognitive and physical exercise through exergaming has more significant potential for preventing cognitive decline [16]. However, two essential factors typically contribute to the success of an exergaming system: its effectiveness in meeting exercise requirements, and the attractiveness in compelling the player to exercise for the recommended duration and frequency [17]. For such training with exergames, this means that exergames should provide

² Information gathered from the professionals during the requirements elicitation process mentioned in chapter 2.

³ https://www.konami.com/games/asia/en/products/ddr_a/

⁴ <https://www.ubisoft.com/en-us/game/just-dance-2018/>

⁵ <https://www.ubisoft.com/en-us/game/shape-up>

⁶ <http://wiifit.com/>

enough variety to allow different training types while keeping the player motivated and avoiding boredom. Also, it is common that one exergame is designed to train one specific physical dimension, so a set of exergames is needed to create a full training program. For instance, Gonçalves et al. presented a set of four exergames which were designed to provide functional fitness training for the senior population [18]. Each game incorporates specific exercises, which allow focusing the training on one specific dimension. A similar concept was presented by Brach et al. who describes a set of 7 mini-games divided into three different types of exercises: strength, dynamic balance, and complex exercises [19]. This separation of the physical dimension allowed to progressively configure the training based on individual performance on each mini-game.

2.5. Review of exergaming systems

This section presents a literature review on representative systems that are similar to the one envisioned for this thesis, in the sense that consists of an all-in-one system that is comprised of multiple games and is used to create physical exercise or rehabilitation training programs, in specific for the senior population.

Konstantinidis et al. developed FitForAll, an easy to use exergaming platform to improve physical fitness and life quality of senior citizens [20], [21]. Their platform uses contemporary controllers such as the Nintendo Wii remote controller and balance board to serve as input to the games. Exercise intensity and difficulty levels are accordingly adjusted to the seniors' physical status progress assessed by a subset of the Fullerton (senior fitness) test [4] which is partially computerized by the system (Figure 2-4).

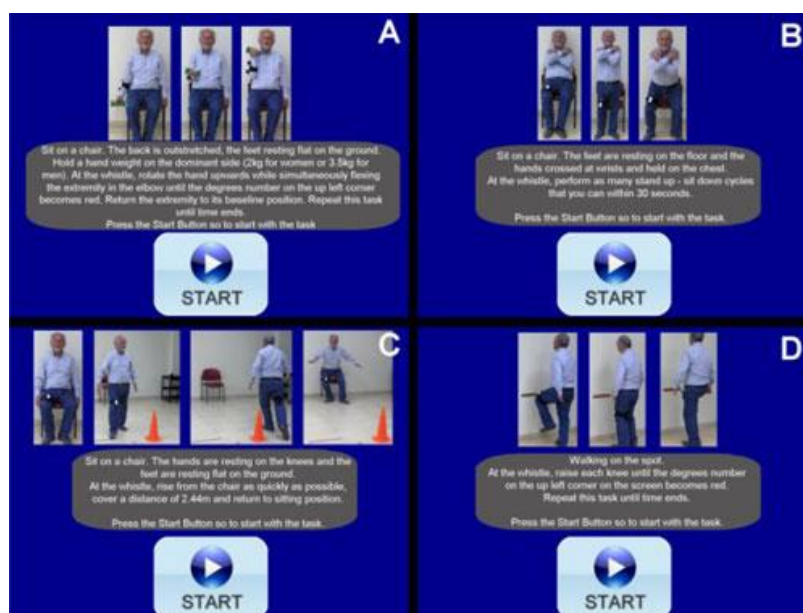


Figure 2-4 Screenshots of the partial computerization of the Fullerton test [20].

Each game encapsulates one exercise which was designed following guidelines and recommendations identified in the literature or provided by experts. In their system, a training session corresponds to a combination of exergames in an ordered sequence, configured to

specific physical exercise objectives. Sessions and games can be edited by health care providers through a native interface.

The architecture of the system shows that the human motion is captured by the hardware layer and is transformed into the game input, which is tested against the semantic layer according to the user characteristics stored in the data layer, while the presentation layer provides feedback for correction (Figure 2-5).

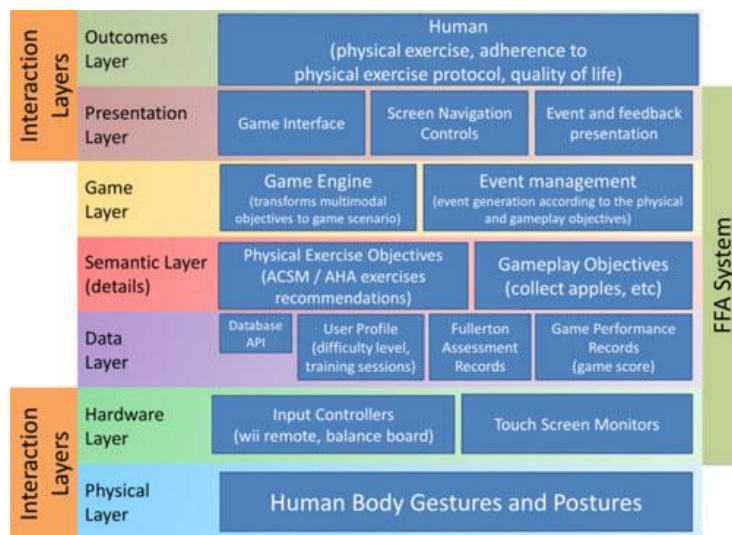


Figure 2-5 Architecture of the FitForAll system [20].

FitForAll was used and evaluated in compliance with exercise guidelines and recommendations for the elderly population. 116 senior citizens successfully engaged in a minimum of 2-3 times per week for 7-8 weeks. Each session lasted around 60 minutes which included exergaming training with aerobic, resistance, flexibility and balance exercises. Intensity was gradually increased based on participants assessment results. Figure 2-6 shows participants performing the exercises while playing the exergames. A control group with the same number of participants received cognitive training with identic session duration and intensity. Their study found strong evidence regarding physical and general wellness and quality of life improvements.



Figure 2-6 Pictures of participants playing the exergames during the intervention [20].

Pirovano et al. developed a game engine specifically tailored to rehabilitation [15], [22], [23]. Their system contains an abstraction layer that enables the games being played using different devices such as Microsoft Kinect, Wii Balance board or the haptic device Novint Falcon, among others. Exercises, parameters, and constraints that make up the games can be manually set by a therapist remotely from the hospital. Such parameters can be further automatically adapted during gameplay by monitoring the success rate. A virtual therapist is presented to the player for guidance in the interface, but also to correct wrong performed exercises and show rewarding messages when the player achieves success. From the hospital, the therapist can follow the player progress and schedule rehabilitation sessions.

The architecture of the system displays the control unit that contains the sessions prepared by the therapist. This unit is also in charge of adapting the parameters while the user is interacting with the game assisted by the virtual therapist (Figure 2-7).

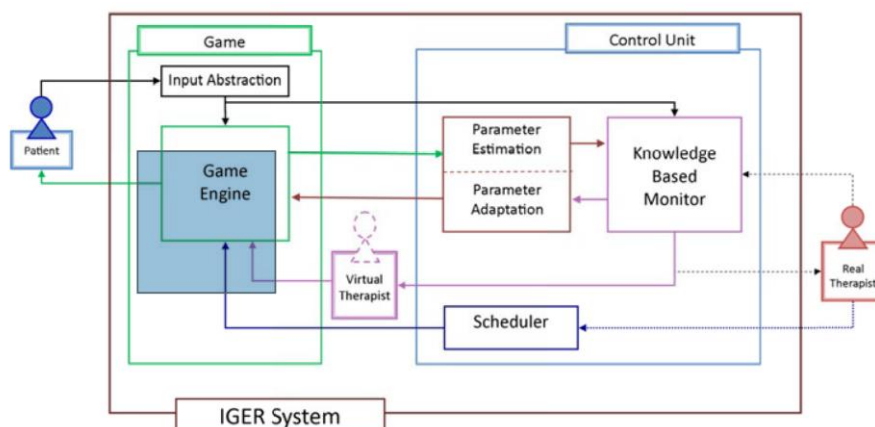


Figure 2-7 Architecture of the IGER system [15].

The IGER system was studied to test its feasibility with the target patient population, in this case, the intervention was run with stroke patients with visuospatial neglect [27].

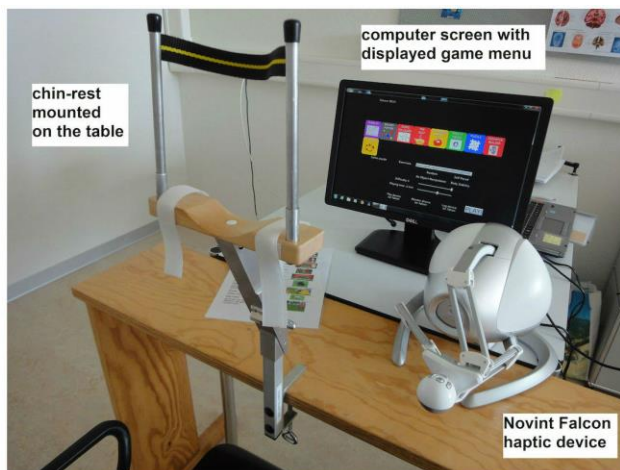


Figure 2-8 Setup of the exergaming training station [27].

Seven patients were included in the VR exergaming program, which had a training phase of 3 weeks, and a median of 14 training sessions. The participants played from 2 to 4 games on each session with difficulty being individually adapted by the therapists according to the patient progress. Figure 2-8 shows the setup of the system. Results of this study showed high adherence to the exergames with 93% of attendance to the 15 planned sessions. The findings displayed improvements in cognitive and spatial exploration skills. Therefore, the authors suggested that the exergames are a promising tool for future investigations.

Brach et al. developed a system with a set of minigames with an established narrative integrating the interests of the elderly aiming at increasing their motivation to exercise [19], [24]. Each minigame targets a specific fitness domain such as balance or strength. When the game targets more than one fitness domain, they named it complex. Microsoft Kinect is used as motion input for all games. The training parameters can be manually adapted by the caregivers or use the standard default parameterization. The levels of difficulty are automatically adjusted based on the user's performance. Data collected along the gameplay can be visualized on a statistics screen. In Figure 2-9 it is possible to see that the exercise configuration (intensity, volume, and control) and game performance (movement performance and game quality), both influence the adaptation rules.

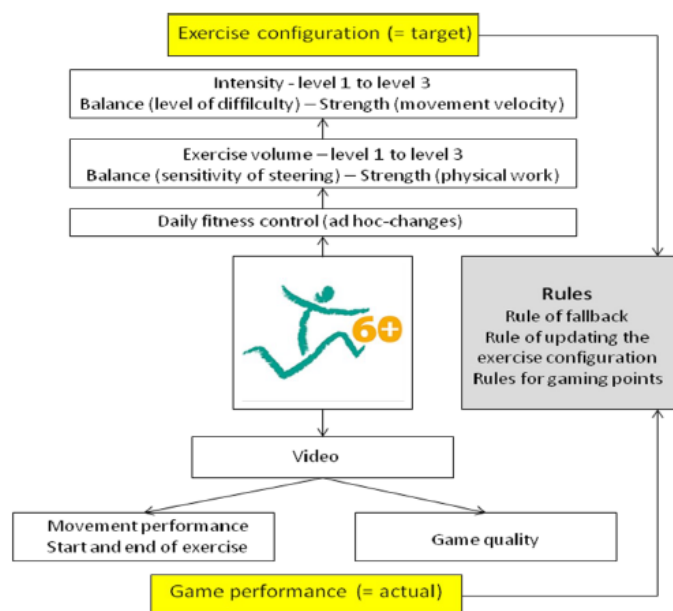


Figure 2-9 Scheme illustrating the multi-level control circuit for exercise configuration and quality control [19].

A set of personalized exergames was presented by Göbel et al. [25]. By using an authoring environment tool, health and sports professionals can define fitness programs using game-based applications that they can create from scratch or by using existing templates from a repository. The different training and exercise modules are structured into game levels.

The system is composed of an adaptive engine which retrieves and processes the vital state of the users which is directly used to influence the gameplay. Devices such as an ergometer, accelerometers, and a camera are used to detect motion and serve as input into the game. The

diagram of the framework displays a module called portal which communicates with the authoring tool in order to create games, either new or from the repository. The adaptive engine captures a user's motion and vital data from sensors, and all that information is passed to the Telemedical service center (Figure 2-10).

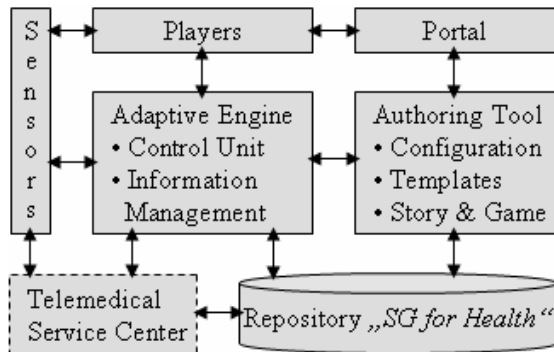


Figure 2-10 Framework for serious games for sports and health [25].

The set of exergames went through one initial technical feasibility study with 26 participants with age ranging from 18 to 75. In general, participants displayed motivation to exercise with the exergames, and according to the opinion of sports and health professionals, the system is a valid solution to be used in the prevention, rehabilitation, and fitness programs.

Another platform that integrates multiple games is the VR² (Virtual Reality Rehabilitation) presented by Paravati et al. [26]. Despite this framework being specific for cognitive rehabilitation and not precisely for exergames, it is essential to look at its architecture and see how it differs from the others. The previously presented platforms all have the games internally, which means that they are restricted to the games in use by the respective platform. However, in this framework, the authors enable their system to integrate independent games applications allowing expandability, meaning that the games are external to the system (Figure 2-11).

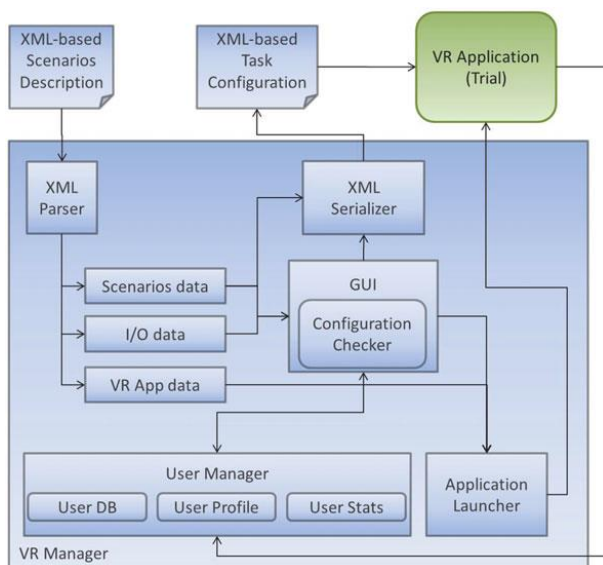


Figure 2-11 the modular architecture of the VR rehabilitation system [26].

Therapists can modify the configuration and the control parameters of each game. The UI of the VR manager is built dynamically in runtime depending on the features of each connected game. User data is stored and presented to the user on each trial. The difficulty between levels is gradually increased. Figure 2-12 shows the interaction using Microsoft Kinect and a wall projection.



Figure 2-12 Picture showing the interaction with the VR² system⁷.

As mentioned above, the customizable VR framework was not specific for exergames. Nevertheless, here are briefly described the details of a usability study performed with 11 individuals. All participants had cerebral lesions, and the age range was from 22 to 70 years. The protocol consisted of a total of 15 sessions of 30 minutes each, held two times per week. Overall, the participants enjoyed the tasks and found no difficulties in performing them. After the VR treatment, all participants had improvements in more than one cognitive area, more specifically in attention, verbal and spatial memory.

2.6. Discussion

The systems presented in section 2.5 are representative solutions of the system envisioned for this thesis. Table 2-1 presents the main system characteristics, which can assist in finding the major contributions of each one. For instance, in [20] the assessment of the user is automatically performed by the system and the starting level is suggested based on the user' profile. Another advantage of this system is that it has an auto-connect functionality making the installation of the system more accessible. The presence of a virtual therapist to guide the user and provide feedback seems to be an essential contribution on [15] together with the possibility to remotely configure and manage training sessions. In [19] the consistent narrative of the games was specifically designed to motivate and compel the seniors to play, while in [25] the social component is enhanced by adding competitive leaderboards and leagues. An important contribution in [26] is its architecture which allows integrating independent game applications and

⁷ screenshot taken from video link provided in [26].

consequently easy expandability. In all systems, there is automated decision support implemented that enables either real-time or in between levels difficulty adaptation.

Table 2-1 Table of comparison of the different systems presented.

	FITFORALL [20]	IGER [15]	AMBIENT ASSISTED LIVING FRAMEWORK [19]	PERSONALIZED EXERGAMES [25]	VR² [26]
Objective	Senior physical fitness	Physical fitness and motor rehabilitation	Senior physical and mental fitness	Physical fitness	Cognitive and sensory-motor rehabilitation
Input devices	Wii remote, Wii balance board, Microsoft Kinect	Microsoft Kinect, Wii Balance Board, Tyromotion Tymo plate, Motion OpenGo Insoles, Sony PS3 Camera, PM10 Robotic Arm, Novint Falcon haptic device	Microsoft Kinect	Ergometer, accelerometers and video camera	Mouse, Keyboard, Joystick, Data Glove, and Kinect, among others
Games	Internal game suite - expandable	Internal game engine	Internal game suite with a consistent narrative	Internal game engine	External game applications - expandable
Setup	Auto connect functionality and guided interface to connect devices	Written, spoken and video instructions configured by the therapist	Not specified	Not specified	Step by step instructions for connecting I/O devices
Feedback / Display of data	Pop-up messages with continuous support and feedback. Score feedback	Virtual therapist with doctor appearance guides and provides feedback	Data on movement correctness is used to give feedback to the user	Competitive leaderboards and leagues	Game performance history presented on each trial
User profile	Database with game and user data including assessment tests	Database with game and user data including assessment tests	User training and game-related data	Documentation and analysis of user workout data	Database with game and user data including assessment tests
Intelligence	Setup automatization. Initial difficulty level and progression based on the partial computerization of the Fullerton test	Bayesian-based in-game adaptation. Real-time performance-based parameter estimation	Adaptation rules based on game and exercise performance	Dynamic adaptation based on game logic, player behavior and vital status	The difficulty gradually increased based on previous game performance
Professional intervention	Adjust difficulty level	Manual configuration of the exercises, constraints and game parameters	Adapt training parameters at the beginning	Define fitness programs, personalized existing game templates or create new	Customize game parameters

The presented systems had their games evaluated with the target population and proved that can be considered promising tools to promote physical activity among the elderly population. However, none mentioned how usable these systems are by the professionals. Some mentioned that the systems were designed in collaboration with therapists or sports professionals, but none

of the studies provided details on how that process happened. Besides the target audience' acceptance, the adoption of such assistive technologies may be highly dependent on the professional's approval and adherence.

2.7. Conclusion

This chapter presented a literature review on the topic of this thesis providing a better understanding of current methods and approaches involved in promoting physical activity among the senior population. The literature reviewed proved that exergames are a promising and valid tool which enables older adults to exercise while having fun. Exergaming systems that enable integrating multiple games emerged to fulfill the compliance with training guidelines which demands variety and configurability.

Some existing systems were presented allowing for an overview of the existing capabilities and features. Such systems assist in managing training sessions and plans enabling sports and health professionals to individually configure the settings and keep track of the end user's progress. By comparing the presented systems, three components are available in all systems. First, a database that stores various types of data, such as training, game, assessments, and user information. Second, all systems contain some kind of intelligence, in some cases, games are personalized based on user profile, in other cases adaptation is provided depending on game performance, either in real-time or at the end of each level or session. Third, all systems depend on the either professionals' intervention to adjust, configure or customize the exergames.

Despite the results with the target population, there is still a lack of design processes and usability studies with the professionals, who correspond to the main interactors with the management system. Therefore, this thesis proposes the design and development of an integrative system to promote physical activity among the senior population, in compliance with professionals' preferences and needs.

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3. Requirements engineering

3.1. Introduction

Requirements engineering is the process of acquiring, analyzing, documenting and managing requirements along the life cycle of any computer-based system [28]. Requirements acquisition occurs at an early stage and is considered to be a critical step on a software's development life cycle, leading to the success or failure of a system [29], [30]. To obtain a good understanding of the needs of the target audience it is vital to choose the right elicitation method(s). In [30], the authors mention four types of requirements elicitation methods: conversational, observational, analytic, and synthetic. Conversational methods are among the most commonly used in software engineering which provide a natural way to understand the problems, needs, and ideas of the stakeholders concerning a software system. Observational methods consist of observing humans performing the tasks in which the software should assist, and they can be useful to acquire information that can be difficult to verbalize. Analytic methods are based on studying and analyzing existing documentation, a legacy software, or an expert's knowledge. Synthetic methods combine conversational, observational and analytic methods and are often mentioned as collaborative methods.

One of the motivations for the development of the here presented system is to facilitate the creation and management of training sessions with exergames by sports and health professionals. Although the system had been conceptualized initially with a generic set of expected features, it was essential to understand how valuable such system could be for the target users, especially considering that they do not use this technology in their daily practice. Since the activity of creating and managing training or rehabilitation sessions is somehow a background activity, a conversational method under the form of a semi-structured interview was chosen to bring forth both foreseen and unexpected information.

This chapter describes the initial requirement engineering process, which started by planning the interviews before obtaining a filtered and ordered requirements list. It is important to mention that requirements were iteratively updated along the various stages of the development lifecycle, which will be further explained in the next chapters.

3.2. Semi-structured interviews planning

The interviews were carefully planned by combining different types of questions such as behavior/experience, opinion/value, and knowledge questions, focussing on open-ended questions that could elicit more information (Appendix A). Questions included categories such as i) knowledge and opinions about similar systems, ii) positive and negative aspects about these types of interactive systems, iii) daily practices in terms of rehabilitation therapies and exercise prescription, iv) expectations of the integration of this system including data visualization, technical assistance, concerns, and constraints.

A script was written with an introduction, planned questions, and alternative questions in case interviewees found some difficulties in answering. The script enabled in leading interviews more

uniformly. Visual elements, such as a generic diagram (Figure 3-1) and a video representative of the system, were used to help on the understanding of the envisioned system (<https://www.youtube.com/watch?v=7kGrI3iETuq>).

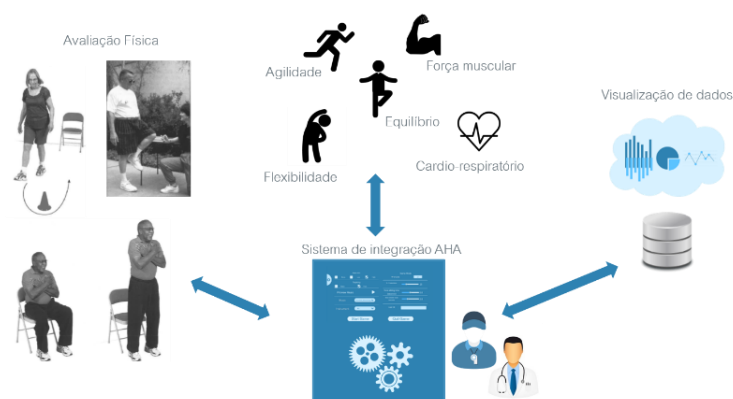


Figure 3-1 Generic diagram of the system which will be able to integrate users' assessments results to be used on exergames recommendation targeting the physical needs of each user. Additionally, it will provide data management and visualization of the historical progress of the user.

The script was presented and discussed in a group meeting prior to the interviews and then revised according to the feedback of the involved researchers. More specifically, the questions were reformulated to improve their clarity.

Literature sustains that two interviewers can lead to more information gathering from the participants [31]. Two interviewers were considered, and general agreement of roles concerning the conducting process was planned, where one would pose the main questions which were previously established, and the other interviewer, which had more conversational skills, would make more exploratory questions depending on the course of the interview.

3.3. Conducting the interviews

12 participants (7 female, 5 male) were invited to collaborate in the initial process of requirements elicitation: 5 physiotherapists, 2 occupational therapists, and 5 physical training instructors, with an average age of 28.9 ± 5.4 , and 5.6 ± 4.7 years of professional experience. Most of the participants had previous experience with older adults or neurologic patients. Interviews were conducted in person with the occupational therapists and physical trainers, and through video calls using Skype⁸ with the physiotherapists. As previously planned, two interviewers led the interviews which lasted around 1 hour each.

One initial interview was conducted to test the script and planned content. After this initial interview, which was included for analysis, only the video used for visual elucidation was replaced

⁸ <https://www.skype.com>

for a more representative one. Also, it was decided that it would be better to use different videos depending on the professional background, specifically for sports⁹ and health¹⁰.

Before starting each interview, the purpose was clearly explained, and the interviewee was asked to read and sign the informed consent (Appendix B) together with optional permission for audio recording. Each interview started with the introduction to the system which was supported by the visual diagram being presented step by step for a better understanding of the expected features (Figure 3-1). The interviewers let each participant talk by keeping a non-judgemental atmosphere leading the interviewee to imagine a system where everything was possible without considering technical limitations, so he/she would not feel shy or restricted. One aspect common to all interviews was that participants kept providing information about the exergames themselves, whereas the target was the integrative system. To address this, and depending on the course of each interview, the interviewers iteratively explored interviewees' answers by making related questions that would make participants focussing more on the integrative system than the exergames.

3.4. Participants

Participants were attributed codes to keep data anonymous, being identified only by their profession. For instance, if the participant code starts with the letter *D*, means he/she is a sports professional, otherwise, when starting with letter *S*, it means the participant is from the healthcare field.

This codification enabled identifying patterns when analyzing the interviews' data. *Table 3-1* summarizes the characteristics of the interviewees concerning their demographic and background information. 10 out of 12 participants allowed recording the audio of their full interviews. Written documents with important notes acquired during the interviews were gathered for further analysis.

Table 3-1 Demographic and background information of the interviewees.

PARTICIPANT CODE	GENDER	AGE (YEARS)	PROFESSION	EXPERIENCE (YEARS)	POPULATION TARGET	INTERVIEW TIME (HH:MM)
D01	F	26	Physical trainer	2	Seniors	01:07
D02	M	30	Physical trainer	4	Football players	01:31
D03	F	42	Physical trainer	16	Seniors	01:14
D04	M	34	Physical trainer	10	Seniors	01:36
D05	F	29	Personal Trainer	10	General	01:11
S01	M	29	Occupational therapist	6	Neurologic patients and children	01:22
S02	F	25	Occupational therapist	< 1	Seniors	00:57
S03	M	29	Physiotherapist	4	Neurologic patients	01:00
S04	M	26	Physiotherapist	4	Neurologic patients	01:00
S05	F	26	Physiotherapist	4	Neurologic patients	00:50
S06	F	22	Physiotherapist	< 1	Neurologic patients	00:32
S07	F	27	Physiotherapist	5	Neurologic patients and seniors	01:01

⁹ <https://www.youtube.com/watch?v=5p6uMdosBAc>

¹⁰ <https://www.youtube.com/watch?v=UeJqaF7BaiA>

3.5. Qualitative data analysis

The data files went through a coding process using the MAXQDA qualitative data analysis tool¹¹. The first step was to import the files and create the main codes that served as parents of the new codes that emerged during the listening process. The main codes were like categories based on the interviews' questions (Figure 3-2).

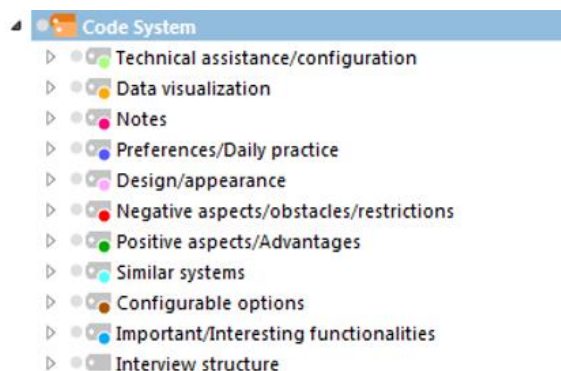
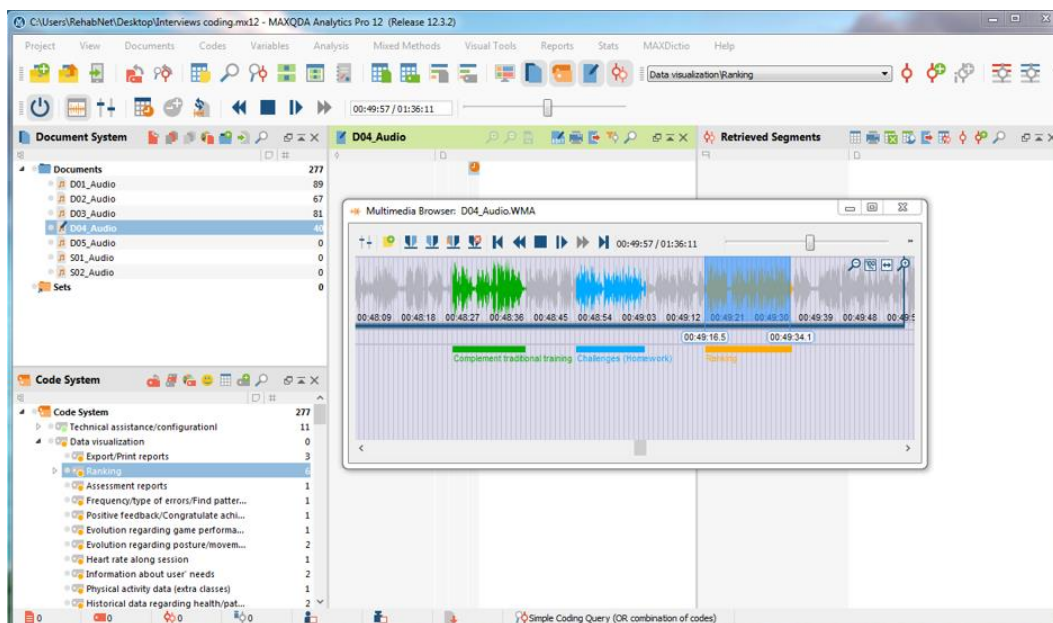


Figure 3-2 Main codes created prior to the coding process.

The coding process consisted on listening to a file, and whenever there was some important information, that area was selected, and a code was attributed under one of the previously created categories (

Figure 3-3). A code could correspond to a feature, a suggestion, a concrete answer, or even an insight that could be a suitable candidate for a requirement of the integrative system.



¹¹ <https://www.maxqda.com/>

Figure 3-3 Coding process in the MAXQDA software.

This process was performed on all the files allowing obtaining a total of 349 different codes with 994 records. These data were then exported to Microsoft Excel¹² and went through one initial cleaning process by merging similar codes, rephrasing codes to clarify the information, and move to more suitable categories the ones that did not fit in the previously chosen ones.

Data were organized by category, each one on a different sheet, and stored in tables with the same header, as seen in Figure 3-4. The first field identifies the code, followed by the number of sports professionals that mentioned that code (#) and its percentage (%) concerning only the sports professionals. The following two fields represent the same results but for the health professionals. Finally, the total of all interviewees can be seen in the last two fields.

Code	Sports professionals		Health professionals		Total	
	#	%	#	%	#	%

Figure 3-4 Table header used to store the interviews' data.

3.6. Results

In this section, the results of the most relevant categories found through the interviews' data analysis are presented, specifically, the results concerning knowledge about similar systems, functionalities of the system, configurable options, and data visualization. On the last subsection, other less relevant categories are briefly explored.

3.6.1. Knowledge about similar systems

Concerning knowledge about similar systems, 83.3% (Figure 3-5) of the interviewees mentioned the console Wii as a similar system. It is important to mention that most of the interviewees said that they did not know similar systems. Hence, it was necessary to pose questions differently to reach the presented answers. Furthermore, such knowledge relies on exergames experiences and not so much on the integrative and management system.

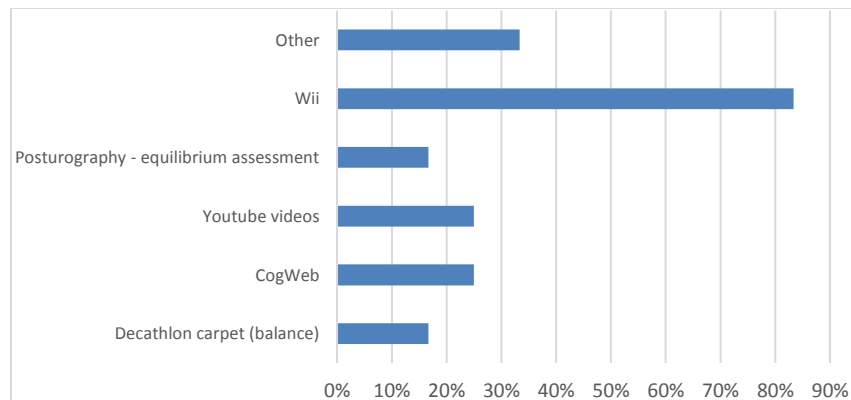


Figure 3-5 Knowledge about similar systems.

¹² <https://products.office.com/en/excel>

Since the Wii console was the most mentioned system, we further explored the subject trying to understand what were the positive (Figure 3-6) and negative (Figure 3-7) aspects. They considered that games are entertaining and playful, and additionally provide useful feedback such as posture correction and warnings/reminders. On the other hand, the fact that games are not adapted for users with specific limitations was considered the most relevant negative aspect.

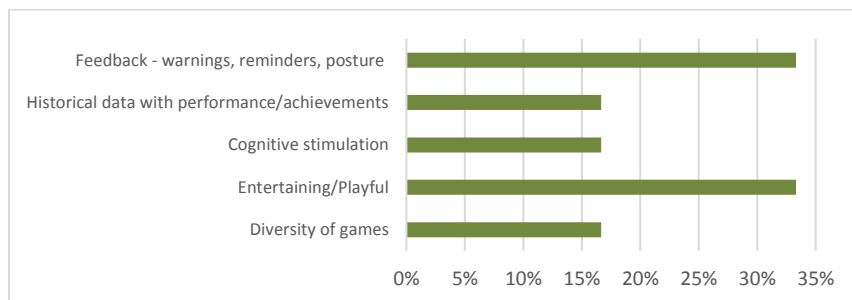


Figure 3-6 Wii console - positive aspects.

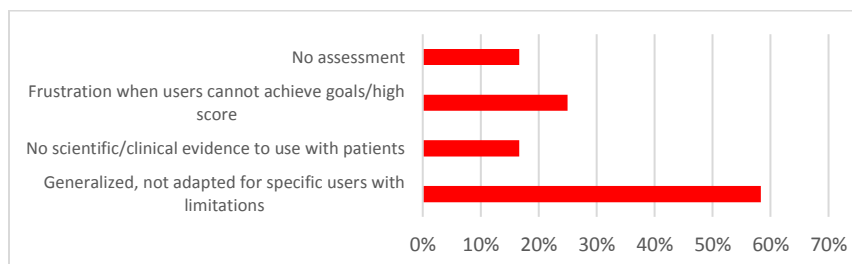


Figure 3-7 Wii console - negative aspects.

3.6.2. Functionalities of the system

Interviewees were asked about features they would like to have implemented in the integrative system. Figure 3-8 compares the most mentioned features of the two types of professionals. For example, “Feedback” was mentioned by all interviewees by being an important feature that these types of systems should have. When they mentioned feedback, they were referring to warnings, reminders, posture correction, and positive feedback to reward achievements.

Concerning the possibility of having data available on each device and having a non-supervised mode with automatic activities suggestion, only sports professionals mentioned these features. On the other side, health professionals suggested that the system should provide activities that assess the end-users. Health professionals also enhanced the importance of activities with cognitive stimulation besides the physical aspect. The option to manually reconfigure the predefined parameters is more relevant for health than sports professionals; this may be due to the high diversity of needs considering physical rehabilitation. Sports professionals pointed out that the exercises should target activities of daily living. The features of storing historical data, monitoring physiological states, and providing a diversity of activities are approximately identical for both sports and health professionals.

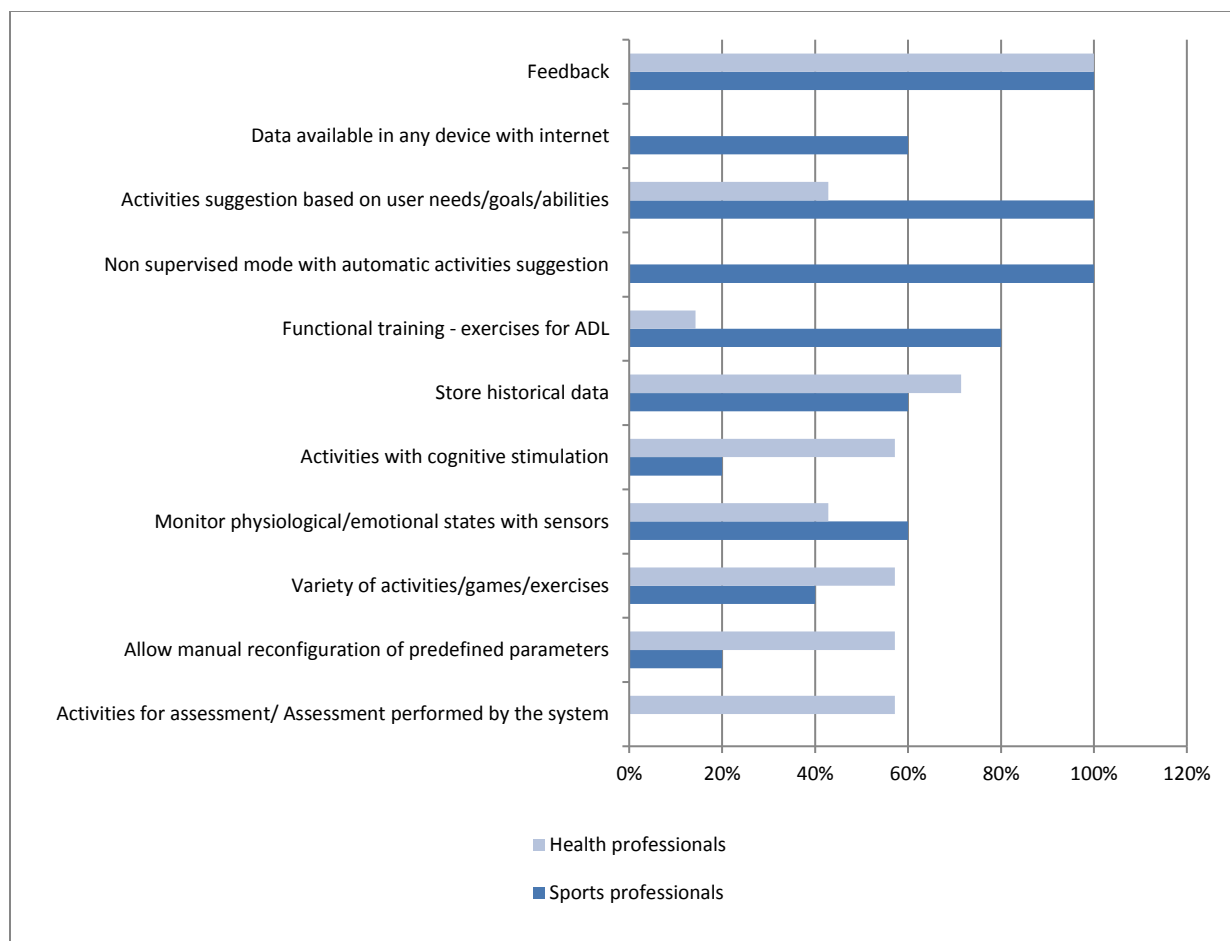


Figure 3-8 The most mentioned functionalities as reported by health and sports professionals.

3.6.3. Configurable options

When asked about configurable options that the system should provide, the complexity/difficulty obtained the highest result, followed by the intensity/frequency, conditions of practice, and music. As seen in Figure 3-9, some differences can be found between the two types of professionals.

The possibility of allowing customization of exercises revealed to be more important for health professionals, while for sports professionals, the possibility to set limits or define some exercises as dangerous has shown to be more important. Configurable options such as velocity and goal/objective, obtained the same results, showing more interest from the health professionals. The option of the game or activity be considered as a configurable option was only mentioned by the health professionals.

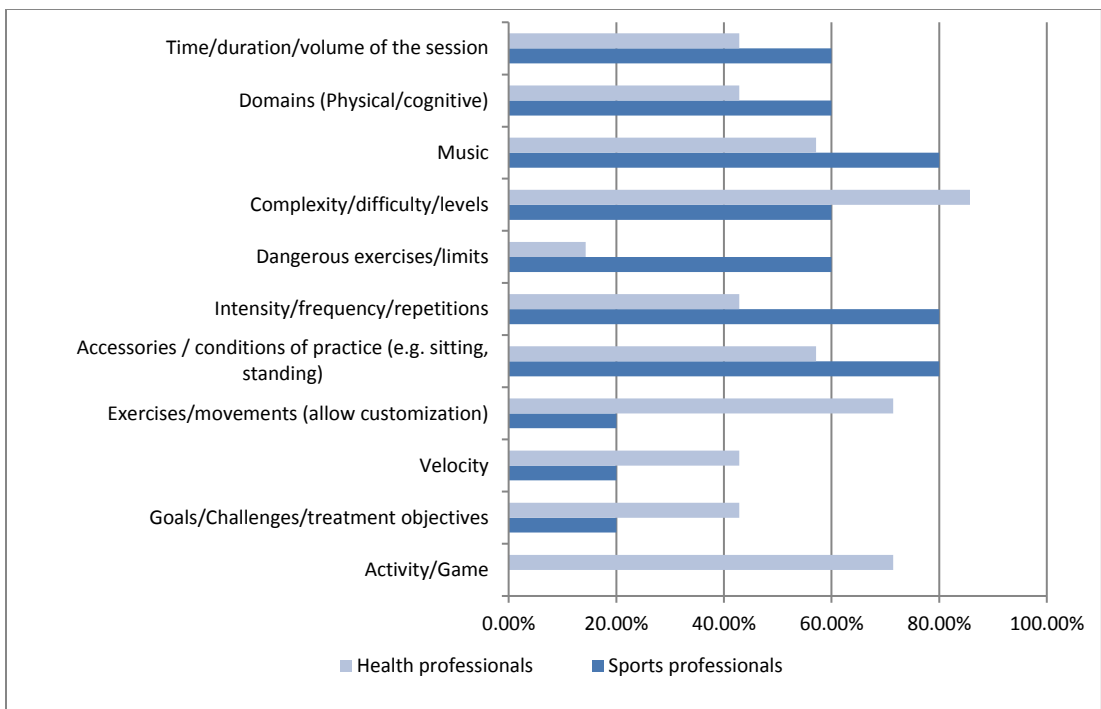


Figure 3-9 Configurable options as reported by health and sports professionals.

3.6.4. Data visualization

Concerning which data that the professionals would like to visualize on the integrative system, it was mostly related to the historical progress of the end-user regarding posture, game performance, and assessments results. Interestingly, the ranking option was more mentioned by sports professionals. In the interviews, they supported this option mentioning that it can offer to end-users more motivation and willingness to engage in the exercise activities. However, in the opinion of health professionals, this option could lead to frustration of end-users since they will mostly be using this system for rehabilitation purposes. The graphic presented in Figure 3-10 displays the data visualization comparison.

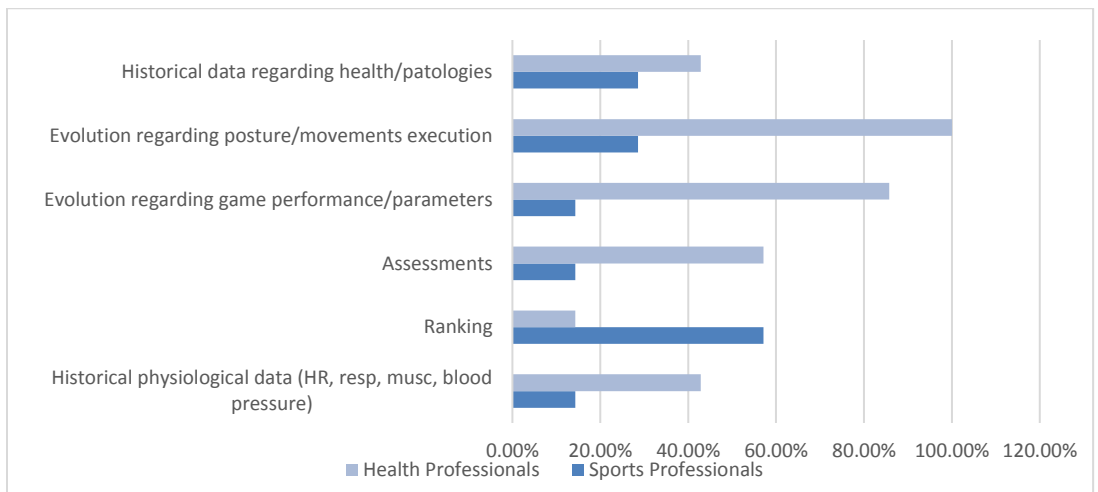


Figure 3-10 Comparative graphic of the most mentioned data visualization options.

3.6.5. Other categories

Concerning technical assistance, there is an evident preference for having a specialized technician providing training and help. On visual preferences, interviewees did not mention much, but 25% suggested the use of visual symbols and colors to assist in information' interpretation. Music was often mentioned because it is used in their daily practice to increase motivation and performance of exercises due to the rhythm and emotional atmosphere that can be created. Moreover, professionals use their own perception/intuition for generic "assessment" of the daily condition of the end-users. Professionals create sessions and plans based on different physical domains and the end user's capacities, recommending alternative exercises in case the end-user is not able to perform it.

When asked about disadvantages or obstacles that the bespoke system could bring, 66.7% of the interviewees showed concern about the risk of falls or injuries. On the advantages side, 41.7% of the interviewees said that the system could be a good complement for traditional training or rehabilitation therapies.

3.6.6. Requirements Prioritization

Requirements prioritization assists in making the right decisions when choosing the most important features to implement in a system [32]. From the data obtained on the previous step, a data cleaning step was manually performed removing feedback which corresponded just to suggestions and opinions that were not considered as requirements for the proposed system due to their high diversity. A final list of 110 requirements was then shared with 6 exergaming researchers who evaluated each requirement with an eleven-point Likert scale considering two perspectives: i) the cruciality of the system, meaning: "does this system work without this functionality?"; and ii) the importance to fulfill the system's objectives. The result was then the same list but ordered according to 3 results: the evaluation from the cruciality perspective (the mean of all participants), the percentage of interviewees that mentioned each specific requirement, and the evaluation from the importance perspective. The ordered requirements list can be found in Appendix C.

3.7. Conclusion

This chapter described the requirements engineering process which revealed of having high importance in finding the essential features to be considered not only for the system's design but also for future implementations on games and related activities.

Having the possibility to meet the health and sports professionals in person, and talk about their expectations, worries, preferences, and daily practices concerning such system, was invaluable for the design of the system. It was not always easy to try to make the professionals talk about an envisioned system that they never saw before and that is not like what they do in their daily practice. Many times along the interviews, and especially when they were asked about their expectations, they often said: "I don't know if it would be technologically possible to...", so offering the possibility of no constraints, by telling them "Imagine that anything is possible", it turned out that they felt less restricted and more open to making suggestions.

Results have shown that preferences among the two types of professionals, may differ in some cases, and may be quite similar in others. In general, all contributed to obtaining the first requirements list which is crucial for the next development stage, the software design.

4. Software Design and Architecture

4.1. Introduction

Before starting designing new software, it is important to choose which modeling standards and guidelines are going to be used to settle on a standard notation. One of the most known modeling languages is the Unified Modeling Language (UML), which defines notation and semantics for common object-oriented projects. UML makes use of visual elements such as symbols, lines, and labels which are consistently used in different types of diagrams to offer a clear and quick overview of the functioning or description of a system and its components. Modeling is the basis of software engineering performed towards an acceptable solution for a problem [33].

This chapter describes the methodology used to create the software diagrams that will serve not only for documenting the system but also in guiding the implementation. All the graphical diagrams were built using the code editor tool Microsoft Visual Studio 2015¹³ which has built-in the required UML templates presented in this chapter. The design of the system was modeled considering most of the functional requirements gathered on the previous stage despite the realization of its future implementation. The process started by creating the use cases based on the requirements list, followed by the design of auxiliary diagrams such as model and class diagrams. Only after this it was possible to outline the architecture. The identification of the main entities and its relationships allowed to create a possible case of interaction using sequential diagrams, which was assisted by the creation of a paper prototype of the User Interface (UI).

4.2. Use cases

A use case describes an action or behavior that an actor can perform while interacting with a system. Consequently, a set of use cases represents the functionality of that same system [33]. So, the first step was to identify the various possible roles and the systems or subsystems involved. For this, an initial brainstorming session was carried out, and three main roles and three subsystems were identified:

Subsystems:

1. **Exergame** – an independent game that promotes physical exercise and targets training of specific physical domain(s).
2. **AHA Integrative System** – the central interaction system providing communication and management of input and generated data. It is a middleware between the independent exergames and the AHA cloud service with which communicates in a bidirectional form. Should be able to work both with and without internet access.
3. **AHA Cloud Service** – is comprised of a database and a web app. Its main purposes are storing and providing visualization of historical data from end-users, exergames, and the AHA integrative system.

¹³ <https://visualstudio.microsoft.com/pt-br/vs/older-downloads/>

requirement it is possible to extract one more use-case: “Adjust objective”. Due to the high number of requirements, the process of building use-cases focused on the generic functionalities that allow the system to convey its main goals, making sure that the requirements were fulfilled. For instance, the “Edit session settings” use case may include multiple requirements such as “Configurable difficulty/complexity” or “Configurable session duration”.

Two use cases diagrams were built for the two most important roles: “professional” and “end-user” (Figure 4-1 and Figure 4-2 respectively). The associations between use-cases in the diagram represent the relationships between them, all of them are “include” relationships, which means that one cannot happen without the other. For instance, the “Launch game” is a use case that the professional can accomplish with the system, however, to achieve this, the professional is required to first “add/open a game”, which includes “open session”, which in turn includes “create session”. Only registered end-users can have sessions, so the use case also includes “register end-user”. “End-user” diagram consists of a reduced version of the “Professional” diagram, meaning that the “End-user” role can perform some of the use cases that the professional can, however, in some circumstances, under limited conditions. For instance, the “edit game parameters” is dependent on the permissions that must be previously set by the professional. Another example is the use case “create session”, the end-user can perform this action with the system. However only the possibility to create automatic sessions generated by the system is allowed because of two reasons, first for simplicity reasons, it can be difficult for the end-user to configure a session and to know which activities should add to the session. Second, for safety reasons, in case the end-user defines some not so recommended settings which may not be beneficial for his/her health.

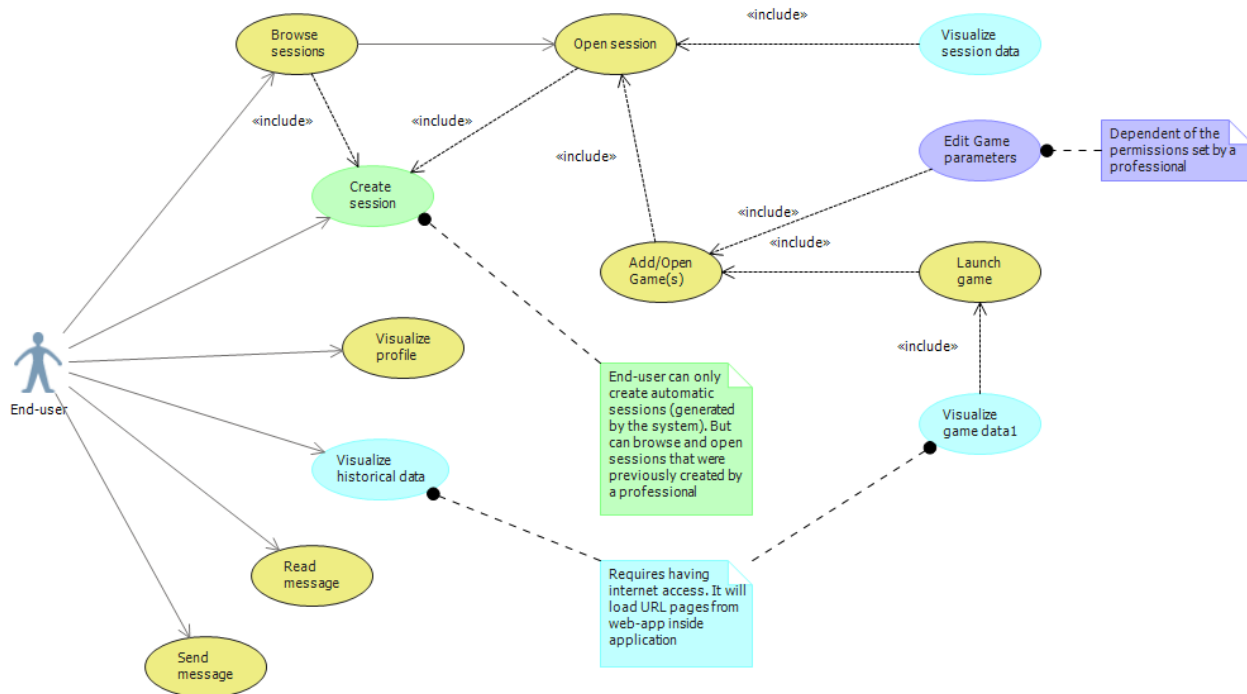


Figure 4-2 Use-cases diagram of the role “End-user”. The use-cases in blue can only be achieved if there is internet access since it relies on cloud database data.

4.4. Conceptual Information model (Class diagrams) design

After having the domain model diagram that assisted in discovering the main entities of the system, the design process went into more detail by creating the conceptual class diagrams which helped in having a better vision of the code structure. The code structure naturally emerges from the system requirements provided by its users. At this point, the focus was on the entities, their attributes, and relationships among them. Good design practices have been applied on the design such as using known design patterns, such as the singleton and the decorator, to obtain an effective solution that could be easily read and understood in the future by other developers [37]. Abstract classes and interfaces were used to create and define functionality that their subclasses can implement and override. In Figure 4-4 and Figure 4-5 are represented two examples of class diagrams created for the software documentation. Figure 4-4 shows the class `User` and its related classes. “End-User” is a subclass of “User”, which has attributes that concern the senior user necessary for the creation of his/her fitness profile, such as age, gender, weight, or height. Enumerated types have been created to restrict the values of the two attributes, gender, and category.

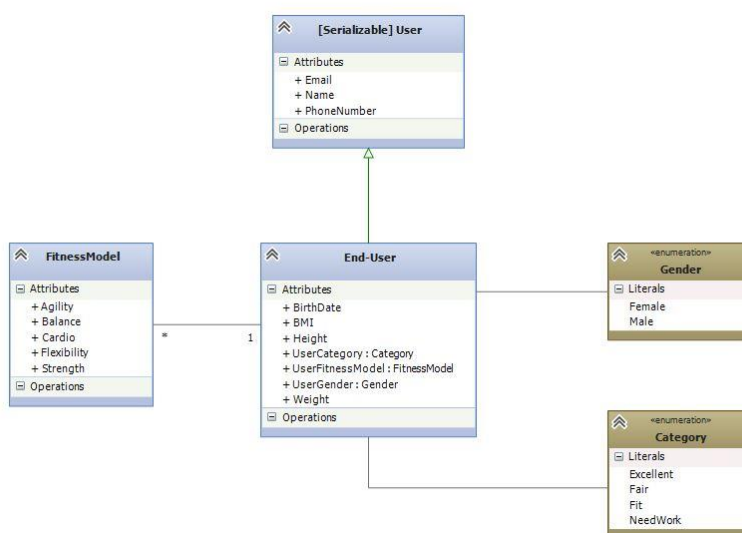


Figure 4-4 The `User`, `End-User`, and `FitnessModel` classes diagrams.

The “`FitnessModel`” class is an important class which is used as a common language across the system, and it defines users’ fitness characteristics regarding agility, balance, cardio, flexibility, and strength. The information on the “`FitnessModel`” is used to determine sessions, plans, and game settings, in other words, the user fitness model will be converted in the game’s “difficulty” or “intensity” level. Figure 4-5 shows the class diagram of all classes that involve the class “`Game`”, which is a concrete class implementing the interface “`IGame`”. Decorators provide a flexible alternative to extending functionality or providing “embellishment” by wrapping additional attributes or functionality. Hence, with the help of the “`GameDecorator`” class, attributes such as accessory weight, game partners, and music can be dynamically added.

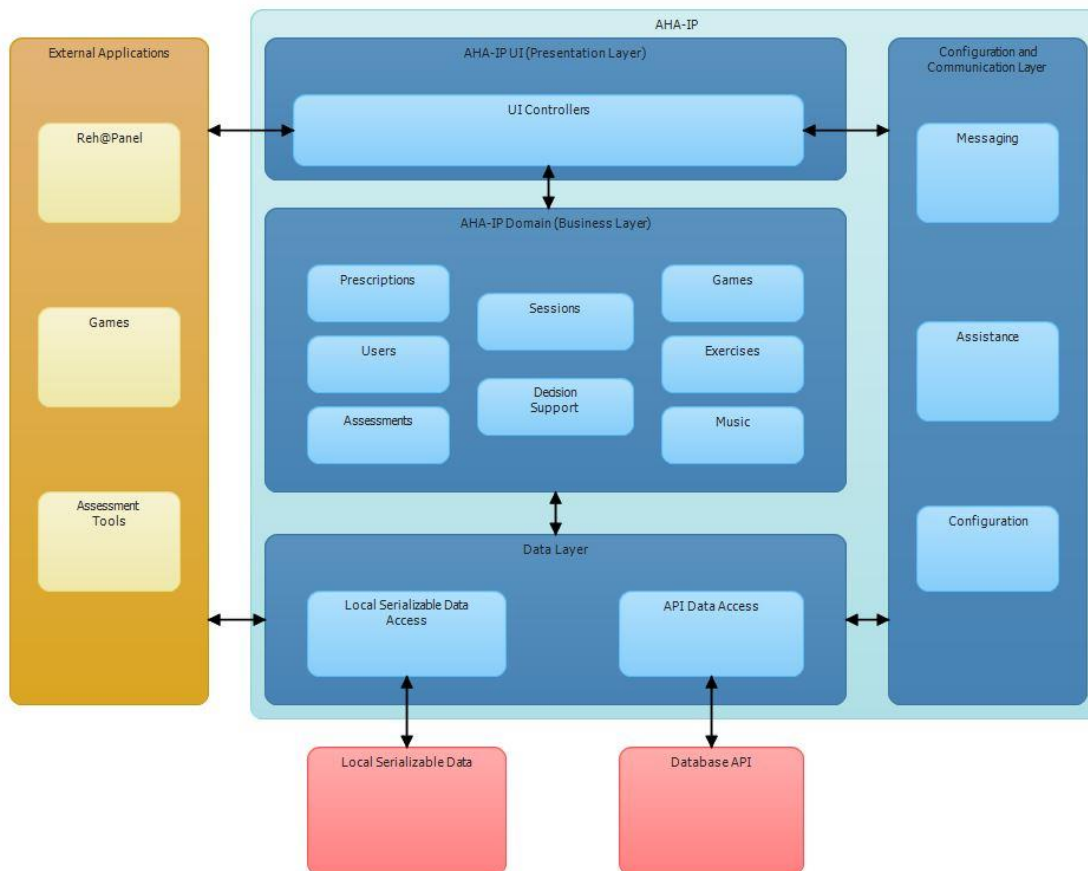


Figure 4-6 Layered architecture diagram of the AHA - Integrative System. Four layers are internal to the system: the presentation, the business, the data, and the configuration and communication layers. Externally there is a layer for the applications and for both databases, local (Local Serializable Data) and cloud-based (Database API).

The domain layer (identified in the diagram as AHA-IP domain) contains the main entities that were previously identified in the domain-driven design. The data layer is responsible for handling the communication with two types of databases, the local, which contains only the data concerning one specific system, and the cloud database, identified in the diagram as API data, which is a remote database that contains data from all the installed systems. The data and domain layers do not know what is “going on” the presentation layer. However, the controllers on the presentation layer need to know or access the information on the domain and data layers. The Messaging entity, which has been previously identified in the domain model has been moved outside the domain component to the communication and configuration layer since it is not highly related with the main goals of the system. This layer also includes the components that will deal with the assistance and technical configuration. Externally it is possible to find three major components: the applications, which the system will be communicating with; the local serialized data, which enables the basic functioning of the system without being connected to the internet; and the cloud service database, which will provide storing and accessing all users’ data for further visualization.

4.6. Activity design

In parallel with the previous steps and based on the use-cases, a rough paper prototype of the UI was built to assist in the identification of the relationships between components and in the understanding of the possible flow of interaction. This paper prototype served as a starting point of the design of activity diagrams which assisted in describing the sequential activity flow to achieve each determined goal. Figure 4-7 describes the process of creating a session or a plan, including session components such as games or assessments, until their final execution. The process starts with the user authentication when logging in the system; this authentication refers to the professional role. The next step is to choose an end-user, only after this, 3 choices are possible: 1 – create a prescription, which mainly consists of creating a set of sessions, for this, is essential to know the FITT model (frequency, intensity, type, time); 2 – choose a previously created session; 3 – create session. After choosing one of the options above, the user (professional role) has three new choices: 1 – Add session component, 2 – Edit session component, or finally 3 – Launch session component, which is the end goal. The user can go back again to adding or editing another component before launching the session component.

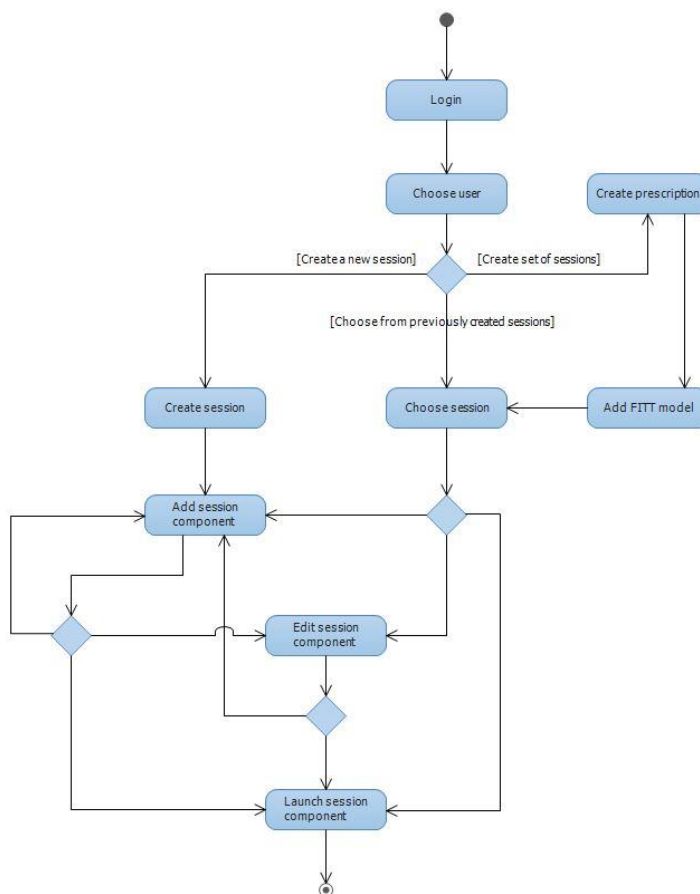


Figure 4-7 Activity diagram: “Launch session component”.

4.7. Conclusion

Designing a software continuously evolves along all development lifecycle. The diagrams and steps presented in this chapter represent the initial efforts to describe and document the envisioned system. The design task was facilitated by using the system requirements, which were provided by experts. In this way, the software structure naturally emerged by using systematic processes found in the literature such as use-cases and domain-driven design. The initial design presented in this chapter conveys the generic description of the system and its main functionalities providing understanding not only for the implementation phase but also to serve as a visual communication mean when presenting the system.

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5. User Interface Design¹⁴

5.1. Introduction

A multitude of systems is designed without consideration of user-centered design guidelines. Therefore, systems are created based on what developers think is the best, which can lead to users' dissatisfaction and even systems' abandonment [39], meaning that both human and economic resources are being wasted in useless systems that do not fulfill the needs of users [39]. Hence, the success of a system is highly dependent on the user's involvement and input [40]. Information on the UI should be organized and presented in a practical way that makes sense to the target audience offering efficient navigation [41]. Among others, card sorting and paper prototype are two user-centric techniques that can be used to assist in the design of the UI according to user expectations [42], [43]. The design process of the AHA-Integrative system started with a user-centric perspective by gathering the requirements directly from target users through semi-structured interviews (Chapter 3). Therefore, target users were also involved in the design process of the UI to get their input to build the information architecture better. This chapter describes the steps performed towards the design of the UI using user-centric techniques.

5.2. Card Sorting

Card sorting is a fast and inexpensive method, which can be used to gather input from users about their expectations concerning how the information should be presented on a screen. The process happens by asking the user to sort a set of cards, labeled with keywords or functionalities, in groups according to what makes more sense to them. Card sorting sessions can be twofold: closed, where the names of the groups are given before the beginning of the sorting process; or open, where the user needs not only to sort the cards into groups but also to give a name to each created group [45]. Open card sorting sessions help in revealing how the users mentally organize the cards, and what terms they choose for each category. For these reasons, the chosen method to assist in the creation of the UI information architecture was the open card sorting.

5.3. Card Sorting Sessions

Card sorting sessions were carefully planned and prepared in advance. Four participants (2 female, 2 male) that made part of the initial interviews were invited: two from the field of sports, and two from the field of healthcare (average age 28.3 ± 2.2 , and 5.3 ± 3.8 years of professional experience). Cards were written in Portuguese and corresponded to functions that the user could accomplish with the system. These functions were based on the user requirements and use cases mentioned in previous chapters 3 and 4 respectively. Fifty-one functions were selected from the overall functionalities or features (see Appendix E for the full list of cards names).

The card sorting sessions ran in a room equipped with a whiteboard which was divided into different areas (Figure 5-1). The cards were initially placed scrambled on the left (Figure 5-1(a)).

¹⁴ Partial text of this chapter was adapted from [44].

On the right, new and empty sticky notes with different colors were made available for the participant to create new cards (Figure 5-1(b)) and duplicate existing if necessary (Figure 5-1(c)), and an area to add deleted cards was also created (Figure 5-1(d)). The middle part of the whiteboard was reserved for the sorting.

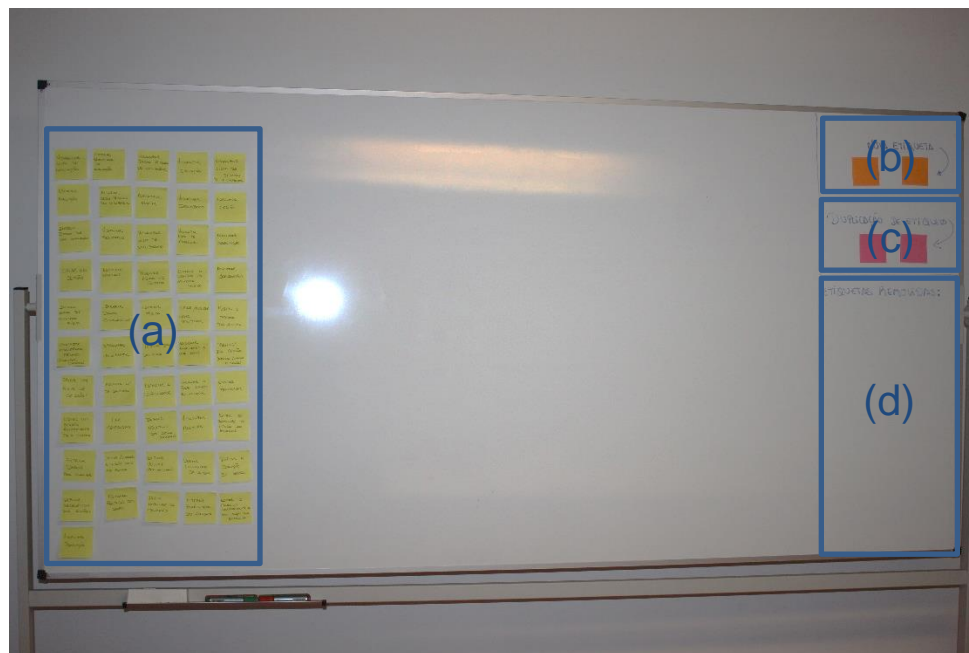


Figure 5-1 Whiteboard layout for the card sorting session. (a) Initial set of cards; (b) sticky notes to create new cards; (c) sticky tones to duplicate cards; (d) space for removed cards.

In the session, the participant was reminded of the system' goals, was asked to group the cards according to what made more sense to him/her, and to think aloud while doing it (Figure 5-2). The participant could make questions and ask for any clarification if needed. In the end, participants were asked to give a brief explanation of their choices in organizing the cards. Each session lasted between 1 and 1.5 hour, which was more than what was initially expected (30 - 40 min). Sessions were video recorded in case of some missing notes.



Figure 5-2 Participants sorting the cards

At the end of each session, pictures were taken for further analysis of the different created groups (Figure 5-3).



Figure 5-3 One of the completed card sorting sessions

After finishing the four sessions, data were inserted in an online card sorting analysis tool (usabiliTEST¹⁵) for quicker and better visualization of the results. The dendrogram in Figure 5-4 enabled identifying four major groups based on grouping patterns. However, the names of the categories created by the participants were very diverse and not coincident (Table 5-1). Therefore, the naming of the groups was based on the majority of functionalities found on each group. For instance, in the first group, most of the functionalities are concerned with assessments and user data, so the group/category was merely named “user and assessments” (Figure 5-4(a)).

Table 5-1 Names of categories per participant.

PARTICIPANT 1	PARTICIPANT 2	PARTICIPANT 3	PARTICIPANT 4
Anamnesis	Plan prescription	First time	Sessions conclusion
Personal information	System configuration	Assessments	Session programming - activities
Health	microcycle	Intervention plan	Difficulty
Additional information	Database / Reassessments		Sessions Management
	Problem-solving		User support
	Macrocycle		Sessions planning
			User profile creation
			Profiles Management

The second group consists of functionalities that concern system configurations, such as changing the language, getting help, and exchanging messages, so the group was named

¹⁵ <https://www.usabilitest.com/>

“settings and help” (Figure 5-4(b)). The third group, “plans and sessions” (Figure 5-4(c)), contains functionalities that relate to sessions and plans settings such as intensity, volume, frequency, exercises, and the number of sessions. The functionalities found on the last group are mostly specific to games parameters such as game goal, game choice, and game settings, so this group was named “games” (Figure 5-4(d)).

It was possible to observe that all participants sequentially grouped cards, meaning that most of the actions should follow a specific order, which was consistent with the first paper prototype built to assist in the software design process (Chapter 4). Hence, as a significant insight, the UI should naturally follow this interaction mode, i.e., sequential instead of grouped information.

Since participants could create new cards, some new features emerged from the sessions. Some new functions mentioned at least by 2 participants were the following:

- Edit plan
- Duplicate session
- Define short- and long-term objective
- Save rating from both user and professional
- Create an experimental session

Participants also provided some additional suggestions that should be considered. For instance, the user profile and last assessment results should always be present or easily accessed when creating a session or plan. Also, if the system is not going to be able to save the physiological data in real time, then the option to upload that data should be asked at the end of each session. Not directly related to the system but to the games, participants reinforced the importance of being able to control the number of sets or repetitions. They said that it would be great if they could manually change the difficulty in real time without interfering with game-play. In addition, given the target audience, seniors or patients, the exercises should focus on activities of daily living which are their most significant target training needs.

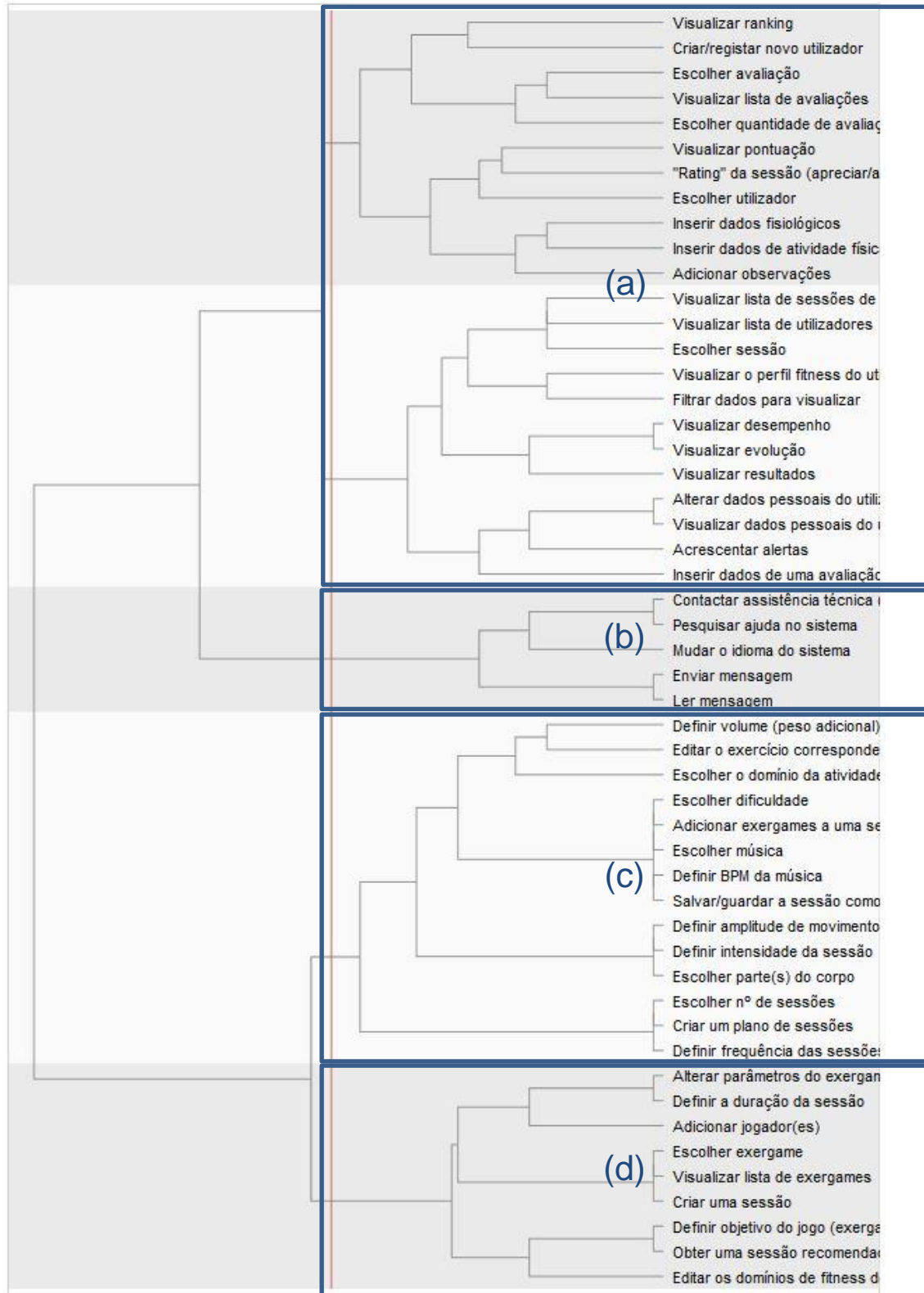


Figure 5-4 Dendrogram extracted from the card sorting analysis displaying the 4 major groups: (a) user and assessments, (b) settings and help, (c) plans and sessions, and (d) games.

5.4. Paper prototype evaluation

Paper prototyping is a valuable, fast and easy way to get usability insights from the representative users about the UI of a system at an early stage and before the implementation of a system. The evaluation of such prototype consists of the user interacting with a paper version of the interface which is manually manipulated by a person pretending to act as if it was a computer [46]. A new paper prototype was built to get new insights before starting with the digital version of the UI. Elements consisted of sticky paper enabling the prototype to be tested and changed in real time. All the new features that emerged from the card sorting sessions mentioned in the previous section have been considered, however, the function “define short and long-term objective”, which was initially considered as game objective, the professionals mentioned that objectives could be very subjective and difficult to quantify universally. For instance, the objective for one end-user can be “being able to achieve climbing 100 steps without stopping”, which is a very specific objective. Therefore, it was decided that the observations field would be used to describe the objective. The low-fidelity prototype consisted of a mix of hand-written text and drawings, with printed elements, mostly icons, to evaluate how intuitive it would be if applied in the final UI.

Two participants were invited (2 males), one from each field, sports, and health, who had previously participated both in the interviews and card sorting sessions (average age 29.5 ± 0.7 , and 5 ± 1.4 years of professional experience). For the sessions, all prototype elements have been sorted on a table, with the main “screen” in front of where the user would sit (Figure 5-5). A pencil was used as “keyboard”. Sessions were audio recorded.



Figure 5-5 Paper prototype elements ready for an evaluation session

Two tasks have been planned for each participant to accomplish during the session. The first task was to create a plan of sessions considering that a new end-user required the first assessment. The second task was to run a previously created session, edit some components of that session,

and check the results. Participants were asked to think aloud while they were performing the actions, and only making questions if necessary (Figure 5-6).



Figure 5-6 One of the participants performing the paper prototype evaluation session

The two participants managed to accomplish both tasks faster than expected (each session lasted about 30 min). Overall, the steps were intuitively performed without the need of much support. However, some modifications emerged to apply on the final UI:

- The automatic session option should recognize when the end-user is new and should recommend the assessments automatically.
- The system should have present on the screen history of the settings previously chosen by the user when creating or editing a plan, session, or activity.

5.5. Digital mockups

Before the implementation of the UI, some digital mockups were created based on the paper prototype previously built. Figure 5-7 and Figure 5-8 are examples of the mockups built with the help of the software tool JustInMind¹⁶. The creation of the digital mockups helped to understand the different UI views' hierarchy and how the navigation flow should be implemented (this will be further explored in chapter 7). For instance, Figure 5-7 shows the sessions gallery of an end-user. To reach this view, it was necessary to have chosen the end-user previously. Otherwise, it would not be possible to reach the view. A game is considered a session component, therefore, to reach the game form it was necessary to have previously chosen an end-user, then opening or creating a session, and then opening or adding the game, and only then would be possible to access this form (Figure 5-8 shows the game form). Despite this could have been analyzed just with the paper prototype, the digital mockups built with the previously mentioned tool allowed to create a demo of the navigation flow which made easier to show to team members before the system implementation.

¹⁶ <https://www.justinmind.com/>

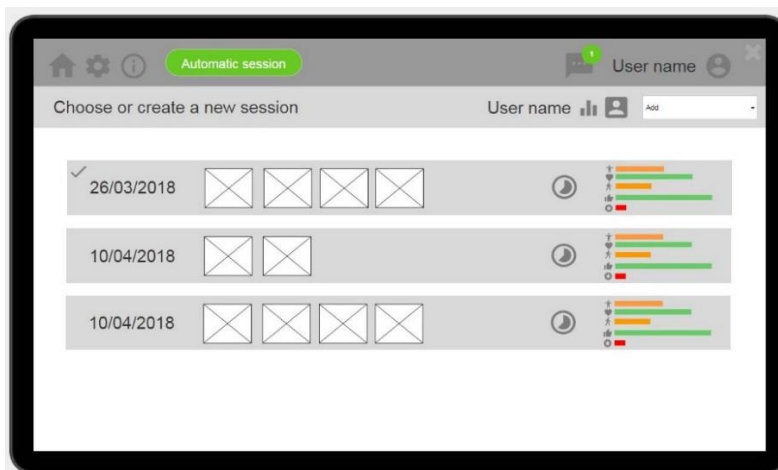


Figure 5-7 Sessions gallery UI mockup



Figure 5-8 Game form UI mockup

5.6. Conclusion

Before moving into designing the UI, it was essential to know the participants perspective when considering how information should be organized and presented to the user. From the card sorting session emerged the interaction mode, which should be sequential like in a step by step task. From both human-centered design techniques, card sorting, and paper prototype evaluation, it was possible to find new features, such as the possibility to edit a training plan at any time or to visualize the previous user settings when configuring a session or plan. A valuable insight from participants on the paper prototype evaluation was that there were too many options present on the system, to address this, the system should start with a straightforward interface, just with the basic functionalities, and then iteratively be incremented according to the needs of the professionals.

6. AHA Exergames integration

6.1. Introduction

In parallel with the design and development of the AHA-Integrative system, a set of exergames was also being iteratively developed and made ready for two upcoming research studies with community-dwelling older citizens. Games were also designed using a user-centric design approach and are highly configurable so that they can be played by different profiles with specific skills and needs. Each game focus on specific domains such as balance, agility, muscular strength, flexibility, and cardiorespiratory fitness. They will be manually configured by a sports professional in the research studies with the objective of validating the games as a complementary training tool. The end goal is that those games are the first ones to be integrated into the system envisioned for this thesis. A set of packages was created to facilitate a smooth integration, enabling a quick and easy process to integrate further games in the future.

This chapter describes the different packages specifically developed for exergames that will be candidates in the future to make part of the AHA-integrative system. All the packages are available online on Bitbucket¹⁷ on specific links indicated in each section. All packages have been documented for easy installation.

6.2. The exergames

A set of exergames was developed in the context of the AHA project, specifically designed to provide functional fitness training for the senior population: “Grape Stomping”, “Rabelos”, “Toboggan”, “Exerfado” [47], and “ExerPong” [48] (Figure 6-1). All games are highly configurable making them adaptable for a broad range of users’ fitness profiles. Following is presented a summary of the fundamental characteristics of the games:

Grape Stomping – inspired on the ancient tradition of stomping the grapes for wine production, the player is required to repeatedly step while simulating pulling the grape bunches with the arms. This game targets cardiorespiratory fitness training.

Rabelos – this name is based on rabelos boats that transport wine barrels along the Douro river. The player needs to simulate rowing to navigate with the boat and lead it to docks where he/she is required to pick or unload wine barrels. Its focus is on upper limb muscular strength training.

Toboggan – specially designed to train balance and trunk muscular strength and flexibility, the goal is to drive a toboggan downhill to collect points and avoid obstacles. The velocity of the toboggan is controlled by trunk leaning forward and backward.

ExerFado – consists of a piano with a scenario of a traditional Portuguese fado house as a background. The player is required to pick the musical notes by placing his/her feet on the right

¹⁷ <https://bitbucket.org>

piano key. Additionally, the bonuses can be picked with arms swipe movements. This game targets agility and lower limb muscular strength.

ExerPong – an adaptation of the classical 2D Pong game where the player controls a virtual paddle to bounce a ball. This game focus on agility, lower limb muscular strength, and cardiorespiratory fitness.



Figure 6-1 Screenshots of the developed exergames: (a) GrapeStomping, (b) Rabelos, (c) Toboggan, (d) ExerFado, and (e) ExerPong.

6.3. AHA standard UI

Appearance aesthetics and consistency are attributes that help to measure the usability of a UI [49]. Two points of view were considered when creating the visual appearance of the AHA standard UI, first from a matter of identity, to match the actual brand of the project, second, from a matter of user experience which ideally should be pleasant [50]. The colors palette and fonts of the AHA project visual identity were used in the UI elements. Simplicity, flexibility, and harmony were the fundamental principles that guided the design of the elements of this UI, with the primary goal of providing clarity of use while having an attractive design solution that allows for a pleasurable interaction.

Different types of elements have been created to satisfy different needs or preferences. For instance, buttons can be found with oval, rectangular, circular, or square shapes in 3 different color combinations. The developer can, therefore, count on 12 different choices while keeping the consistency with the AHA visual identity (Figure 6-2). Icons for the most used options in games also have been created and were inspired by already existing ones to facilitate recognition.

Since most games are usually built with the Game Engine Unity3D¹⁸, a project repository was created to enable easy importing into games (Figure 6-3). The project contains not only the raw images, colored and plain but also Unity3d prefabs that enable the creation of UI elements as easy as drag and drop. Instructions of use can be found in the project landing page: <https://bitbucket.org/neurorehablab/aha-interface/wiki/Home>.

¹⁸ <https://unity3d.com/>

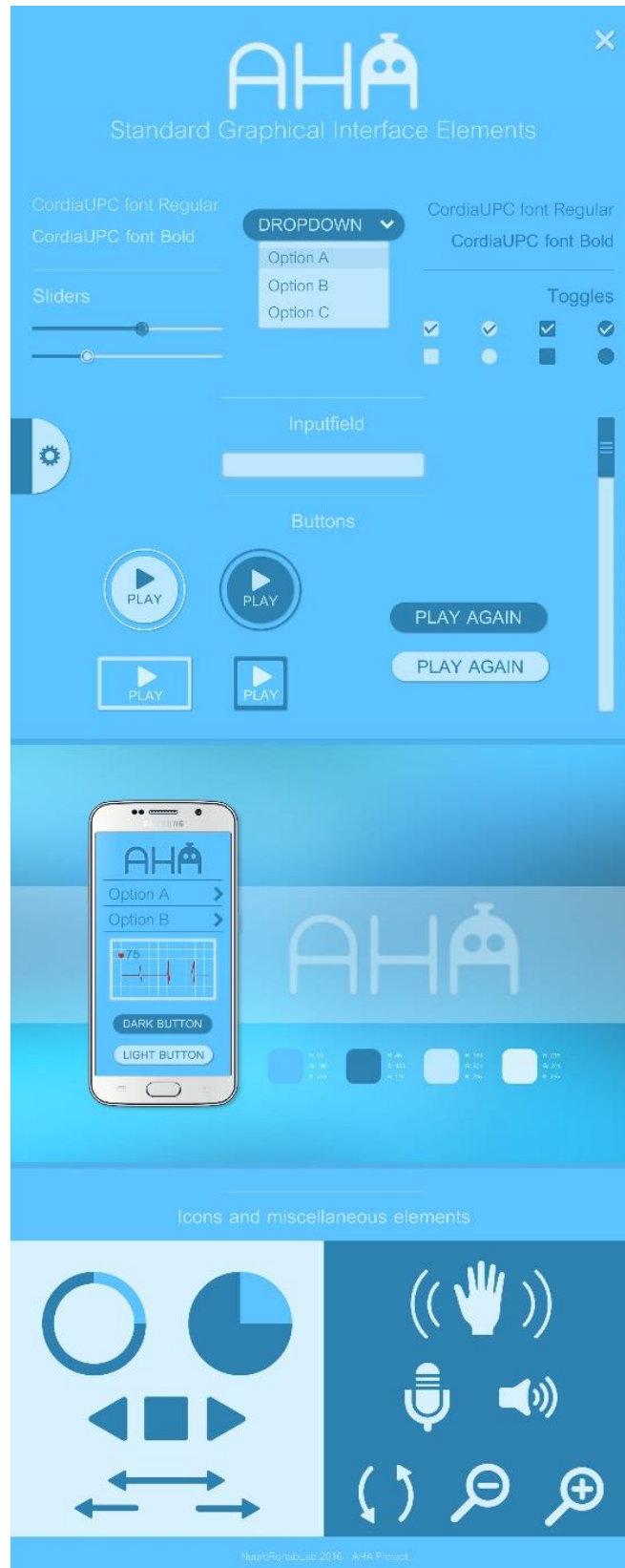


Figure 6-2 Poster representative of the AHA standard UI elements such as fonts, sliders, dropdown, input field, different types of buttons, color palette codes, and multiple icons commonly used in games interfaces.

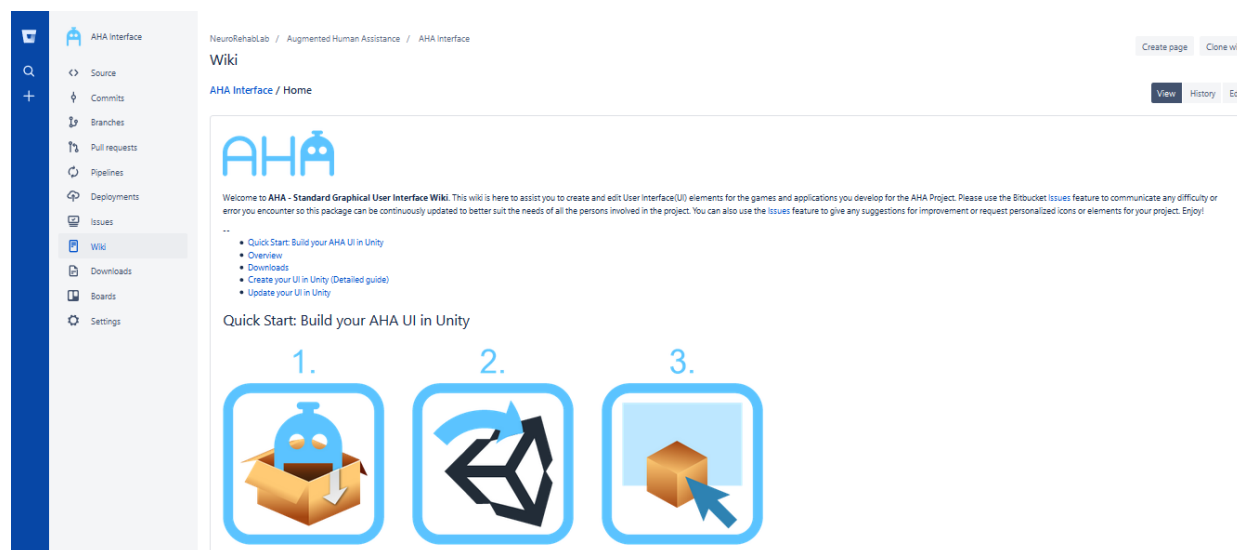


Figure 6-3 Screenshot of the landing page of the AHA - standard interface repository.

6.4. UDP (User Datagram Protocol) module

Exergames receive human movement as input for control and interaction. One of the most common motion sensing devices is the Microsoft Kinect¹⁹ which is considered a natural user interface often used to control games with gestures. In order to allow the exergames being controlled by different motion sensing devices, a module was created to facilitate the integration with the software tool Reh@Panel which is a middleware that can stream data through UDP from a variety of input devices [51]. The developed UDP module has three main functions:

- **Data reception** - receive the raw data through UDP, which mainly consists of the raw coordinates given by the device in use;
- **Calibration** – consists of transforming the raw coordinates from the real-world space into the game world coordinates;
- **Data saving and loading** – once the calibration process is done, often there is no need to repeat calibration if the space being used remains the same. Hence, the UDP module contains two functions, one for saving the values used in the calculation, and the other to load those same values each time the exergame is launched. Data are stored in an XML (Extensible Markup Language) file inside the application folder.

The interface of the UDP module is made up of the UI elements of the AHA standard UI and provides a variety of options such as choosing the port, level of filtering, the axis in use, invert axis, and specific incoming data (Figure 6-4). The UDP module can be downloaded as a Unity package or project from the bitbucket repository where instructions of use are provided in the landing page: https://bitbucket.org/neurorehablab/udp_module/wiki/Home.

¹⁹ <https://developer.microsoft.com/en-us/windows/kinect>



Figure 6-4 Screenshot of the UDP module UI.

6.5. Data logging module

One of the most important aspects of the exergames is the generated data because it is through it that it is possible to follow the end-users progress regarding game performance. Game data can only be easily accessed and read if well-structured and saved in files in a universal form that enables it to be read by a variety of statistics tools. Hence, the CSV (Comma-Separated Values) format was used, a file format used to store tabular data such as a spreadsheet or database. Files in the CSV format can be imported to and exported from programs that store data in tables such as Microsoft Excel, IBM SPSS or MathWorks MatLab.

The primary function of the data logging module is to save game variables and their respective values on a CSV file which will be located on the application folder. It is also a bitbucket repository which can also be downloaded as a Unity3D package or project. Instructions of use are available on the landing page: <https://bitbucket.org/neurorehablab/dataloggingmodule>.

6.6. Multilingual module

Doing repetitive and less creative work can be less pleasant to developers. The task of translating UI text and enabling it in different languages can be tedious and time-consuming and is often left to the end of the project because it is seen as a less important feature. However, the ability to be displayed in more than one language enables software to be used in different countries or by people from different nationalities. The multilingual module was created to facilitate this process. All text is stored in XML files inside the application folder, one file per language. The fields names in the XML files are equal in all files and correspond to the unity UI objects names in a scene that are of type "Text" and that require to be translated. The content of the field corresponds to the translated text that will be displayed depending on the selected language. For instance, if there is a game object of type UI Text with the name "title", the text that UI object will display will be the one in the content of that field of the respective XML file (Figure 6-5).

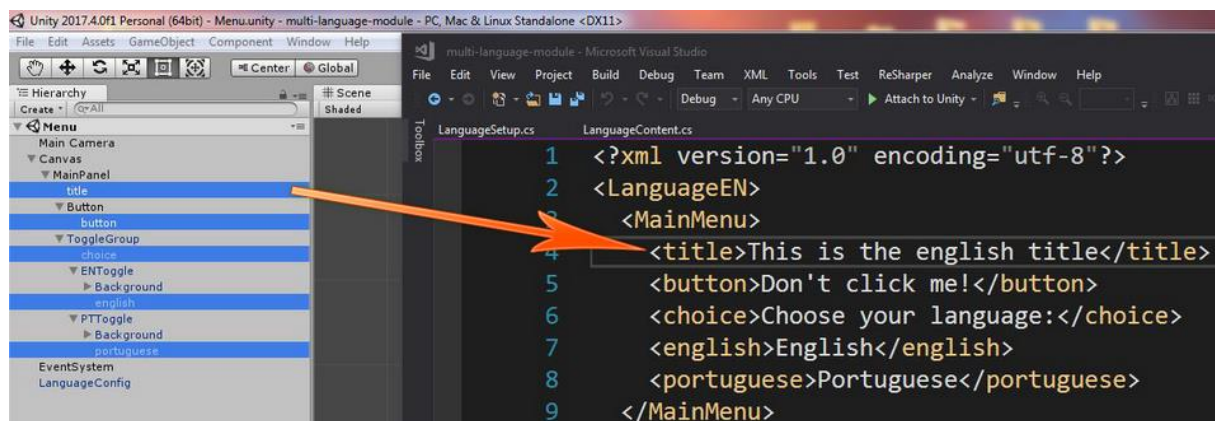


Figure 6-5 The names of the game objects in the game scene corresponding to the fields' names in the XML file.

6.7. Positive feedback module

One of the top requirements gathered from the interviews with the professionals was the feedback that the games should provide. More specifically positive feedback should be provided to promote motivation and encouragement to continue exercise while playing, leading to more satisfaction and adherence to the games. For this purpose, the positive feedback module was created, which can be easily implemented in any game. The module is provided as a unity package and can be downloaded from the project repository on Bitbucket²⁰.



Figure 6-6 Bronze, Silver and Gold medals that can be achieved during gameplay.

Positive feedback is given under the form of medals that will represent specific achievements in the game (Figure 6-6). The module has all game assets and scripts ready to be added to the game. The game developer only needs to drag the required prefab into the game canvas, to position the elements according to the game layout and add some lines of code according to the provided instructions on the repository and depending on the game score set to the different achievements. During gameplay, an animated star is displayed each time a new medal is achieved (Figure 6-7).

²⁰ <https://bitbucket.org/neurorehablab/positive-feedback-module/wiki/Home>

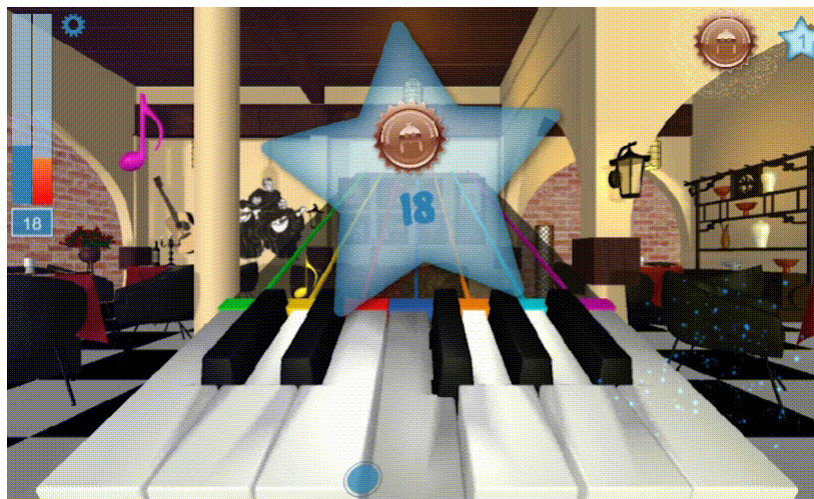


Figure 6-7 Screenshot of ExerFado at the moment of achieving a bronze medal.

6.8. Score evolution module

Another important requirement gathered from the interviews process was the possibility to see the user's performance over time, which is also a feature that can promote motivation and adherence to the exergames. This feature was one of the requirements of the AHA-integrative system. However, the system was still in its design phase and distant to reach such a mature implementation on time for the research studies interventions that were about to start. To overcome this, and since this requirement was also one on the top of the list, a simple graphical visualization was created, also as a Unity3D package, to be easily implemented in all the games. The visualization (Figure 6-8) consists of a bar chart where each bar corresponds to a session on a specific date (X-axis) with its correspondent game score (Y axis). At the bottom of each bar, it is also displayed the medal achieved at the end of the session.

The main functions of this module are:

- **Saving the score** – at the end of the game, saves the date, score, and medal achieved on a CSV file identified by the user ID;
- **Load all scores** – loads and displays in a graphic with bars the scores of the last twelve sessions.

The project repository can be found here: <https://bitbucket.org/neurorehablab/score-evolution-module/wiki/Home>, together with the instructions of use.



Figure 6-8 Graphic with bars that displays the historical game performance. Y-axis corresponds to the game score achieved at the end of the session.

6.9. Conclusion

This chapter presented a description of a set of modules that enabled the AHA games to be integrated under a consistent form. The AHA standard UI was designed to enable all games to have the same colors, elements, and fonts. Despite being independent games, the feeling of belonging to one single system was achieved. The UDP module enabled easy communication with the Reh@Panel to get data from the Microsoft Kinect. The data logging module assisted in saving all game data in tabular format. All games have their UI elements in Portuguese and English, this was easily implemented with the help of the multilingual module, which will enable adding new languages in a universal way. The positive feedback module was developed to offer a mode of rewarding that could be identical in all games. Finally, the score evolution module aimed at displaying a history of the user scores over time. All these modules have been developed once and then imported and recycled in all games. The modules and documentation guides created are vital resources for future games that will be candidates to make part of the integrative system.

7. Integrative system implementation

7.1. Introduction

In this chapter, different aspects of the implementation process are described. Even though the software design has been documented and the project itself has been systematically managed over time, it is difficult to describe all steps of implementation to its fullest because of space constraints in this document. Hence, to provide an overview, only some topics are approached, namely those that the author considers that can contribute in assisting other developers of similar systems in having a basic understanding of how the implementation process occurred. The system has been very simplified during the implementation process in order to not provide too much information on the screen. This has been enhanced on the previous human-centered design sessions by participants that referred that it would be better to start simple and then evolve along with the needs of the professionals. So as a starting point for the first digital prototype, only the main features that were mostly related to physical fitness have been implemented. Section 7.2 describes the development environment and how it was managed over time to keep track of all changes. Then, in section 7.3, some aspects related to the database structure are presented, followed by section 7.4, which describes how the data serialization and deserialization process was implemented. In section 7.5, some aspects of games integration are presented. The process of building the user fitness profile based on assessment results is explored in section 7.6. The UI hierarchy and navigation are described in section 7.7. To sum up, the chapter is concluded in section 7.8.

7.2. Development environment

7.2.1. Unity and Visual Studio

Unity is a cross-platform game engine used to create games, simulations, and applications, allowing deploying for the most known environments such as Windows, Android, and iOS, among others [52]. Unity was the tool used to build the initial set of exergames and was the chosen tool to develop the integrative system. However, the system's architecture enables the integration of games made with any other game engine. The code was edited using Microsoft Visual Studio.

The scripts were structurally organized in folders according to the layers defined in the software design structure (Figure 7-1). On the architecture diagram in Chapter 4, when the system was initially ideated, there was not a "Controller" layer. This layer was added during the implementation to keep good coding practices and use software design patterns commonly used in effective software projects. The decision to add the "Controller" layer was based on the Model-View-Controller pattern, where the Controller serves as a manager that handles data requests from the UI View (UI or presentation layer) and processes the response by getting the required data from the Model (Data layer) [53].

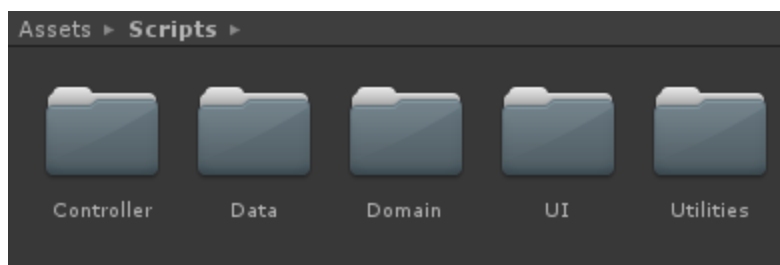


Figure 7-1 Folder organization of the scripts inside the Unity editor.

7.2.2. Version Control

Version control systems allow managing and keeping track of software changes over time. Management of the integrative system project changes was done with the help of Bitbucket which is based in GIT²¹, a distributed version control system (Figure 7-2). The remote repository hosted in Bitbucket also served as a backup of all the files and assets of the whole software project.

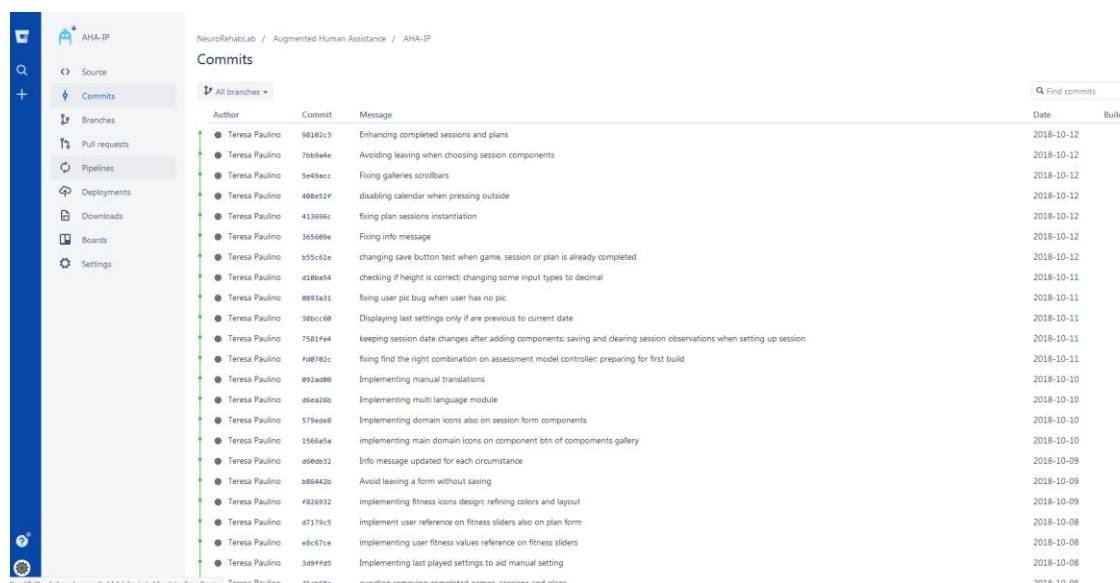


Figure 7-2 Screenshot of the online Bitbucket repository where it is possible to see the partial list of commits.

Each feature or system modification was submitted to the online repository hosted in bitbucket using the desktop application SourceTree²² (Figure 7-3). SourceTree is a GIT visual interface that simplifies the interaction between local code and the remote repository. By tracking all changes, it enabled reverting them in case needed.

²¹ <https://git-scm.com>

²² <https://www.sourcetreeapp.com>

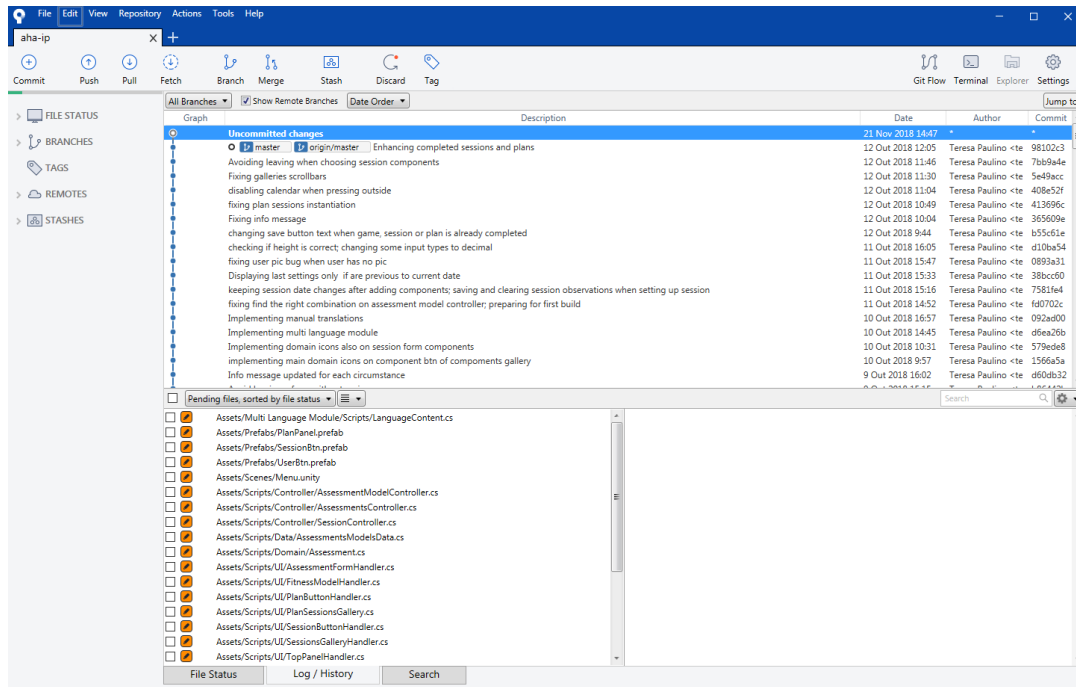


Figure 7-3 Screenshot of the interface of the SourceTree desktop application.

7.2.3. Management and communication

Managing a software project can be complicated since it involves multiple stages and components, often involving different team members with different backgrounds. Even if a plan is established from the beginning, the lifecycle of a software project is often accompanied by uncertainty and new information coming on each new iteration. Hence, to keep track of the progress of the overall project, Trello²³ was used. Trello is an online collaboration tool that helps in organizing projects into boards. It assists to have a clear vision of the tasks that are yet to be done, the ones that were already performed, and what is currently being performed. Besides assisting in organizing the project, and because it is a collaborative tool, the same project can be shared by teammates allowing to know each one's progress and tasks, while enabling communication.

The implementation of the cloud service for the integrative system was being developed by another team member at Instituto Superior Técnico at Lisbon. Therefore, each one kept a Trello board for the two components of the system, enabling keeping track of each one's work while also serving as a communication tool for questions and comments. Figure 7-4 shows a screenshot of the Trello board of the integrative system. Additionally, Trello enables integration with Bitbucket, so both code and overall engineering projects were connected.

²³ <https://trello.com>

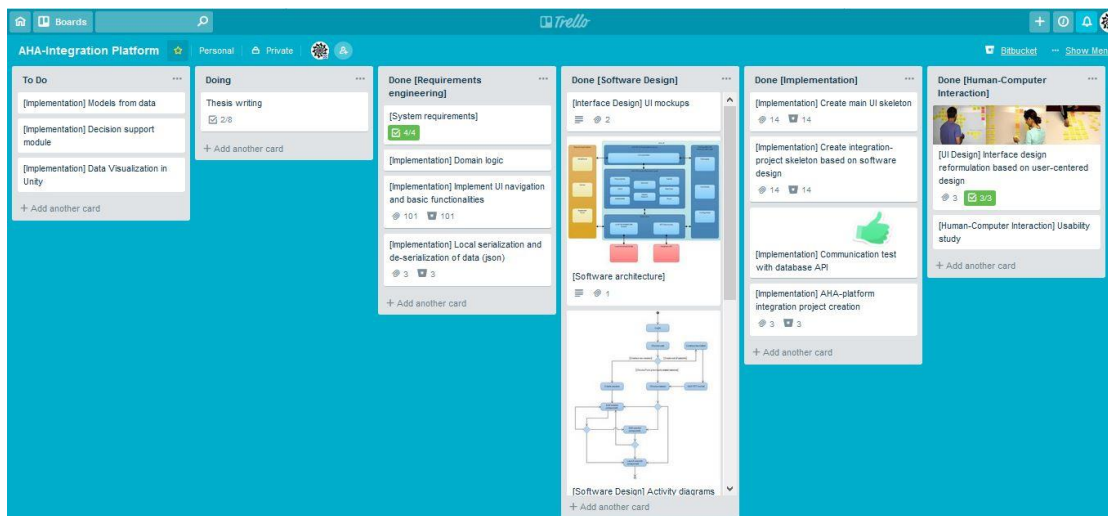


Figure 7-4 Screenshot of the integrative system Trello board.

7.3. Database and API (Application Programming Interface)

As mentioned in the previous section, the cloud service was being developed by a different team, and the integrative system was expected to share the same database, which was based in MongoDB²⁴. This type of database stores information in JSON²⁵ (JavaScript Object Notation) format. MongoDB is scalable and flexible since it is a NoSQL²⁶ (No relational Structured Query Language) database, which allowed to easily accommodate the integrative system data structure. The proposed structure was based on the actual domain layer included on the software design, and collections names referred to object classes and its respective attributes. Attributes names have been kept, written in the same form, to easily identify data through the API used for communication between the integrative system and the cloud service database.

The initially designed database structure consisted of 5 main collections: “users”, “platforms”, “games”, “game_events”, and “notifications”. Since NoSQL database structures can embed collections within collections, it was expected that the plans and sessions concerning each user would be embedded in the users’ collection. However, during implementation, the design had to be modified, and for separation of concerns related with code organization, it was decided to keep each collection separated. Therefore, instead of having the plans and sessions embedded in the users’ collection, all were kept separately. On the first iteration of the digital prototype, collections and their respective fields were structured as described on Appendix F. The local database consists of the same collections.

²⁴ <https://www.mongodb.com>

²⁵ <https://www.json.org>

²⁶ <https://www.mongodb.com/nosql-explained>

Concerning the API, as an initial proposal it was considered that it should enable the following functions:

GET functions:

- User data by user_id, email, and phone;
- Users' data by pro_id and platform_id;
- Games' data by platform_id;
- Game events data by game_id + session_id + prescription_id + user_id;
- Notifications data by sender_id and recipient_id.

POST functions:

- Insert new platform;
- Insert new user;
- Insert new game;
- Edit user data by user_id (including sessions and plans);
- Insert game events;
- Insert notifications;
- Upload zip files of games logging by game_id + session_id + plan_id + user_id.

However, and because the cloud service was in its initial stage of implementation, the API was made available in the following way:

To get all data from a collection, the API URL was: <http://app.aha.isr.tecnico.ulisboa.pt/api/> + the name of the collection, for instance, “users” or “platforms”.

To insert a new object into a collection, the API URL was the same: <http://app.aha.isr.tecnico.ulisboa.pt/api/> + the name of the object, for example, “user” or “platform”.

For this, two C#²⁷ functions, one to get and one to post, were created in the system's code so that they could be universally invoked for any collection and any object. The process of getting data required to indicate the name of the collection and a callback action would be returned with the text retrieved by the API. The process of posting data was very similar, requiring one single function to be used to insert any object. The name of the collection and the object data had to be provided.

The process to save and load data from the local database was created the same way. The difference was that, instead of using get and post, it used options to read and write JSON files. Additionally, the system loads information from local games and assessments, which will be further explained in 7.5 and 7.6 (Figure 7-5).

²⁷ The programming language used in Unity: <https://docs.microsoft.com/en-us/dotnet/csharp/>

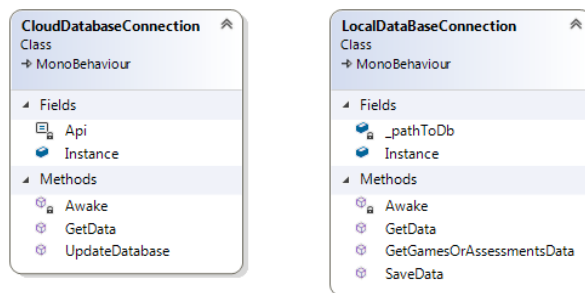


Figure 7-5 Database connections classes, cloud and local.

7.4. Serialization and Deserialization of data

“Serialization is the process of converting an object into a stream of bytes to store the object or transmit it to memory, a database, or a file” [54]. The Unity game engine has a built-in feature (JSON utility²⁸) that enables easy serialization and deserialization of data. However, its functionalities are limited. For instance, it is not able to parse a list of JSON objects by itself. Hence, to achieve this goal, the use of the external plugin SimpleJson [55] was also required.

The process was implemented as follows:

1. Getting all data from a collection - the text is read from the file as mentioned in the previous section. Then, the text is parsed from JSON using the SimpleJson plugin which enables splitting the list into one JSON string per object. Finally, JSON utility is used to create the object by reading its attributes data.
2. Saving the collection’s data - the process is very similar. However, only the built-in JSON utility is required. A collection of objects is iterated in order that all JSON data are added to a single string variable. The process ends by writing the text of this string on the JSON file. Figure 7-6 shows the data objects all implemented using the “LocalDataBaseConnection” to load and save data.

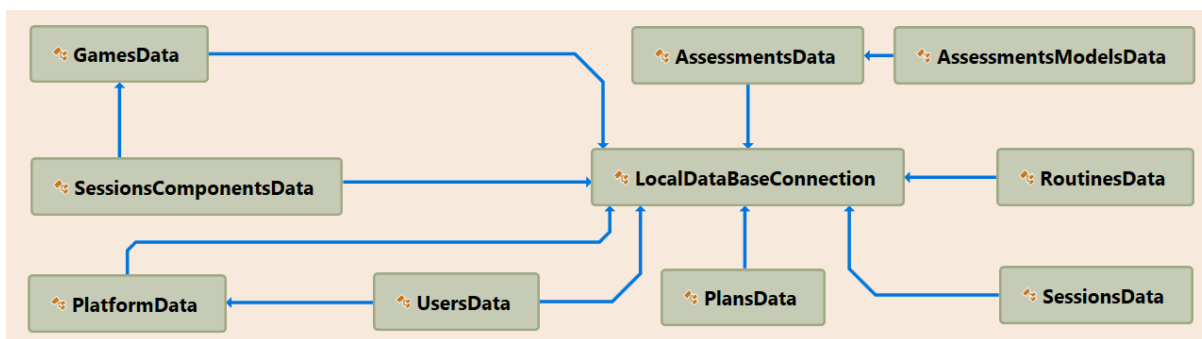


Figure 7-6 High-level class diagram of the data layer showing the usage dependencies.

²⁸ <https://docs.unity3d.com/ScriptReference/JsonUtility.html>

7.5. Integration of games

Any game can be integrated into the system since it universally reads game data. This process was implemented in the first iteration as follows.

Each game folder is placed inside the Games folder that can be found inside the StreamingAssets of the application (.../Application Folder/ StreamingAssets/ Applications/ Games). Each game needs to provide the following three files, all with the same name as the game folder:

- the executable file that allows running the game;
- the game picture that will be displayed dynamically in the interface;
- the JSON file that contains the game info: “game_id”, “name”, and “fitnessDomains”, which is a list of the physical domains that the game targets.

In future iterations, a model will exist that defines how fitness levels will influence the game parameters. Figure 7-7 shows an overview of the main classes that involve the games and their display to the user. On the “Data” layer, all games’ information is loaded and parsed. The “GamesController” class of the “Controller” layer assists in getting the right data to be displayed on the presentation layer (“UI”) handled by the “ComponentsGalleryHandler” class. All classes use the “Domain” layer since it holds the Game class which is derived from the “SessionComponent” class.

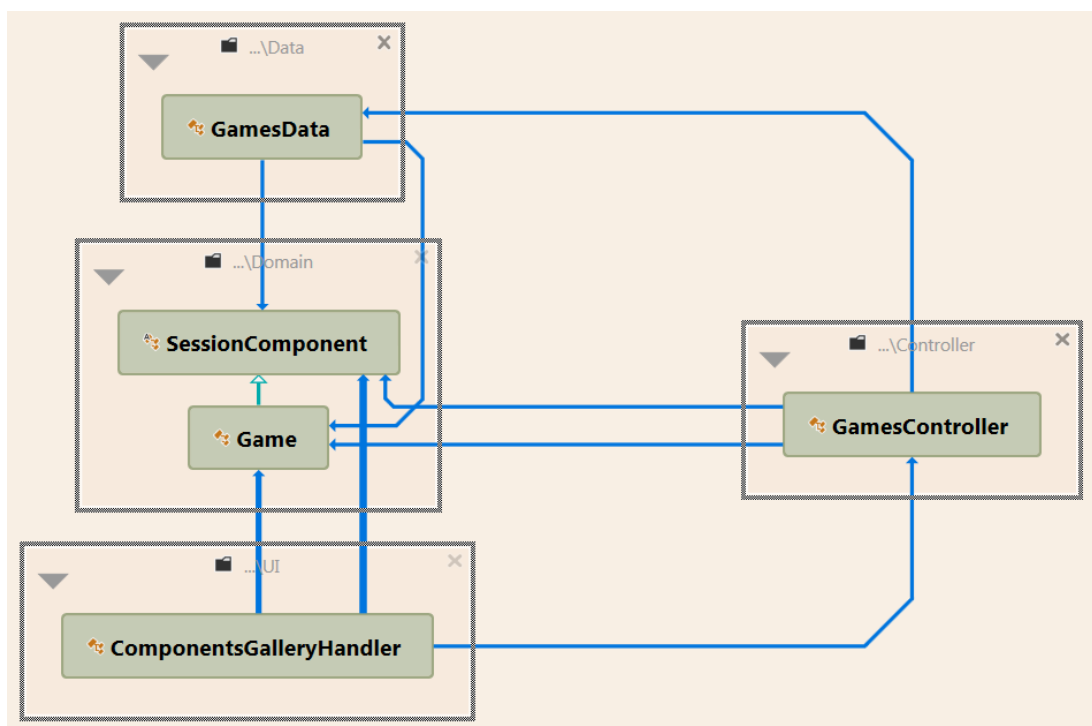


Figure 7-7 The high-level class diagram showing the main classes of the system that involves games.

7.6. User fitness profile and normative data

One of the most important features of the system is the possibility to provide decision support based on the characteristics of the user. For this, it is essential for the system to know how to interpret the different assessment results that enable building such profile. This section describes how the overall assessments module was implemented on the system. This module is a significant contribution considering that this implementation can be used for other systems that need to build the user profile based on assessments' results. It is important to mention that this implementation is not restricted for only some types of assessments. The way it was built enables easy integration of any assessment without the need for internal programming. There are only two conditions that may limit the integration: first, the results must be under the form of numerical results, and second, there must be normative data for comparison.

7.6.1. Assessments integration

The system needs to know each assessment information in order to enable its dynamic presentation on the interface. Hence, similarly to how it was done for the games, inside the StreamingAssets folder of the application folder there is a folder called "Assessments". Each assessment model is placed in a separate folder. The JSON file that contains all the assessment form information must be placed in that folder. This file needs to have the same name as its folder and contains the fields described in Table 7-1.

Table 7-1 List of assessment fields and types contained in the JSON file.

FIELD NAME	FIELD TYPE
assessment_id	String (must be different for each assessment)
name	String
fields	List of strings (short names that identify the fields)
fieldsDescriptionEN (should have one list per language implemented in the system)	List of strings (long names of the fields to be displayed in the interface)
fieldsDomains	List of strings (the list should have the same size as the number of fields and informs each field domain)
duration	Integer (indicates the estimated time to perform the assessment to be added to the session)

Inside the assessment's folder another folder, named Normative Data, must exist. This folder contains at least one CSV file that has the information that will be compared with the results of the user. If normative data for different locations exist, each CSV file should be named with the name of the location. The CSV file must be structured using the following format:

- The first field needs to correspond to the field short name, or in case the whole assessment evaluates one single domain, the field name should be called "Sum", so the system can recognize that needs to sum the result of all fields to compare with the normative data.
- The next field(s) correspond to the field(s) that is/are going to be compared with the user attributes. For instance, age or gender. The name of these fields is required to start with

“CF-” followed by the attribute name. This name needs to be precisely the same as the user object attribute. For instance, in the case of age, it must be written “CF-age”. This way, the system knows that it is a comparative field, so it will iterate for all user attributes until finding the attribute that is named “age”.

- Next, there should be the percentiles fields that should start by “P-” and its respective value. For instance, percentile 25 should be written “P-25”.

All this information is loaded in runtime when the application starts and is stored in objects, making them available for the moment they will be needed. Figure 7-8 shows the two classes responsible for loading assessments data. The “AssessmentsData” class deals with all information contained the JSON file that has information about the assessment fields. The “AssessmentsModelsData” class is concerned with all information contained on the CSV file of the normative data.

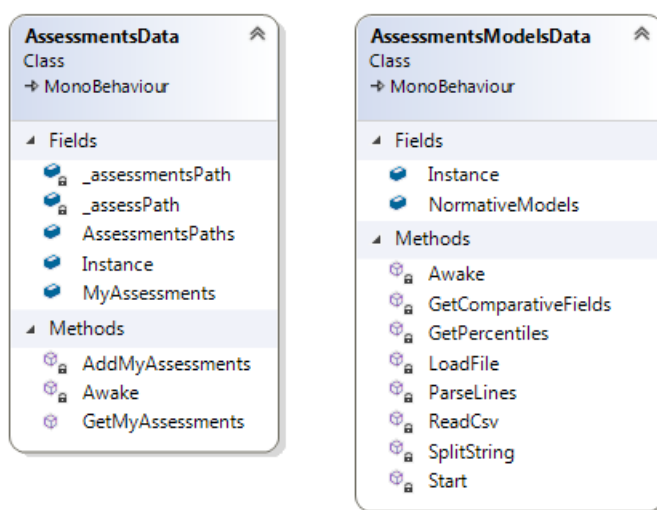


Figure 7-8 Object classes that handle the assessments and normative data.

Assessment fields vary by assessment type. Hence, when the assessment is selected in the interface (displayed by the “ComponentsGalleryHandler” class), the fields list is iterated and the form fields (“AssessmentFieldHandler”) are dynamically added to the view by the “AssessmentFormHandler” class. The “AssessmentsController” class is responsible for getting the required data to be displayed in the presentation layer. The diagram in Figure 7-9 shows the classes concerning assessments.

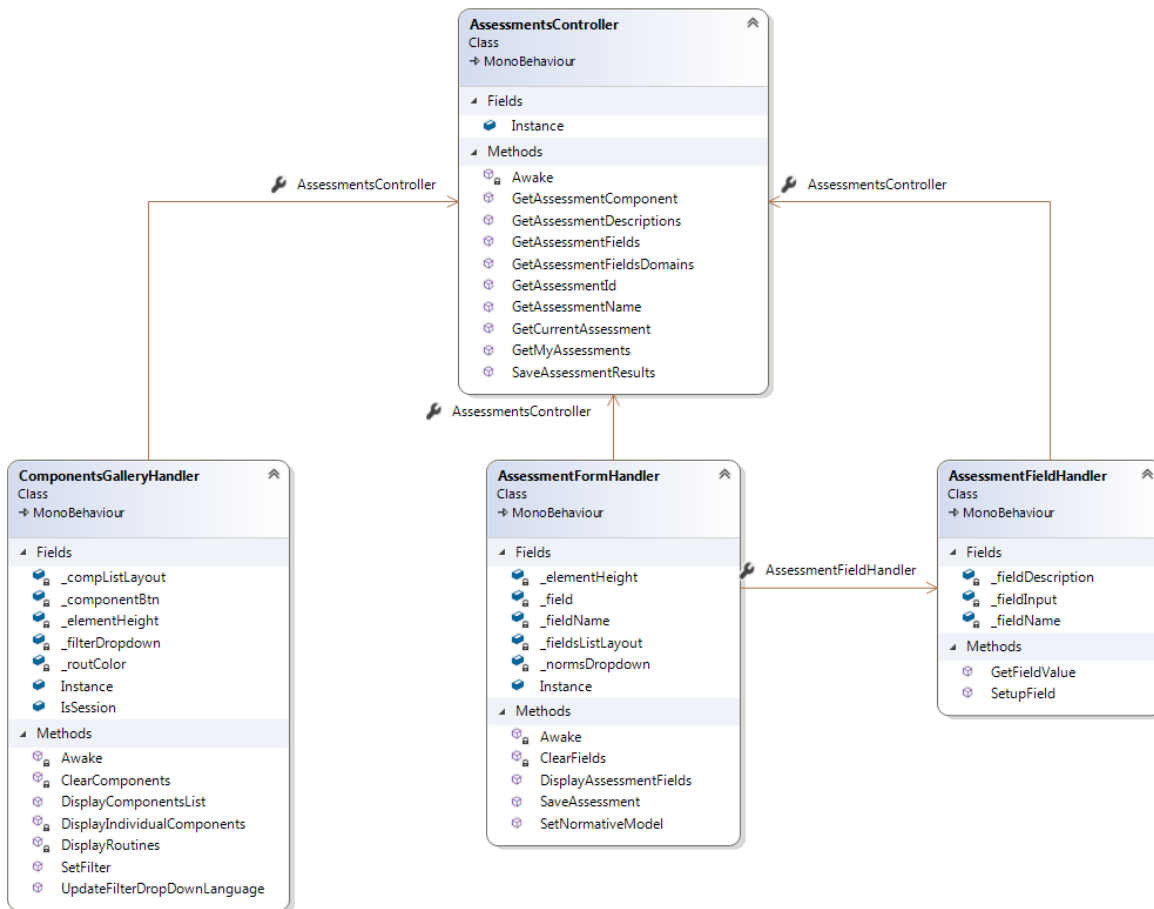


Figure 7-9 Diagram classes concerning assessments.

7.6.2. Fitness profile generation

A fitness profile is composed of 5 domains: balance, agility, flexibility, cardio, and strength. These were the most identified domains in the literature (Chapter 2) and during the exergames design process mentioned in chapter 6. For instance, the World Health Organization provides recommendations on the cardiorespiratory and muscular strength domains [5]. The Senior Fitness Test Manual enhances the assessing and monitoring of these five mentioned domains to understand the functional mobility in older adults [4]. This fitness profile is used to identify the user fitness characteristics, but also to define games, sessions, and training plans parameters. So, this profile is used throughout the system to serve as a universal way of communicating between all the different components: users, games, sessions, assessments, and plans.

When one assessment is saved, the process of generating the fitness profile is initiated, which goes through different steps:

1. Finding the comparative attributes – the user class is deserialized in order to compare the attributes names with the comparative fields mentioned in the normative data. The values of the attribute(s) that match the same name(s) are stored in a list named “cfValues”.

2. Finding the right combination – “cfValues” are compared with the values present in the normative data. For instance, if the comparative fields are age and gender, and if the user is 69 years old and is female, the function that finds the right combination iterates through all combinations until finding the one that fits the user. From this process, an integer number is returned (pos), which corresponds to the position (line) in the list of percentiles.
3. Getting the percentile – assessment results (or its sum) is compared with the different percentiles values. Values can be in ascendant or descendant order, so the algorithm to find the right percentile was implemented to know and act depending on each situation.
4. Calculating fitness profile – the final step consists of looping through all the percentiles found and check their fitness domain. If the assessment is based on a sum of all fields, then it only assesses one fitness domain so that the respective percentile will be the new value of that fitness domain. For instance, if the assessment test assesses only the balance domain and the result leads to a percentile of 75, the user balance domain is updated to 75%. If different fields are related to different domains, then the algorithm loops through all the percentiles found and get the average of each fitness domain in order to update the user fitness profile. Figure 7-10 shows the class responsible for all this process which is the “AssessmentModelController” class.

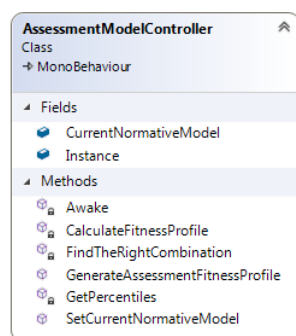


Figure 7-10 AssessmentModelController class.

7.7. UI hierarchy and navigation

The user interface was implemented in Unity using the UI elements from the standard interface mentioned in Chapter 6. One single canvas was used for the whole system’s interface. The interface was organized hierarchically with panels that hold other panels as children. The four main panels are: “LoginPanel”, “GalleryPanel”, “FormPanel”, and “TopBarPanel”. However, there are other panels such as “HelpPanel”, “ConfigurationPanel”, and “DataViewPanel” (Figure 7-11). These panels were not implemented in the context of this thesis. The help panel is expected to provide documentation which enables searching for help when using the system. Also, it helps in displaying contact information to get technical support. The configuration panel is expected to deal with system settings such as user permissions and sensors connection. The data panel has the responsibility to provide data visualization directly from the cloud service, since its implementation was not yet completed, this panel could not also be implemented at this point. The “Language” panel consists of the language toggle group that enables changing the language of the system. It is implemented as a main panel, so it can always be present on the screen to

enable changing language at any time, therefore appearing on top of all other panels, except the “DemoPanel”. Because of being in the last position in the hierarchy, the “DemoPanel” appears in front of all panels when active. This panel was implemented for the evaluation tests, only for demo purposes of the features that have not been implemented yet.

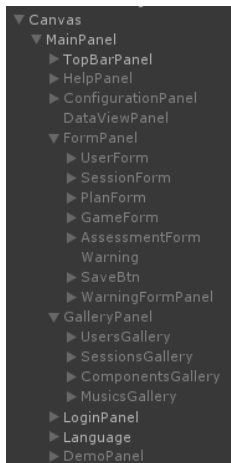


Figure 7-11 Screenshot of the canvas hierarchy in Unity editor.

Each panel has its own script/class responsible for handling the presentation of the UI elements and content of its respective panel. Hence, all are controlled by the “UiNavigation” script, which enables and disables panels depending on the chosen state (Figure 7-12).

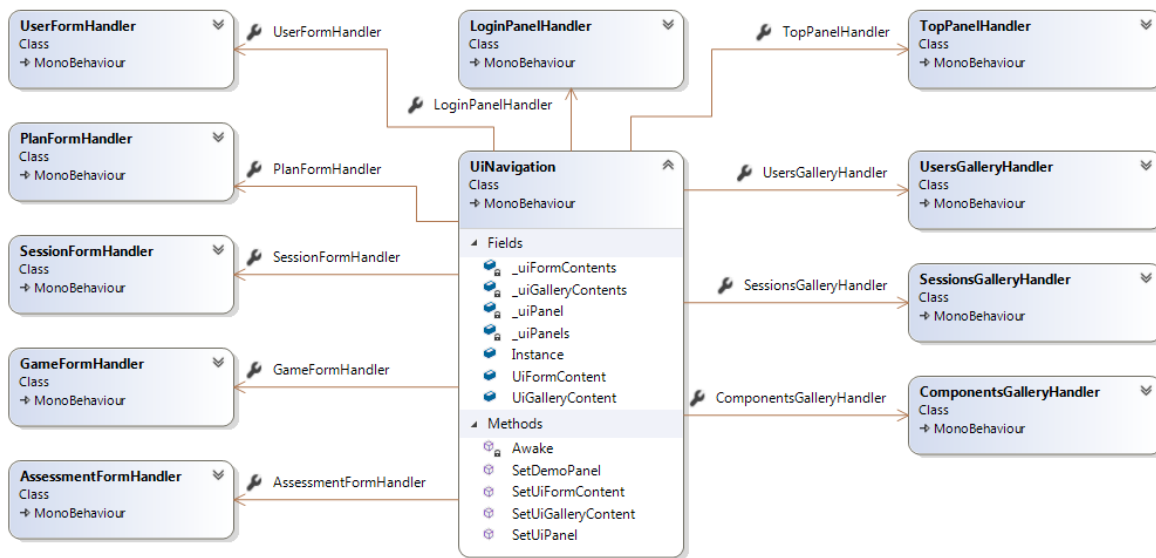


Figure 7-12 Class diagram of the main UI classes.

The “LoginPanel” is the first to be displayed on the application. Once the login is performed by the user, the “TopBarPanel” (Figure 7-13) and the “GalleryPanel” are enabled. The “TopBarPanel” remains active all the time and contains information and access to actions concerning the logged user and the end-user once it has been chosen. The “UsersGallery” is the first panel to be

displayed and is also considered the “Home” screen, which enables the user to visualize the end-users list.

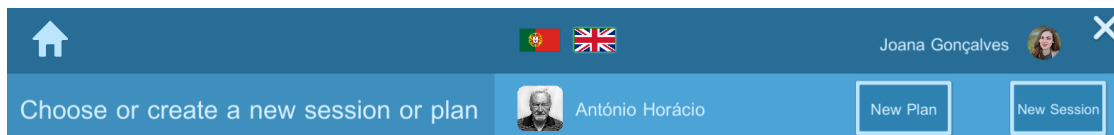


Figure 7-13 Screenshot of the "TopBarPanel".

All the panels that are children of the “FormPanel”, allow editing or inserting data concerning their respective classes. For instance, “UserForm” enables creating a new user or editing the user details. On the other hand, the children of “GalleryPanel” enable displaying lists of items for choosing one at a time. For instance, “ComponentsGallery” can display a list of all objects of type “SessionComponent”, which can be “Game”, “Assessment”, or even “Routine”, which corresponds to a grouped set of session components.

Two integer values were used to indicate the states of the form and gallery panels: “UiGalleryContent” and “UiFormContent”. “UiGalleryContent” recognizes four different values: 0 – “UsersGallery”, 1 – “SessionsGallery”, 2 – “ComponentsGallery”, and 3 – “MusicsGallery”²⁹. “UiFormContent” recognizes 5 values: 0 – “UserForm”, 1 – “SessionForm”, 2 – “PlanForm”, 3 – “GameForm”, and 4 – “AssessmentForm”. The event state diagram in Figure 7-14 shows how the transition between the different UI panels occurs depending on the values of these two variables.

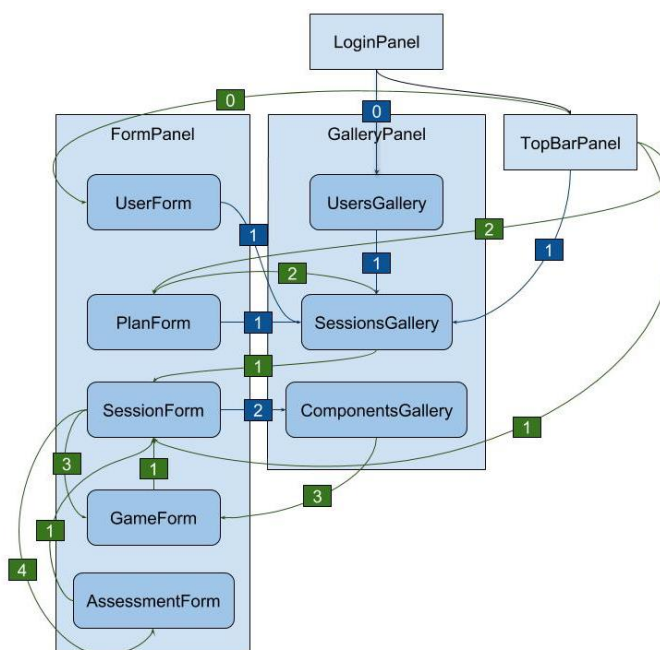


Figure 7-14 Event state diagram depending on the values of the two variables: "UiGalleryContent" (in blue), and "UiFormContent" (in green).

²⁹ Not yet implemented at this stage.

7.8. Conclusion

This chapter described the main topics concerning the implementation of the system. Creating the software design and using management tools have shown to be essential to guide and document the implementation process. The integrative system has been implemented in Unity using Visual Studio as code editor. Bitbucket platform was used to keep track of all progress using versioning control based on GIT. Management of the overall project was facilitated by the Trello online tool which assisted in tracking the progress and keeping tasks organized. A structure for the database was presented, as well as a description of the main database API functions. The most essential implementation details have been described, such as data serialization and deserialization, games and assessments integration, the user fitness profile and its generation, the UI hierarchy and navigation. These features have been illustrated with diagrams that assist in their understanding.

8. Decision support module

8.1. Introduction

This chapter explores valuable information on related literature that can help to build a conceptual structure of models for a decision support module of an exergaming system. Section 8.2 explores automated decision-making in exergames. A concept for the implementation of decision support on the integrative system is presented illustrated by a possible scenario in section 8.3. Discussion and the wrap up are presented in sections 8.4 and 8.5 respectively.

8.2. Automated decision-making in exergames

Senior gymnasiums, nursing homes, and rehabilitation centers can benefit from having exergaming systems to promote physical activity or rehabilitation of their users/patients. Since these games are highly configurable, health and sports professionals can manually set game parameters according to each user profile. However, as a result of the diversity of needs and capacities, most of the times there are no predefined configurations that facilitate the selection of the right parameters for each situation [15], [18], [23]. Additionally, users may evolve their skills over time, so exergames parameters should be progressively adjusted to provide a good gameplay experience [19], [56], [57]. Manual configuration can, therefore, be time-consuming showing that there is an evident need for automatization of the decision-making processes for ideal parameters selection.

When having just a few options to choose from may be easy to choose the right game, however, when the number of games increases, the choice of the ideal game or set of games to build training sessions becomes more complicated. Therefore, there is also an obvious need for decision-making processes for ideal game or activity selection when faced with multiple options.

8.2.1. Decisions and decision modeling

Every decision-making process starts by defining the decision problem. Models contain knowledge about the decision problem decomposed and structured in smaller components which are often represented employing algebraic, logical or statistical attributes and their relationships. Mathematical methods are applied over the models to analyze them and reach the best outcome of a decision-making process [58].

There is a considerable amount of modeling methods and analytical techniques that can be implemented in decision support systems. The next subsections present some proposals found in the literature in the field of exergames or closely related that explore the two primary decision problems that the integrative system is expected to solve:

- What is the ideal game or set of games for a specific user?
- What are the ideal game parameters for each specific user?

From the analysis of the problems, four different essential entities/components that require modeling are identified in the literature: the player, the exercise, the game, and the rules.

8.2.2. Player modeling

Player models capture the player information regarding his/her skills, weaknesses, preferences, and other characteristics [59]. The primary goal of creating player models is because we want the game to recognize and adjust the difficulty to each type of player, therefore the importance of player modeling [25], [56], [59], [60]. A player model contains a set of attributes relevant to the personalization, ideally represented numerically, which allows being compared under a universal scale [58].

The physical characteristics of the player are essential for exergames personalization and can be provided to the system under the form of assessment results. Ideally, the system should automatically assess the user with the help of gesture detection sensors like the system proposed in [61] which consists of a computerized subset of the Senior Fitness Test [4]. In another example [14], player modeling is performed with two methods, first by providing the system with basic information about the player needs. Secondly, the system executes a short calibration process where the player is asked to perform some actions. This way the system gets to know the behavioral characteristics of the player and uses them to define the game difficulty. In [20], the player model is constructed based on the results of a physical assessment test similar to the one found in [61].

Typical attributes of player models for exergames are common physical features found in assessment tests such as agility, balance, cardiorespiratory endurance, muscular strength, flexibility, resistance, body composition, weight, among others [4], [62], [63]. Substantial health risks or medical information may also be considered as attributes for player modeling in exergames which can be used to define limits, constraints or game-play conditions. These risk attributes will be used in the decision rules as better described in subsection 8.2.5.

8.2.3. Exercise modeling

Player's models contain valuable information for the system about the user skills and needs. Specific to exergames, it is important to mention that game difficulty is highly related to exercise configurations that the system is required to recognize and relate with the specific game parameters. Along with the player characteristics, the system should make decisions based on training guidelines recommended for the target population, the elderly [63], [64]. In [19], [24]. The authors use attributes such as volume, intensity and cognitive load, which are used to adjust the different game parameters. The term intensity is also found in [20] where the exercise intensity component is translated into repetitions per exercise that the player will have to perform while playing.

8.2.4. Game modeling

Personalization involves adjusting a game to tailor the experience to a player. Player models influence game difficulty which is related to one or more game components. Different components of a personalized game were identified in the literature (Figure 8-1) [60]:

- **Space/Environment** - elements such as the number or type of game objects, events, or environmental conditions, for instance, light or weather.

- **Mission/task** - player skills and weaknesses may directly influence the game or level goal, which should evolve directly or indirectly based on player's performance. The evolution of missions within a game may equally influence the other game components.
- **Character** - involves manipulating the character by changing its characteristics such as abilities, appearance, accessories, or behavior.
- **Game mechanics** - are composed of a set of rules or methods that determine the different game states. One example of personalizing a game to a player can be simplifying or increasing the complexity of game mechanics.
- **Narrative** - this component is also related to interactive storytelling where the content and form of game elements are adjusted to player preferences, needs, and style of play, often being customized in real time.
- **Music/sound** - game adherence and immersion levels can be achieved by personalizing the music or sounds type according to the player preferences. The music itself has features that can be adjusted, for instance, music velocity or BPM (beats per minute) are essential aspects taken into consideration in exercise training.
- **Player matching** - whether in collaborative or in competitive games, a personalized game in multiplayer mode may help matching players with similar profiles to avoid frustration and loss of interest. Moreover, it is possible to find in literature games that allow players with different skill levels to play together by providing dynamic balancing of difficulty adaptation [65].

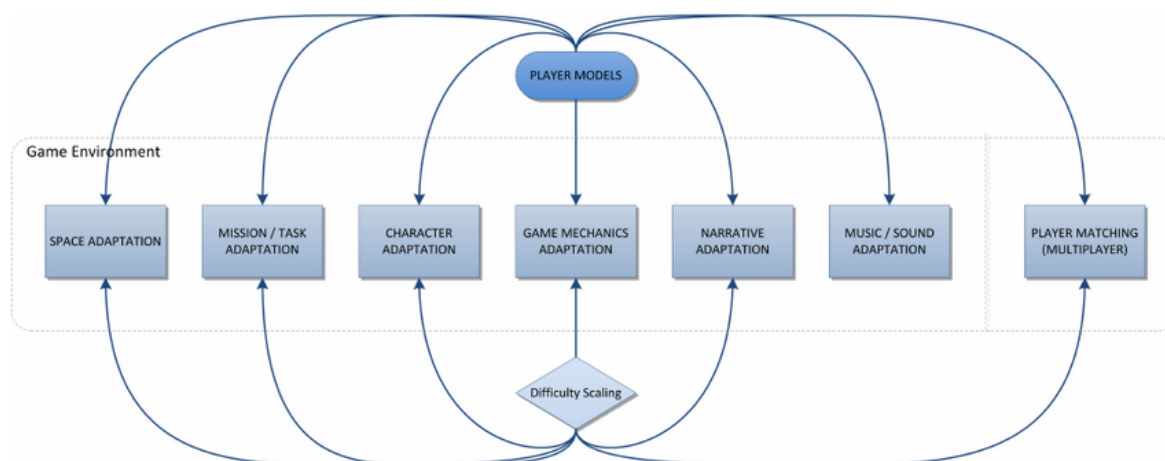


Figure 8-1 Personalized gaming diagram [60].

8.2.5. Decision rules modeling

Decisions are made under pre-established rules, often under the form of thresholds that the system will use to set game parameters. For instance, the work presented in [14] uses thresholds to define the conditions of gameplay, sitting or standing, and the agility value returned by the calibration process has a direct impact on gesture precision and time settings. Thresholds were also implemented in [15], [66] where clinicians can configure constraints to limit the range of movement of the different exercises while also defining the level of severity that will inform the

system whether the violation of a constraint will trigger a simple warning or an error. The system developed by the authors of [19], measures and evaluates user performance, and a set of rules enables deciding on changes of configuration.

8.2.6. Attributes

The previous subsections described different components/entities that may be used for implementation of an automated decision process in exergames. Those different components may have different attributes (see Table 8-1 for the most common attributes identified in the literature).

Table 8-1 List of components and attributes identified in the literature.

Component	Attributes
Player	Age, weight, height, gender, body mass index, agility, flexibility, balance, cardiorespiratory endurance, muscular strength, fall risk
Exercise	Frequency, intensity, type, duration, volume, body part, range of movement
Game	Environment, goal, character, mechanics, narrative, sound, multiplayer
Rules	Constraints, thresholds, performance, progression, level, difficulty

It is important to mention that some attributes may even be subdivided into more specific attributes. For instance, when mentioning the game attributes, notice that no specific parameters are declared. As an illustration, the goal attribute would have to be decomposed in the game parameters that define the goal. For example, imagine a game where the goal is to catch fruits falling from a tree (as one of the games from [15]). Parameters that may vary could be the size or the fall distance of the fruits. This example served to demonstrate that attributes can be hierarchically structured when modeling components of a decision problem. However, due to the diversity of parameters that can be found in games, it is essential to build the models for the decision-making process the most abstract as possible enabling comparing and analyzing the different alternatives universally to be compatible for all games. One possibility is that all models speak the same language, this means the same attributes can be found in all models allowing easy comparing.

8.3. Decision support concept for the integrative system

The first decision problem described at the beginning of subsection 8.2.1 (What is the ideal game for a specific user?) is here considered through a simple scenario. For the sake of simplicity, the concept is presented using only two models, the game and the player, with three common attributes: balance, agility, and cardio.

The system has implemented the multi-attribute utility method [67] which consists of 4 distinct steps:

1. Identification of the different alternatives and relevant attributes – for this scenario there are three different games (A, B, and C) available, each one training the three different physical attributes mentioned above but having one as the main focus of training.
2. Attribute's scoring - using a natural and linear scale from 1 to 3, all games are scored with different values depending on the intensity of training for each attribute — natural meaning that as higher the score, more important it is, and linear meaning that there is equal distance between each scoring value. Table 8-II shows the example scoring values.

Table 8-II Example of attributes' scoring of the 3 different games.

ATTRIBUTE	GAME A	GAME B	GAME C
Balance	3	1	2
Agility	1	3	2
Cardio	1	2	3

3. The attributes' weighing - this step will define each attribute' importance from the agent's point of view. Supposing one senior user wants to play the ideal game for his fitness profile. The user was previously assessed, and the results of his fitness profile are translated into training needs. Here, the higher the value, the more need to exercise that physical attribute. This weighting example can take values from 0 to 1. Table 8-III shows the user fitness profile that will be used in the decision-making process. The highest is balance; therefore the user needs to train balance more than the other attributes.

Table 8-III User attributes' weighting.

ATTRIBUTE	USER FITNESS PROFILE
Balance	0.7
Agility	0.3
Cardio	0.4

4. Scoring and weighting aggregation - using a weighted linear additive function, the evaluation of an alternative is obtained by multiplying each attribute scoring by its relative weight and then summing up all the results. After aggregating of scoring and weighting the attributes of this scenario, the ideal game of choice is game C:

$$\text{Game A} = (3 \times 0.7) + (1 \times 0.3) + (1 \times 0.4) = 2.8$$

$$\text{Game B} = (1 \times 0.7) + (3 \times 0.3) + (2 \times 0.4) = 2.4$$

$$\text{Game C} = (2 \times 0.7) + (2 \times 0.3) + (3 \times 0.4) = 3.2$$

We can conclude that despite the game A being at first instance the best choice since it focusses on training the attribute that the user needs the most, game C is after all the best choice considering his overall fitness profile.

This concept represented a possible solution for the decision-making problem presented. However, for the choice of game parameters, more components and rules should be implemented. If considering player, exercise, game, and decision rules models, one may influence the others. For instance, decision rules will be impacted by the user assessment results, the exercise model and the game model. The decision rules model will determine the outcome of game and parameters selection, which may lead to a good or deficient performance by the user. Consequently, the user model will have to be adapted, therefore leading to a new process of personalization. A possible influence diagram for the decision-making process is presented in Figure 8-2.

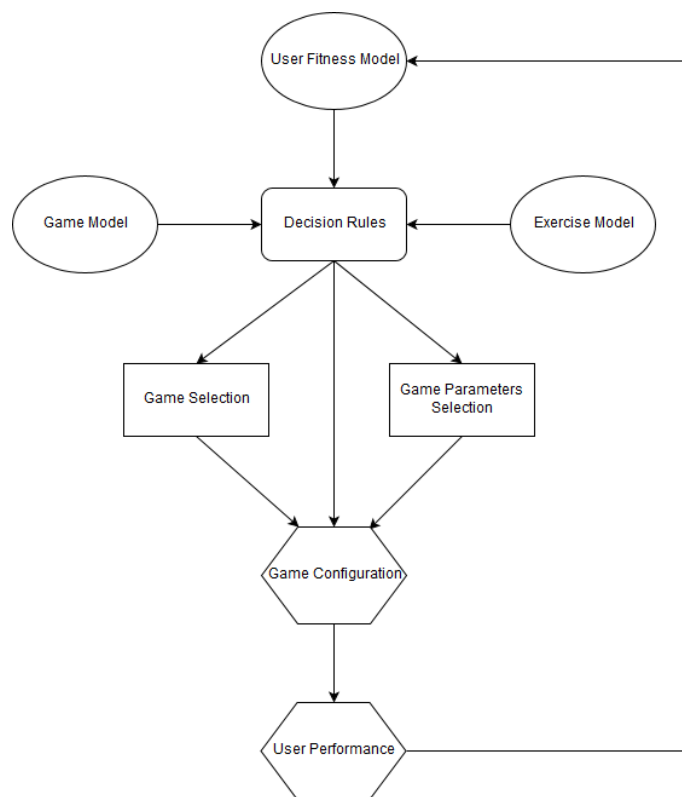


Figure 8-2 – Conceptual influence diagram implementation for exergame personalization.

The multi-attribute utility method may not be enough to choose the ideal game parameters, especially because attributes may vary from one model to the other. Because of that, the decision rules model may combine different techniques such as decision trees that will specify thresholds, constraints, or ranges for the definition of possible outcomes.

8.4. Discussion

Two important subjects were not tackled in this chapter and are crucial for the success of a system that it is expected to recommend the best choices in exergames: the motivation of the user and previous knowledge (level of uncertainty). An effective personalization of exergames should assure not only that the user experience fits the individual user fitness needs, but also considers the user' motivation and enjoyment of the game. A game that can detect the emotional state of the user is named affective game and often enables dynamic game adaptation to the user in real time [68]–[70]. Moreover, effective models should be based on previous knowledge which provides information on the probabilities for each alternative allowing to maximize the expected utility. For instance, the outcome of the scenario presented in section 8.3 could have been different if the success probabilities were known in advance.

8.5. Conclusion

This chapter analyzed automated decision in exergames and explored decision modeling by reviewing related work which helped to identify different components that require to be modeled in order to implement automatic decision making in exergames. The identified components are player, exercise, game, and decision rules. A concept for the decision support module of the integrative system has been ideated using the multi-attribute method. Furthermore, a hypothesis for an influence diagram has been conceptualized considering the decision process for the most suitable game parameters.

Although the decision support module has not yet been implemented in the system, the architecture was designed considering all the components identified above. For instance, the User class holds the information of the player attributes: the fitness profile. This fitness profile will influence the game and exercise (training) settings based on decision rules. The actual implementation is ready to read games attributes and to adjust the training settings based on the fitness profile. What is missing is the module that will contain the decision rules. This module will have to contain information concerning how the user fitness profile translates into training needs; this corresponds to the attribute's weighting mentioned in section 8.3. In order to intelligently provide support for the best decision in games parameters' configuration, the system should make use of past data and apply machine learning techniques.

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9. Description of the system

9.1. Introduction

The previous chapters described steps of the design, conceptualization, and implementation of the system that assisted in shaping the system based on the target users' preferences. From the requirements elicitation, was possible to find the main functionalities to be implemented. The list of requirements consisted of very specific features which were then structured and organized when creating the use-cases. The card sorting sessions assisted in validating this organization. From the card sorting session, was also possible to confirm that the interaction mode should be sequential like in a step by step task (Appendix C - requirement 48). This is going to be further explored and illustrated in this chapter, for instance, the user is first required to log into the system, which is briefly explained in section 9.2. From the professional's perspective the next sequential step would be to select or create a new end-user; this is explained in section 9.3. One of the main goals of the system is to provide management of training sessions and plans. Sessions and their components are explored in section 9.4 with the help of a fictitious scenario. In section 9.5, the process of creating a training plan is analyzed. In section 9.6, a discussion of the functionalities that have not been implemented or that have been implemented directly in the exergames is presented. The chapter is summed up in section 9.7. The requirements numbers mentioned along this section can be found in Appendix C.

9.2. Authentication

When starting the application, what the user sees in the initial view is the authentication form. As explained in chapters 6 and 7, the visual appearance is consistent with the visual identity of the AHA project, and also the logo is present for identification. In the first view the user can switch languages (Portuguese or English) (Figure 9-1(a)) and also disable the virtual keyboard in case the monitor does not have a touchscreen (Figure 9-1(b)). Language switch is available in every view of the application.

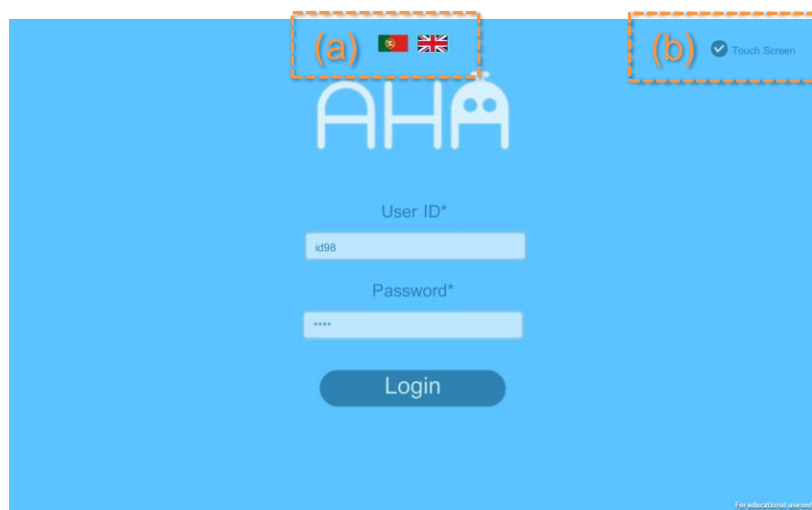


Figure 9-1 Screenshot of the login form.

Only registered users can use the integrative system when the application is executed. Hence, the user is asked to insert his/her credentials: user id and password. As soon as the user presses the login button, a background process is initiated to check if the user id and the password match a user in the database. If yes, the application loads to the next view; if not, an error message is displayed (Figure 9-2).

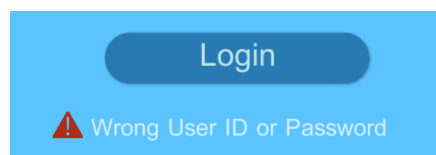


Figure 9-2 Error message if user id or password is not correct.

This authentication process is required to differentiate the user type: a professional or an end-user as enhanced in the use cases (Section 4.2).

9.3. User

The actual implementation only supports the professional authentication. Considering this, after the login process comes the next sequential view: the end-users list. This view is also considered the home view which is displayed each time the home button is pressed (Figure 9-3(a)).

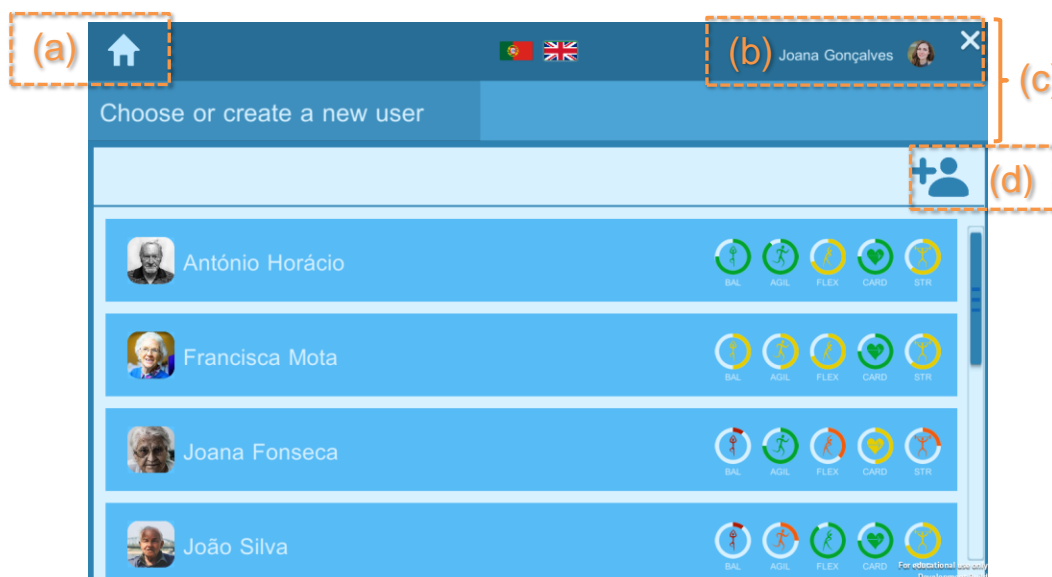


Figure 9-3 Screenshot of the home view displaying the end-users List.

The professional's picture and name are displayed on the top right of the top bar panel for identification (Figure 9-3(b)). This top bar panel (Figure 9-3(c)) is always present on all views, except on the login view. The professional can then select an existing end-user from the list or create a new end-user on the system by pressing the respective button (Figure 9-3(d)). When creating a new end-user, the view changes to the user profile (Figure 9-4), where some fields are required such as username, birth date, gender, user id, and password. The fields weight, height, and email are not mandatory for user registration, but this could be changed. The existence of

the observations field (Figure 9-4(a)) allows saving additional information such as pathologies or other relevant information. (Implementation of requirements 24, 25, 37, 57, and 96)

Figure 9-4 Screenshot of the empty user profile.

9.4. Sessions

In order to understand the process of creating sessions, it's presented here a hypothetical scenario. Joana Gonçalves is a sports professional that works on a gym specific for the senior population. Teresa Teixeira is a new gym member, so Joana creates her profile. Next, Joana wants to create an assessment session for Teresa, so that she can get to know her fitness characteristics levels and configure sessions accordingly.

Figure 9-5 Screenshot of the empty session form.

In the system, Joana just selected Teresa as end-user and pressed the button “New Session” in the top bar panel to create a new session (Figure 9-5 (a)). The blank form of a session appears, and now Joana needs to add session components to the session, in this case, the required assessments to create Teresa’s fitness profile. Joana presses the “+” button, and a gallery of

components that she can add to the session appears (Figure 9-6). A routine (which will be further explained at the end of this section) with the general assessments used in the gym for the first time has been previously created. Hence, Joana scrolls down in the gallery to find that routine. At the moment, the system is not composed of too many different session components, but in the future, Joana can filter the components being displayed by its type using the dropdown on the top right (Figure 9-6(a)), which enables filtering by game, assessment, or routine (requirements 5, 10, 17, 60, and 77).



Figure 9-6 Screenshot of the session components gallery.

Joana chooses the assessment routine, and the assessments are automatically added to the session form (Figure 9-7(a)). The session time is updated to 50 minutes (Figure 9-7 (b)), the estimated time that it takes to complete both tests. (Requirement 9)

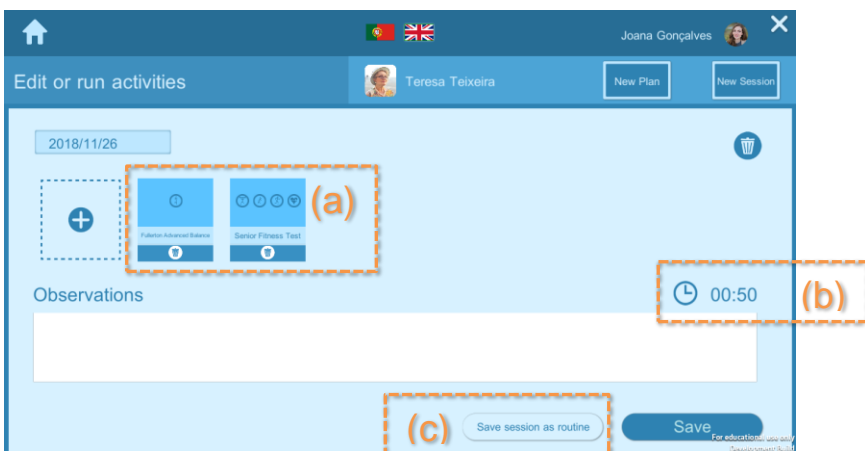


Figure 9-7 Screenshot of the session form with the two just added components.

Teresa has now time to perform the assessment tests. For that, Joana selects the first test, executes the tasks and fills in the result of each assessment field (Figure 9-8).

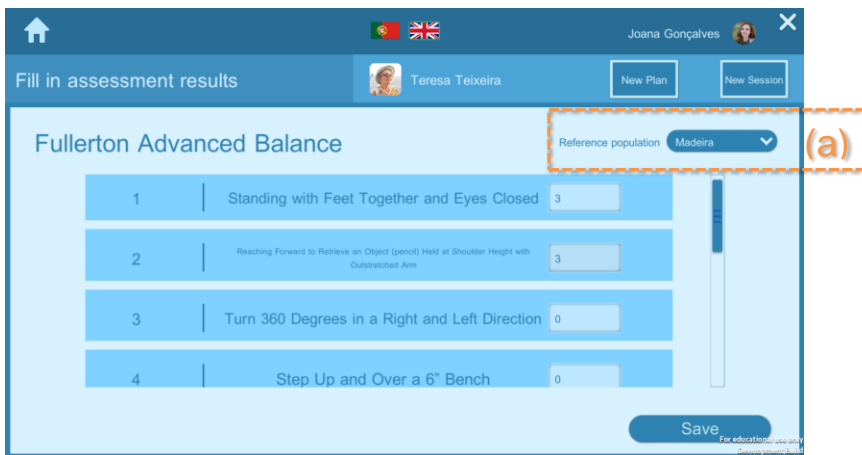


Figure 9-8 Screenshot of the assessment form with the assessment fields that were dynamically created.

The system enables to select the reference population for comparison, in this case, the gym is located on Madeira island. However, Joana could use any other reference if it was previously made available to the system (Figure 9-8(a)). Joana saves the assessment results and repeats the steps for the other assessment. After saving the session, Teresa’s fitness profile is created and can be visualized on her end-user profile (Figure 9-9(a)). This system will automatically configure new sessions and plans based on this fitness profile. (Requirements 19, 36, 46, 50, and 58)



Figure 9-9 - Screenshot of Teresa Teixeira's profile.

Sessions with games are created identically. Each session component can be removed or edited if not yet completed. The small “trash” icon button on each component enables it to remove it (Figure 9-10(a)). The play button (Figure 9-10(b)) launches the game. To edit a component, the user just needs to press it.



Figure 9-10 Screenshot of a session with games added.

When editing a game, the system allows changing the fitness training configuration (Figure 9-11(a)) and time of play in minutes (Figure 9-11(b)) (requirements 6, 15, 52, and 59). The end-user levels are kept as a reference. For instance, in Figure 9-11 it is possible to see that the balance training was set to 45%. However, the end user value is lower. In front of each fitness domain, the last session value is also displayed for reference (Figure 9-11(c)). The options of keeping the end-user fitness levels and the display of the last session values were implemented based on the feedback of participants during the human-centered design process.



Figure 9-11 Screenshot of the game form where is possible to change the settings.

In their daily practice, professionals may feel the need to use one same session for multiple users. For instance, in the fictitious scenario presented at the beginning of this section, the professional had to create the first assessment session for the new user. Since this type of session will be used equally for each new user, it would be useful to have it as a default assessment session. For this, the system allows saving the session as a routine (Figure 9-7(c)), which makes it available in the sessions components gallery for later use. (Requirement 16)

9.5. Plans

A training plan corresponds to a set of sessions that can contain either games or assessments. The plan form in the system enables the professional to quickly create a set of sessions and schedule assessments based on the end-user profile and with the frequency, duration and recurrence that he/she wishes to define (requirement 1 and 20). Figure 9-12 shows an example of the definitions used to create a training plan.

Figure 9-12 Screenshot of the plan form.

All input fields are required to be filled in, so the system can know the plan details in order to generate the sessions dynamically. Figure 9-13 shows the list of sessions generated after saving a plan. A plan can be edited even if some sessions were already performed, keeping the ones that were already completed as they are and updating only the remaining ones (requirements 11, 22, 40, and 62). The fitness profile is used universally as a common language between user fitness characteristics and game, session, or plan fitness settings.

Session	Date	Time	Fitness Training
2018/11/01	00:30	[Icons]	BAL: 45%, AGE: 50%, FLEX: 62%, CARD: 90%, STR: 70%
2018/11/05	00:30	[Icons]	BAL: 45%, AGE: 50%, FLEX: 62%, CARD: 90%, STR: 70%
2018/11/09	00:30	[Icons]	BAL: 45%, AGE: 50%, FLEX: 62%, CARD: 90%, STR: 70%

Figure 9-13 Screenshot of the plan and sessions list.

9.6. Functionalities implemented vs. not implemented

This section presents an overview of the functionalities that were implemented in the system versus the ones that were not. Besides the functionalities already identified along this chapter, which were referenced by their requirements numbers, the requirement “Store historical data” (requirement 13), has been fully implemented since all user and game data is saved locally, and additionally the system is prepared to stream the data to the hosted database. In total, 29 out of the initial 110 requirements have been fully implemented in the system.

Some requirements have been achieved not by implementing them on the system, but directly on games. For instance, the requirements 8, 14, 18, 35, 72, and 88, which are highly related with historical game data, have been implemented through the score evolution module (Section 6.8). Another example is the positive feedback module (Section 6.7) which served to implement the requirements 2, 32, and 39. Requirement 33: “Display the correct posture/movement for guidance” already was implemented on the most part of the integrated games by providing videos showing how to perform the exercises correctly.

A total of 50 requirements have been considered in the software design but did not reach the implementation stage. Most of them are related with the data visualization or remote managing which were expected to be implemented on the cloud service (requirements 3, 4, 21, 28, 29, 49, 54, 55, 61, 63, 65, 66, 70, 71, 73, 74, 75, 76, 81, 82, 83, 85, 90, 99, 102, 103, 104 and 109). Others were just delayed for future implementations. For instance, the requirements 12 and 64 concerns the integration of activities for assessment, which was highly considered in the software design and architecture. However, since the integration of any kind of manual assessment has been achieved, the priority of this functionality has been reduced. Other examples are the requirements 26, 30, 34, 39, 41, 42, 43, 44, 45, 47, 53, 68, 69, 78, 80, 86, 101, and 107 which consist of very specific functionalities, such as saving the rating of music and activities, or defining which body side requires training. These functionalities have been considered and even designed on the initial prototypes, but they have been removed or delayed the implementation considering the feedback gathered along the human-centric processes which was clear about not providing too much information on the screen. Two requirements were related with the decision support module which was not yet implemented at this stage: “Recommend multiple options based on end-user profile” (requirement 31) and “Learn the professionals’ decisions” (requirement 98).

Some non-functional requirements were too specific that couldn’t be included in the generic domains agreed for the fitness profile, for instance, “Activities with facial or sensorial stimulation” (requirements 108 and 110), or “Activities for daily living” (requirement 67), or “Activities with cognitive stimulation/Games with configurable content” (requirements 27 and 92). However, as mentioned before, the system can integrate exergames with any type of activity. What is missing is to integrate more domains that can reach more specific goals, for example, cognitive rehabilitation.

16 requirements were not considered for design or implementation, which are justified as follow:

- Requirement 23 – “One unique method for projection mapper” – this requirement was not gathered from the professionals, but the developers involved in the AHA team. This requirement ended up by not being necessary since the system was integrated into a portable platform with a projector that does not need perspective correction.
- Requirements 51, 56, 79, 94, 100, and 106 – are highly related to monitoring the physical and physiological data in real time. This monitoring module was expected to be designed and implemented separately by a different team of the AHA project, therefore was not considered for this system.
- Requirements 83, 84, 87, 89, 91, 93, 97, 105 – are too specific for physiotherapy or rehabilitation and were not considered at this stage. Information such as the base of support, the center of mass, number of falls, reaction time, weight transfer, and physical activity data extra exergaming would require further study and implementation. Since these requirements were near the bottom of the list, were delayed for future design iterations.
- Requirement 95 – “Configure game parameters in real time” – Since the integrated games at this stage do not support manual configuration of their parameters in real time, the implementation of this requirement would need time-expensive developments both on games and on the system. Considering this, and since this requirement was also one with the less priority, it was not considered for design or implementation.

9.7. Conclusion

This chapter presented an overview of the system providing an understanding of the main functionalities that have been implemented. Screenshots of the UI and a fictitious scenario were used to illustrate the sequential flow of the usage of the system. Features such as authentication, the user profile, sessions and plans have been explored establishing the connection with the respective requirements from which have unfolded. Additionally, an overview of the implemented versus the not implemented requirements was presented and discussed.

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10. Usability study

10.1. Introduction

It is critical for the success of a system that during its development life cycle it is ensured that it is usable by the target audience. This chapter presents the efforts towards evaluating the first digital prototype of the integrative system. First, some concepts concerning usability are presented in section 10.2, followed by a description of the methodology used. Section 10.4 presents the results of usability sessions performed with 10 end users, and in section 10.5, the list of modifications to be implemented based on the usability evaluation results are presented. The chapter is wrapped up in conclusion presented in section 10.6.

10.2. Usability

Usability is a multidimensional concept that has been studied and explored over time by different researchers, which added different aspects to its definition [71]–[73]. According to [73], usability is defined by five quality components: learnability, efficiency, memorability, errors, and satisfaction. More recently the international standard ISO 9241-11:2018 defines usability as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use” [74]. Effectiveness corresponds to what extent a task was completed, or an objective achieved. The number of errors or the error intensity can be used to define the level of effectiveness. Efficiency can be measured by considering the tasks time and productivity considering the time used to accomplish a task. Satisfaction considers measures such as user pleasure, physical comfort, and feature utilization. A list of measures that can be used to define effectiveness, efficiency, and satisfaction are presented in Table 10-1 [49].

Table 10-1 Measures of effectiveness, efficiency, and satisfaction [49].

Effectiveness	Efficiency	Satisfaction
Tasks completed	Task time	Overall satisfaction
Objectives achieved	Time efficiency	Satisfaction with features
Errors in a task	Cost-effectiveness	Discretionary usage
Tasks with errors	Productive time ratio	Feature utilisation
Task error intensity	Unnecessary actions	Proportion of users complaining
	Fatigue	Proportion of user complaints about a particular feature
		User trust
		User pleasure
		Physical comfort

10.3. Methodology

10.3.1. Setup

Setup of the usability tests consisted of a computer and a screen with touch capability. The user sits in front of the screen performing the test of the software.

10.3.2. Participants

10 sports professionals (7 female, 3 male, 32.7±8.8 years old, 8±6.9 years of experience) that did not know the system were invited to participate in the usability evaluation sessions (Table 10-II).

Table 10-II Characterization of the participants.

PARTICIPANT ID	GENDER	AGE	YEARS OF EXPERIENCE	DIGITAL TECHNOLOGIES USED IN DAILY PRACTICE	USE OF DIGITAL TECHNOLOGIES' PURPOSE
1	Male	22	1	Microsoft Excel	Users' database
2	Male	30		Microsoft Office	Users' database and exercise training planning
3	Male	35	3	Microsoft Word/Excel	Users' database
4	Female	41	19	Microsoft Word/Excel	Users' database and exercise training planning
5	Female	27	6	Microsoft Excel	Users' database
6	Female	21	1	Microsoft Word/Excel, Canva	Users' database and exercise training planning
7	Female	39	15	Microsoft Word/Powerpoint	Attendance database, physical activity
8	Female	27	2	-	-
9	Female	48	15	Operating systems	Users' database
10	Female	37	10	Microsoft Word/Excel/Powerpoint	Attendance database, presentations, general information

All participants had previous experience in prescribing physical exercise for the senior population. Concerning the use of digital technologies in their daily practice, none uses exergames or similar tools as training complement. The use of digital technologies is used mainly in the context of administrative functions such as organizing users' data and planning classes, for this, Microsoft Office tools are the preference among most participants.

10.3.3. Procedure

In order to run all usability evaluation sessions in a standardized way, a script (Appendix G) was written and divided into three main stages:

1. **Introduction to the system** - in this stage, three videos of the exergames were shown to the participant to provide a general idea of the type of games and different physical domains trained. After the videos, a diagram representing an overview of the system was explained for the participant to understand the main objectives of the integrative system.

This stage concluded by describing what would happen during the usability evaluation and asking the participant to sign an informed consent (Appendix H).

2. **Usability evaluation** - in this stage, a fictitious scenario (Appendix I) was presented to the participant who was led through a set of micro-tasks in order to accomplish 2 activities with the system. The participant was invited to speak out loud while performing the tasks (Figure 10-1). The two activities corresponded to the two of the most important functionalities of the integrative system, namely, create sessions and training plans. Hence, the first activity (A1) had the primary goal to create an assessment session and was divided into six microtasks. The second activity (A2), was composed of 3 microtasks, and the main goal was to create a training plan. The complexity of the third column of Table 10-III corresponds to the number of steps, gestures or “clicks” that the participant had to perform to accomplish the microtask (Appendix J). The last one was the most complex of all, basically consisting of filling in a form with given details.

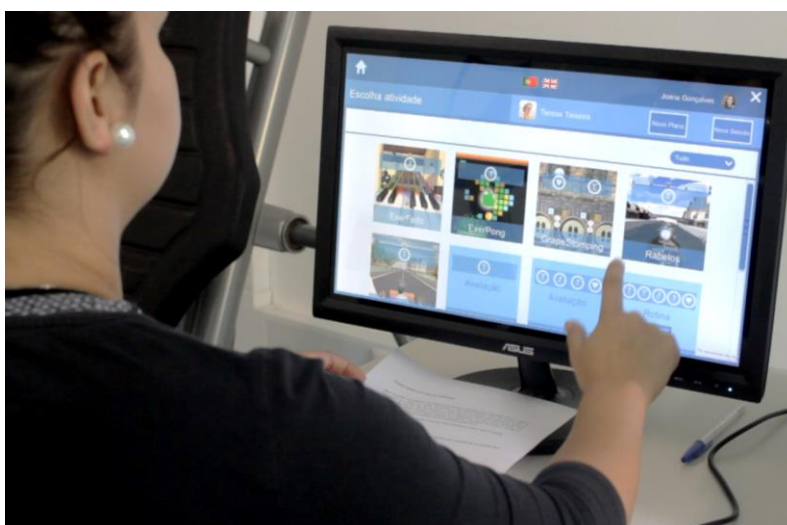


Figure 10-1 Participant performing the fictitious scenario steps during the usability evaluation of the integrative system.

Table 10-III List of the usability test microtasks and their complexity.

MICROTASK	BRIEF DESCRIPTION	COMPLEXITY
A1.1	Log in the system	5
A1.2	Select a specific user	2
A1.3	Create a session for this user	1
A1.4	Add the general assessment routine to the session	3
A1.5	Edit session date	2
A1.6	Save session	1
A2.1	Select another specific user	2
A2.2	Open this user profile	1
A2.3	Create a training plan with given details	22

3. **Usability questionnaire** – at the end of the evaluation session the participants were asked to fill in the Portuguese version of the Usefulness, Satisfaction and Ease of use (USE) questionnaire [77]–[79] (Appendix K). The USE questionnaire aims to measure the subjective usability of a product or service, in this case, a software system. It is composed of 30 items and examines four dimensions of usability: usefulness, ease of use, ease of learning, and satisfaction. Participants rate each item on a 7-point Likert scale (1 = “Strongly Disagree”; 7 = “Strongly Agree”) with an “N/A” option. In the end, participants may freely indicate the negative and positive aspects of the system. The scoring of the USE is found in literature as being conducted separately for each of the four dimensions by averaging the item scores in the dimension [79].

All participants allowed to video record the sessions which enabled in further logging of the events and checking tasks accomplishment. Each session lasted approximately 25 to 30 minutes.

Event logging was planned to be manually registered during the sessions and video recording to be used as a backup in case some event was missed. However, the execution of some microtasks was very fast, making event logging almost impossible to be performed in real time. A better solution would have been to have implemented the event data logging on the system itself. Nonetheless, that would only allow to keep track of the duration of each microtask and not registering the user comments and difficulties. Hence, video recording ended up by being the most efficient tool, which also freed the moderator to be focused on the participant behavior and session.

Data analysis was performed using IBM SPSS Statistics version 25.0 for Windows (Armonk, NY: IBM Corp.).

10.4. Results

10.4.1. Usability test logging

From the video recording analysis, the logging of events was highly useful to identify the major usability problems and errors of the system. Table 10-IV shows the average duration of microtasks, the number of occurrences and accomplishment (see Appendix L for the individual registry). Concerning microtask duration, which is presented in minutes and seconds, it is consistent with the complexity of the task. For instance, the fastest to accomplish were A1.3 and A1.6 with an average of 0:08 seconds. The two tasks had a complexity of 1, and this means that each task is only composed of one single step, for instance, pressing a button, as previously explained in subsection 3.3.

Interestingly, there was another microtask with the same complexity, which also only required to press one button, but had the least accomplishment rate which was the microtask of viewing the user profile (A2.2). In this task, the participant only had to press the user photo to open the profile. However, this was not intuitive since most of the participants clicked on the username to try to open the profile, which resulted in ignoring this task possibly because by pressing the username nothing was changing. The longest task was the A2.3, consistent with its complexity, and was the one that had the highest number of occurrences.

Table 10-IV Microtasks average duration, occurrences, and accomplishment rate.

MICROTASK	COMPLEXITY	ACCOMPLISHMENT	DURATION (MM:SS)	NUMBER OF OCCURRENCES
A1.1	5	2	00:20	0.3
A1.2	2	2	00:25	1.4
A1.3	1	2	00:08	0.0
A1.4	3	1.7	01:07	3.3
A1.5	2	2	00:14	0.7
A1.6	1	2	00:08	0.6
A2.1	2	2	00:18	0.5
A2.2	1	0.7	00:29	2.1
A2.3	22	1.8	02:26	4.7

The accomplishment was measured in three ways: if the participant accomplished the microtask as requested it got a value of 2, if the microtask was accomplished but not precisely as requested it got a value of 1, and 0 if the microtask was not accomplished. All microtasks on average were accomplished except microtasks A1.4, A2.2, and A2.3. In the A1.4, it happened that some participants did not add the assessment routine to the session. Instead, they added a single assessment and concluded the microtask considering they had done it well. The microtask A2.2, as mentioned above, opening the profile was not intuitive at all in the current implementation, most participants pressed the username instead of the user picture to open the profile. The microtask A2.3 was accomplished by all participants. However, some did not input the correct details given in the scenario sheet.

Table 10-V Summary of the occurrences registered by microtask and participant.

MICROTASK	CODE	DESCRIPTION	NUMBER OF PARTICIPANTS
A1.1	X	Tries to close the virtual keyboard with the enter key	2
A1.1	B	Login button does not respond quickly, so the user presses again resulting in a wrong user selection	3
A1.2	X	The system detected touch while swiping resulting in wrong selection	2
A1.2	A	Comment from moderator to assist	3
A1.2	X	Closes the application trying to exit view	1
A1.4	M	Wrong component selection	5
A1.4	A	Comment from moderator to assist	10
A1.4	X	The system detected touch while swiping resulting in wrong selection	1
A1.4	M	Participant opens the assessment to explore	4
A1.4	X	Closes the application trying to exit view	1
A1.4	M	Saves session as routine	1
A2.1	X	Touches the info message thinking it is interactable	1
A2.1	X	Touches the username trying to change user	1

A2.1	X	Closes the application trying to exit view	1
A2.2	X	Touches the username trying to open the user profile	5
A2.2	M	Ignores opening the user profile	3
A2.2	X	Opens the existing session trying to open the user profile	2
A2.2	A	Comment from moderator to assist	1
A2.3	X	Touches the current month trying to change month	5
A2.3	A	Comment from moderator to assist	8
A2.3	B	Dropdown does not work properly when clicked without exiting the virtual keyboard	3
A2.3	X	Touches the year trying to change the year	2
A2.3	X	Tries to close the virtual keyboard with the enter key	1
A2.3	B	Buttons not responding at first try	5
A2.3	B/X	Opens the second calendar without closing the first	1
A2.3	X	Presses at left and right of the slider trying to change its value	1
A2.3	G	Participant suggests the date to be in the Portuguese format	1
A2.3	P	Participant says the calendar interaction is excellent	1
A2.3	X	Ignores frequency/recurrence input fields after opening virtual keyboard	2
A2.3	X	Adds text on numeric input fields	2
A2.3	X	Saves plan without being all filled in	1
A2.3	G	"Calendar interaction is just like in mobile phones"	1
A2.3	G	Says that duration can be wrongly introduced for example if 1 hour, the system would recognize 1 min	1

Occurrences correspond to events on the logging sheet and can be of the following types: (A) assistance from the moderator, (B) bug, (G) general comment, (M) miscellaneous event, (P) positive opinion, and (X) usability problem. Table 10-V shows the list of the registered events and the number of participants that had that occurrence at least once. Following, a description of the most critical issues (registered by 5 or more participants):

- Issue 1: Wrong component selection (A1.4) – as mentioned above, some participants added the wrong component to the session, this may be because the scenario was requesting to add an assessment routine, and since the individual assessments appeared first on the list, the participant immediately adds one without scanning the following items in search for the routine.
- Issue 2: Comment from moderator to assist (A1.4) – assistance was given in two different circumstances on this microtask. First, after opening the session, the participant could not always find intuitively how to add the routine to the session, in this situation the moderator led the participant to think how he/she could add the session component. Second, this was one of the microtasks that led to wrong performing (adding wrong components), in the situations that the user realized it, in some circumstances he/she got blocked without knowing how to go back to solve the mistake, so again, the moderator had to intervene to lead the participant to think. In any circumstance, the moderator told the participant how to perform the task.

- Issue 3: Touches the username trying to open the user profile (A2.2) – this occurrence in this microtask has already been discussed above.
- Issue 4: Touches the current month trying to change the month (A2.3) – when opening calendar to select a date, participant intuitively pressed the current month label considering that it was a button and that will enable change month.
- Issue 5: Comment from moderator to assist (A2.3) – this assistance was given mostly concerning the input type or by restarting the application when the participant closed it thinking it would close only that view.
- Issue 6: Buttons are not responding at first try (A2.3) – this happened when pressing dropdowns after selecting the plan’s end date. Also, when pressing the “add” button when adding assessments to the plan. Responsiveness of the buttons was somehow random.

10.4.2. USE questionnaire

Results from the USE questionnaire were high, and in general, the first impressions to the system were very good which supports the value and applicability of the integrative system. The results of the USE questionnaire were analyzed by its domains: usefulness, ease of use, ease of learning and satisfaction. Boxplots for these domains depict results above the value of 5 of the Likert scale (Figure 10-2) where 7 is the best usability score that one item can get. One user was identified as an outlier who displayed very bad acceptance and skepticism concerning the presented system. All domains display agreement since all obtained high scores with the usability domain (mean 5.3 ± 1.4) being the lowest. The highest score was identified in the ease of learning domain which obtained a mean of 6 ± 1.3 . The domains ease of use and satisfaction both obtained identical results regarding mean and standard deviation: 5.7 ± 1.3 .

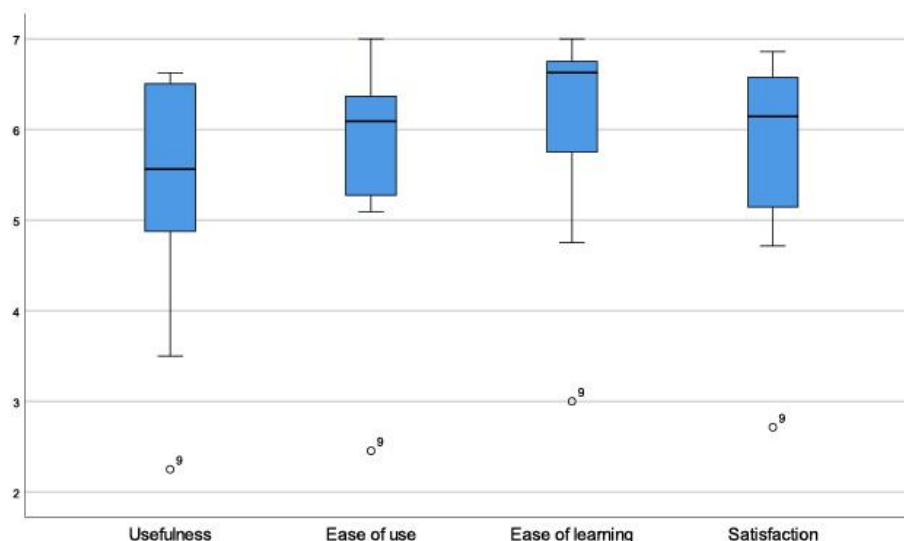


Figure 10-2 USE questionnaire results averaged by domain. The Y axis corresponds to the answer on the Likert scale from 1 to 7.

In the final part of the USE questionnaire, each participant was invited to mention the negative and positive aspects of the evaluated system. Among all participants, 10 negative and 27 positive

aspects were mentioned, showing that this system causes a more positive than a negative impression (Appendix 7). In the positive side, the ease of use, the intuitive interface and the possibility for long-term planning were the most mentioned aspects. The most mentioned negative aspect was the fact that games are not playable by big groups at the same time, this may be because is something very different from the daily routine of sports professionals who typically prescribe physical exercise to groups not to one individual at a time.

10.5. Improvements

Based on the observation and registry of occurrences during the usability sessions, the following implementations should be considered for the next iteration:

1. Adding components to a session was not so intuitive as it should be (Issues 1 and 2). The users need clarifications from the moderator to accomplish the task. Adding over text short descriptions when hovering icon buttons can probably help.
2. Both the username and photo should be used as a button to open the profile (Issue 3).
3. Calendar interaction should be redesigned because it was not intuitive for some participants (Issue 4). Perhaps distinguishing better which are buttons from those that are not, or implementing functionality as participants were expecting (i.e. enabling changing month or year when touching it).
4. Swipe gesture was many times detected as touch, while other times touching buttons or drop-down selection did not respond as they should, and users needed to press more than once (Issue 6). Hence, the touch interaction must be revisited and redesigned to avoid such usability problems.
5. When pressing the login button, sometimes the system took longer to respond, which led the participant to press twice or more (Issue 6). As a consequence, a wrong user was selected on the next screen. The existence of a loading screen for a few seconds may avoid selecting a user by mistake.
6. Session components should be better distinguished or presented separately (Issue 1).
7. Quit button was sometimes interpreted as a button to close the view (Issue 5). The icon should be changed.
8. The input of text in numeric fields resulted in a system error (Issue 5). Hence, adding restrictions on numeric input fields, or changing the input method for the frequency, moments of assessments and session duration fields will overcome this problem.
9. The option to close the virtual keyboard when pressing return/enter must be implemented (Issue 6).

10.6. Conclusion

This chapter presented the methodology applied to the usability evaluation of the integrative system. The usability sessions were planed in advance, uniformly ran, and video recorded to allow further event log analysis. Participants answered a usability questionnaire which enabled in evaluating the system in four domains: usefulness, ease of use, ease of learn, and satisfaction with the system.

The high results of the USE questionnaire show that this integrative system is a promising tool that sports professionals may be willing to use on their daily practice. Therefore, further implementations and improvements should be considered to bring this system to life.

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11. Conclusion

The main objectives of this thesis consisted of designing, implementing and evaluating an integrative system for exergames targeting the senior population following human-centric techniques. The system was envisioned to manage training sessions and plans with exergames, providing decision support based on the end-user profile.

According to the here presented literature review, most of the existing systems that are similar to the one developed in this thesis, none followed user-centric techniques considering the main system interactors, which have the responsibility to prescribe or manage exercise trainings for the senior population: the sports and health professionals, or other caregivers in general. Therefore, the used approach from the beginning of the design cycle was crucial to guiding the development of this system.

The process started with the requirements engineering where the professionals have been invited to participate in interviews with the primary goal of obtaining a requirements list. The knowledge, expectations, and opinions provided by the professionals assisted in defining the essential features to be implemented. The outcome of this step worked as input to materialize the overall diagrams that are commonly used in software engineering such as class, activity or architecture diagrams. The professionals have been involved during the process to validate the proposed design through card sorting sessions and paper prototype evaluations. This step assisted in finding new features and aspects relevant to make the UI more clear and intuitive. Before moving into implementing the system, there was the need to make some implementations on games towards the integration in the system. The integrative system was implemented in Unity, and an overview of the most important aspects of implementation have been described in this thesis. The decision support module was one of the features that have not yet been implemented, mostly because it would require a large amount of data in what concerns in automatically finding the ideal settings for each specific profile. However, an initial review of literature and conceptual decision support strategy was investigated and presented. A description of the system and its functionalities were provided, illustrated with screenshots of the UI and references to the initial requirements.

As defined in the first chapter of this thesis, the three main objectives were largely accomplished. Concerning the first objective, the design process using human-centric techniques was achieved using different techniques such as the already mentioned: semi-structured interviews, card sorting sessions, and paper prototype evaluations. The inclusion of the professionals in the process turned out to be empowering for them since they could see the system emerge from their contributions. The second objective concerns the implementation of the software system. Not all the features have been implemented, however, the design included all the ones considered feasible for implementation, and the code structure is prepared to welcome the missing features. The implemented features enabled accomplishing the third objective, which was a usability study of the UI and its most essential functionalities with a sample of the main prospective interactors of the system. The usability study helped in finding UI functionalities that were not so intuitive, and also errors caused by unexpected input. Results of the study displayed high interest and

acceptability of the system, which shows that the integrative system is a promising tool that should be further iterated.

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Appendix

Appendix A. Main questions list of the semi-structured interview (Portuguese)

1. Apresentação do sistema acompanhado de um diagrama.
 - a. Já experimentou ou conhece algum sistema similar ao que foi apresentado?
 - b. Pode explicar como foi a sua experiência com o sistema?
2. Apresentação de vídeo representativo do sistema.
 - a. Quais as funcionalidades que achou mais úteis ou interessantes?
3. Se tivesse um sistema deste tipo na sua instituição, que funcionalidades considera importantes que o sistema deveria ter?
4. Que opções configuráveis o sistema deveria ter para se adaptar a diferentes necessidades e a diferentes utilizadores?
5. Que tipo de informação gostaria que este sistema apresentasse?
6. O sistema vai estar integrado numa plataforma que necessitará de instalação do equipamento e configuração inicial.
 - a. De que forma o sistema deverá assistir na instalação do equipamento?
 - b. Já depois do equipamento instalado, de que forma o sistema deverá fornecer ajuda para ajudá-lo em relação à configuração inicial do equipamento?
7. Que preocupações / restrições poderia encontrar ao usar este sistema na sua prática diária?
8. Existe alguma informação que não tenhamos falado e que considere útil e que gostaria que ficasse registada?

Appendix B. Informed consent (Portuguese)

Consentimento informado - Entrevista semi-estruturada

Eu, _____ aceito participar de livre vontade no estudo de Teresa Paulino (aluna da Universidade da Madeira e assistente técnica do Instituto de Tecnologias Interativas da Madeira), orientado por: Professora Doutora Mónica Cameirão e Professor Doutor Sergi Bermudez i Badia (Professores da Universidade da Madeira), no âmbito da dissertação de Mestrado em Engenharia Informática integrada no projeto de investigação AHA – Assistência Humana Aumentada (CMUP-ERI/HCI/0046/2013).

Foram-me explicados e compreendo os objectivos principais deste estudo.

Aceito responder a uma entrevista que explora questões sobre um sistema integrado de jogos que promovem o exercício físico.

Compreendo que a minha participação neste estudo é voluntária, podendo desistir a qualquer momento, sem que essa decisão se reflecta em qualquer prejuízo para mim.

Ao participar neste trabalho, estou a colaborar para o desenvolvimento da investigação na área de tecnologias para a saúde, não sendo, contudo, acordado qualquer benefício directo ou indirecto pela minha colaboração.

Entendo, ainda, que toda a informação obtida neste estudo será estritamente confidencial e que a minha identidade nunca será revelada em qualquer relatório ou publicação, ou a qualquer pessoa não relacionada directamente com este estudo, a menos que eu o autorize por escrito.

Autorizo Não autorizo - a gravação audio da entrevista.

Nome _____ Fem. Masc.

Idade: _____ Profissão: _____

Público-alvo para quem exerce a atividade: _____

Anos de Experiência Profissional _____

Contacto (opcional) _____

Data ___/___/___

Assinatura _____

Assinatura do(a) investigador(a) _____

Appendix C. Ordered Requirements List

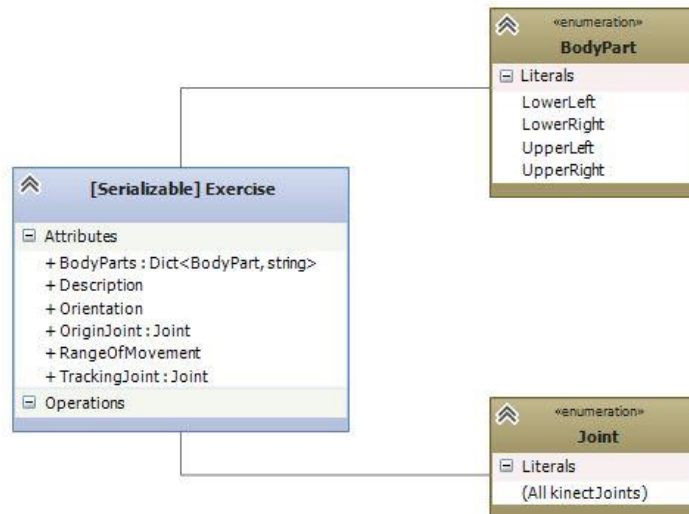
Requirement number	REQUIREMENT	CRUCIALITY MEAN	INTERVIEWS %	IMPORTANCE MEAN
1	Configurable - Time/duration/volume of the session	9.2	76.39%	9.3
2	Audio/visual Feedback	8.3	69.44%	9.2
3	Cloud Service - Assessments historical data (evolution)	8.3	69.44%	8.8
4	Cloud Service - Assessments summary	8.3	69.44%	8.5
5	Provide variety of activities/games/exercises	8.2	68.06%	9.0
6	Configurable - Game parameters	8.2	68.06%	9.3
7	Configurable - Complexity/difficulty/levels	8.2	68.06%	9.3
8	Cloud Service - Summaries/totals	8.2	68.06%	8.5
9	Cloud Service - Session time	8.2	68.06%	8.5
10	Integration of the independent applications	8.0	0.00%	7.5
11	Cloud Service - Number of sessions	8.0	66.67%	8.3
12	Activities for assessment/ Assessment performed by the system	7.8	65.28%	7.8
13	Store historical data	7.5	62.50%	7.0
14	Cloud Service - Evolution regarding game performance/parameters	7.5	62.50%	7.7
15	Configurable - Physical domain/Cognitive domain	7.2	59.72%	7.3
16	Save routines, plans	7.0	58.33%	7.8
17	Configurable - Activity/Game	7.0	58.33%	8.7
18	Cloud Service - Graphics that facilitate data interpretation	7.0	58.33%	8.3
19	Activities recommendation based on user needs/goals/abilities	6.8	56.94%	7.3
20	Configurable - Intensity/frequency/repetitions	6.8	56.94%	8.5
21	Cloud Service - Filter data to show to the patient or for specific analysis	6.8	56.94%	6.0
22	Cloud Service - List of performed exercises/activities/games	6.8	56.94%	8.0
23	One unique method for projection mapping	6.7	0.00%	5.8
24	Configurable - User profile (demographics)	6.7	55.56%	7.8
25	Cloud Service - User demographics	6.7	55.56%	7.2
26	Configurable - Goals/Challenges/treatment objectives	6.5	54.17%	6.8
27	Activities with cognitive stimulation	6.5	54.17%	8.3
28	Cloud Service - Historical activity data (steps, energy expenditure, exercise type, etc.)	6.5	54.17%	8.0
29	Dynamic difficulty adaptation	6.3	52.78%	8.2
30	Non-supervised mode with automatic activities suggestion	6.2	51.39%	6.7
31	Recommend multiple options based on end-user profile, allow to choose	6.2	51.39%	7.2
32	Positive feedback/Congratulate achievements	6.2	51.39%	8.5
33	Display the correct posture/movement for guidance	6.2	51.39%	7.3
34	Configurable - Dangerous exercises/limits	6.2	51.39%	8.2
35	Cloud Service - Latest scores	6.2	51.39%	7.3
36	Cloud Service - Assessments results compared with normative data	6.2	51.39%	7.5
37	Cloud Service - User weight, BMI, etc	6.2	51.39%	7.0

38	Display game performance in real-time	6.0	50.00%	8.3
39	Activities for people with audio/vision/mobility issues	6.0	50.00%	6.3
40	Schedule assessments to re-adjust objectives	5.8	48.61%	5.2
41	Configurable - Music/rhythm	5.8	48.61%	7.0
42	Configurable - Music/rhythm BPM	5.8	48.61%	7.0
43	Reminders/Warnings related to specific pathologies/alarms	5.7	47.22%	5.7
44	Universal calibration (no need to calibrate for each game)	5.7	0.00%	6.0
45	Configurable - Exercises/movements (allow customization)	5.7	47.22%	7.8
46	Cloud Service - Graphical comparison of exercise performance with normative data	5.7	47.22%	6.7
47	Warnings/reminders/suggestions based on past sessions	5.5	45.83%	6.3
48	Step by step guide/Interface steps are guided	5.5	45.83%	7.3
49	Cloud Service - Historical kinematics data (range of movement, the distance between members, movement velocity, movement trajectory, etc.)	5.5	45.83%	7.0
50	Automatic classification of the user	5.3	44.44%	7.0
51	Monitor physiological/emotional states with sensors	5.3	44.44%	5.7
52	Configurable - Range/angle of movement	5.3	44.44%	7.2
53	Configurable - Accessories / conditions of practice (e.g. sitting, standing)	5.3	44.44%	6.5
54	Cloud Service - Evolution regarding posture/movements execution	5.3	44.44%	7.2
55	Save physical activity data, e.g., energy expenditure, steps, etc	5.2	43.06%	7.8
56	Display posture performance in real time	5.2	43.06%	7.3
57	Save clinical data (pathologies)	5.2	43.06%	6.3
58	Cloud Service - Information about user' needs/goals/limitations	5.2	43.06%	6.5
59	Configurable - Velocity	5.0	41.67%	6.3
60	Configurable - Assessment type	4.8	40.28%	7.3
61	Cloud Service - Data not editable by the end user, just for visualization	4.8	40.28%	4.8
62	Cloud Service - Attendance to classes/sessions	4.8	40.28%	5.0
63	Cloud Service - Export/Print reports	4.8	40.28%	6.0
64	Automatic detection of the range of movement	4.7	38.89%	6.3
65	Remote management and analysis of sessions and plans	4.7	38.89%	6.5
66	Cloud Service - Filter users with similar needs/pathologies for group creations	4.7	38.89%	5.3
67	Configurable - Activity function (ADL-eg sit, stand, reach, rotate, walk, up and down steps)	4.5	37.50%	7.2
68	Configurable - Side of the body that needs more focus (left/right/upper/lower)	4.5	37.50%	6.7
69	Activities with more than one exercise at the same time	4.5	37.50%	6.2
70	Cloud Service - Data organized by patient name with access by all professionals	4.5	37.50%	5.3
71	Cloud Service - Historical data regarding health/pathologies	4.5	37.50%	5.7
72	Cloud Service - Reports by task with visual graphics	4.3	36.11%	5.5
73	Cloud Service - Frequency/type of errors to find patterns	4.3	36.11%	5.3
74	Cloud Service - Physiological signals along session	4.3	36.11%	5.5
75	Cloud Service - Data available on any device with internet	4.3	36.11%	4.7

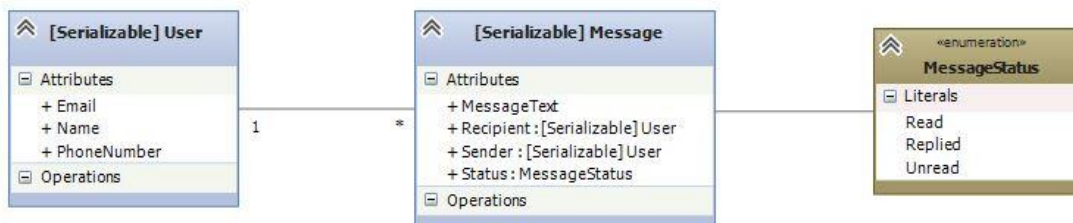
76	Rehabilitation at home	4.2	34.72%	6.2
77	Allow different types of assessment	4.2	34.72%	6.8
78	Multi-user interaction	4.0	33.33%	7.0
79	Visual representation of user movements in real time (user reflection)	4.0	33.33%	5.2
80	Optional guidance/help	4.0	33.33%	6.0
81	Cloud Service - Activities/games ranking (most voted/ most played)	4.0	33.33%	4.8
82	Cloud Service - Historical physiological data (HR, respiratory, muscular, blood pressure)	4.0	33.33%	6.2
83	Cloud Service - Information about the base of support	4.0	33.33%	4.0
84	Cloud Service - Information about the center of mass	4.0	33.33%	4.2
85	Allow installing in any computer (portable system)	3.8	31.94%	5.3
86	Save user feedback/rating of session/activity/exercise	3.8	31.94%	5.2
87	Cloud Service - Number of physical states specific to each pathology (Falls or almost falls, the aggressiveness' focus, etc.)	3.8	31.94%	5.2
88	Cloud Service - Personal ranking, not compared with others	3.7	30.56%	5.0
89	Cloud Service - Information regarding reaction time	3.7	30.56%	3.8
90	Remote assessments	3.5	29.17%	5.7
91	Configurable - Reaction time	3.5	29.17%	5.7
92	Configurable - Content (allow add images/ change objects - specific therapies)	3.3	27.78%	4.8
93	Configurable - Weight transfer	3.3	27.78%	4.3
94	Display physiological state in real-time	3.2	26.39%	5.5
95	Configurable - game parameters in runtime	3.2	26.39%	4.7
96	Allow saving notes/extra observations	3.0	25.00%	6.0
97	Fall detection	3.0	25.00%	6.0
98	Learn the professionals' decisions	2.8	23.61%	4.3
99	Cloud Service - Best moments, records	2.8	23.61%	5.8
100	Tips and suggestions, e.g., "Don't forget to drink water."	2.7	22.22%	4.3
101	Configurable - Accessory weight	2.7	22.22%	4.2
102	Cloud Service - Ranking according to abilities/limitations	2.7	22.22%	3.8
103	Cloud Service - Private ranking for group comparison just for professionals' analysis	2.7	22.22%	4.5
104	Cloud Service - Evolution through pictures/videos (posture)	2.7	22.22%	2.8
105	Cloud Service - Physical activity data (extra classes)	2.7	22.22%	3.2
106	Virtual guide	2.3	19.44%	4.2
107	Save music rating	2.2	18.06%	3.7
108	Activities with facial motor stimulation for speech therapists	1.7	13.89%	2.2
109	Forum for communication/ messages exchange	1.5	12.50%	3.3
110	Activities with sensorial stimulation (e.g. touch, smell)	1.3	11.11%	1.8

Appendix D. Class diagrams

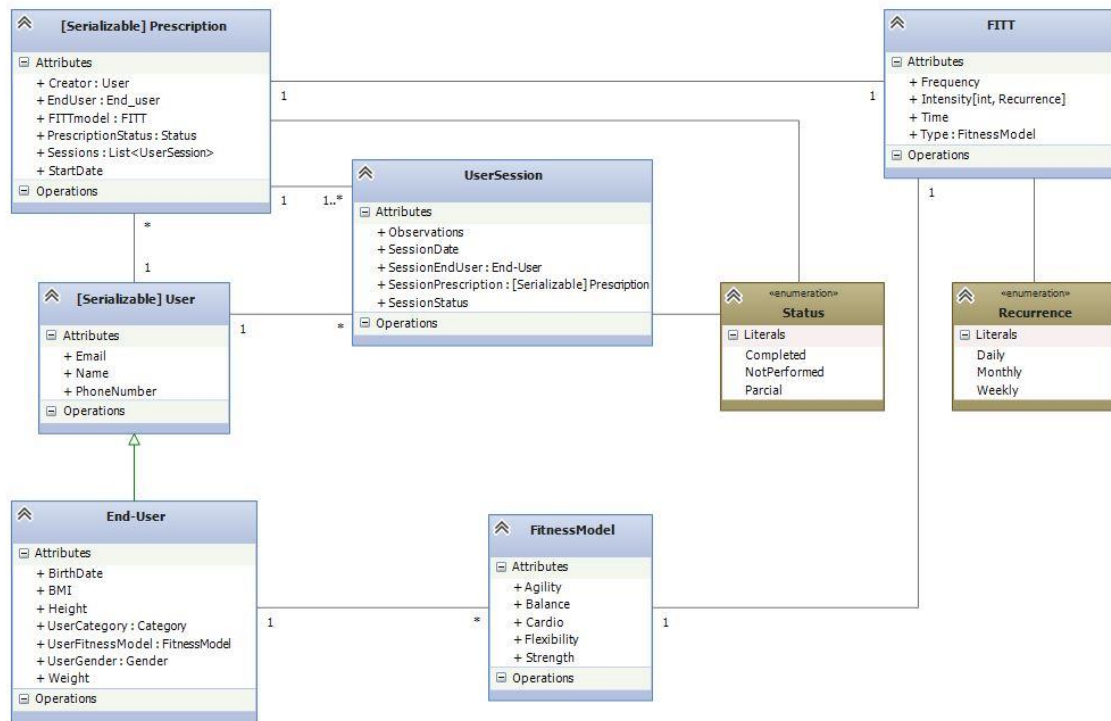
Exercise class diagram



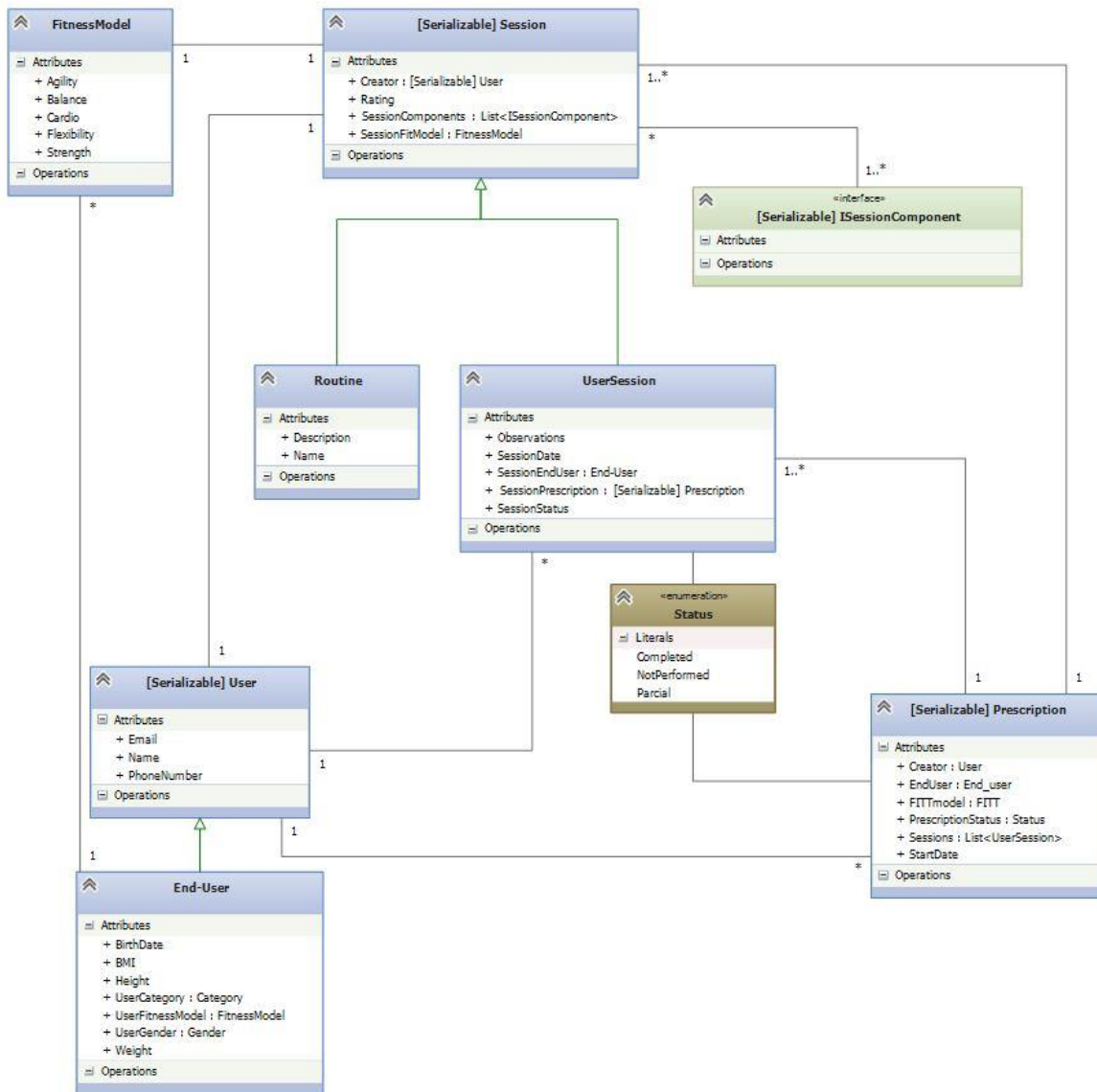
Message class diagram



Prescription class diagram



Session class diagram



Appendix E. Cards labels

PORTUGUESE	ENGLISH
Visualizar lista de avaliações	Visualize assessments list
Inserir dados de atividade física	Insert physical activity data
Editar o exercício correspondente a uma ação no exergame	Edit exercise
Escolher avaliação	Choose assessment
Visualizar lista de exergames	Visualize Exergames list
"Rating" da sessão (apreciar/avaliar)	Rate session
Escolher quantidade de avaliações	Choose assessments' quantity
Visualizar lista de utilizadores	Visualize users list
Adicionar exergames a uma sessão	Add exergame to session
Visualizar evolução	Check evolution
Visualizar lista de sessões de 1 utilizador	View user sessions list
Escolher dificuldade	Choose difficulty
Visualizar desempenho	Visualise performance
Escolher exergame	Choose Exergame
Filtrar dados para visualizar	Filter data to visualize
Visualizar resultados	Visualize results
Escolher sessão	Choose session
Visualizar o perfil fitness do utilizador	Visualize user fitness profile
Escolher utilizador	Choose user
Criar uma sessão	Create a session
Salvar/guardar a sessão como uma rotina	Save session as routine
Criar/registar novo utilizador	Register new user
Adicionar observações	Add observations
Definir bpm da música	Define music BPM
Mudar o idioma do sistema	Change system's language
Criar um plano de sessões	Create sessions plan
Escolher música	Choose music
Pesquisar ajuda no sistema	Search system's help
Escolher nº de sessões	Choose number of sessions
Adicionar jogador(es)	Add players
Contactar assistência técnica	Contact technical support
Definir volume (peso adicional)	Define volume
Editar os domínios de fitness do exergame	Edit Exergame fitness domains
Visualizar dados pessoais do utilizador	Visualize user personal data
Definir intensidade da sessão	Define session intensity
Visualizar ranking	Visualize ranking
Alterar dados pessoais do utilizador	Change user data
Definir a duração da sessão	Define session duration
Visualizar pontuação	Visualize score

Acrescentar alertas	Add alerts
Definir frequência das sessões	Define sessions frequency
Ler mensagem	Read message
Inserir dados de uma avaliação	Add assessment results
Definir amplitude de movimento	Define the range of movement
Enviar mensagem	Send message
Escolher o domínio da atividade física	Choose physical domain
Escolher parte(s) do corpo	Choose body part
Obter uma sessão recomendada pelo sistema	Get recommended session
Inserir dados fisiológicos	Insert physiological data
Alterar parâmetros do exergame	Edit exergame parameters
Definir objetivo do jogo (exergame)	Define goal

Appendix F. Database collections and fields

COLLECTION NAME	FIELDS (ATTRIBUTES) AND TYPES
<i>Plans</i>	_id: string plan_id: string creator_id: string endUser_id: string startDate: string endDate: string fitnessModel: list of integers timesPerRec: integer frequency: string assessMoments: integer assessRecurrence: string duration: integer planStatus: string planAssessments: list of strings
<i>Platforms</i>	_id: string platform_id: string location: string
<i>Routines</i>	_id: string creatorId: string rating: integer routine_id: string name: string
<i>SessionComponents</i>	_id: string comp_id: string name: string compStatus: string duration: integer compPosition: integer type: string session_id: string game_id: string goal: float gameFitnessModel: list of integers fitnessDomains: list of strings
<i>Sessions</i>	_id: string creatorId: string rating: integer endUserId: string session_id: string sessionDate: string observations: string sessionStatus: string

<i>Users</i>	plan_id: string
	_id: string
	user_id: string
	password: string
	type: string
	platform_id: string
	name: string
	birthdate: string
	gender: string
	age: integer
	email: string
	phone: integer
	location: string
	weight: float
	height: float
	bmi: float
	userFitnessModel: list of integers
userCategory: string	
observations: string	

Appendix G. Usability test script (Portuguese)

1ª parte (Apresentação dos jogos e sistema - texto)

Introdução - Os investigadores do projeto AHA desenvolveram um conjunto de Exergames que foram testados recentemente nos ginásios de Santo António e de São Martinho.

Nos seguintes videos é mostrado:

(Slide 1 – video do Exerpong) – O jogo Exerpong, um jogo inspirado no clássico Pong em que o utilizador necessita de controlar um “paddle” de forma a não perder a bola, e foi desenvolvido para treinar agilidade e cardio;

(Slide 2 – video do grapestomping) – O GrapeStomping, um jogo que simula o pisar das uvas para fazer o vinho, treina cardio e força muscular.

(Slide 3 – Video do Rabelos) – O Rabelos, inspirado nos barcos do rio Douro que transporta os barris de vinho, especialmente desenvolvido para treinar a força muscular superior e também a agilidade.

(Slide 4 – screenshot da evolução) - Ao fim de cada sessão é apresentada a evolução do desempenho ao longo do tempo.

(Slide 5 – diagrama do sistema) - O sistema que vimos aqui testar hoje é um sistema que permite integrar diversos Exergames permitindo serem controlados por uma interface comum. O sistema permitirá também inserir resultados de avaliações dos utilizadores. Essa informação vai apoiar no processo de decisão no momento de criar sessões e planos de treino com os jogos e definições mais aconselháveis para cada perfil de utilizador. Este sistema irá armazenar as informações permitindo assim visualizar o evolução do desempenho de cada utilizador ao longo do tempo.

Agradecemos desde já a sua disponibilidade em colaborar neste estudo, sendo que vai ajudar-nos a descobrir o quão útil e fácil de usar este sistema é. Informamos que se trata ainda de um protótipo e que ocasionalmente poderá ocorrer algum erro, se assim for, este teste também nos ajuda assim a melhorar na próxima versão.

Pedimos que leia o seguinte consentimento informado e que assine caso concorde na gravação audiovisual do teste.

2ª parte (teste de usabilidade)

Entrega do texto com cenário de utilização.

Mostrar disponibilidade para esclarecer qualquer dúvida antes de começar.

Pedir que informe do momento em que deseja iniciar a realização das atividades.

Tomar nota de todos os eventos no formulário para logging.

3ª parte (preenchimento de questionário)

Após a realização das atividades, agradecer de novo e mostrar abertura para receber sugestões e responder a alguma questão.

Entregar questionário USE para preenchimento.

No final, agradecer e mostrar disponibilidade para futuros contactos.

Appendix H. Usability study - informed consent (Portuguese)

Estudo de usabilidade – sistema integrativo para exergames

O objetivo deste estudo é compreender como as pessoas usam um sistema integrativo de jogos que promovem o exercício físico para a população idosa. A sua participação neste estudo é importante e irá contribuir para que o laboratório de investigação NeuroRehabLab identifique erros e aplique as modificações necessárias para que o sistema se torne mais fácil de usar.

A sua participação neste estudo é completamente voluntária. Pode recusar, desistir de participar, e/ou fazer perguntas a qualquer momento deste estudo.

Durante o estudo serão pedidas algumas tarefas para realizar com o sistema integrativo para Exergames. Vamos observá-lo(a) a executar essas tarefas e pedimos que verbalize as suas ações, pensamentos e dificuldades ao longo da sessão. A sua interação com o sistema será gravada bem como tomaremos notas escritas. Os dados recolhidos poderão ser usados para publicações científicas sendo que serão tratados de forma anónima e confidencial.

Foram-me explicados os objetivos e condições deste estudo, tendo tido oportunidade para esclarecer quaisquer dúvidas sobre o mesmo.

Autorizo a gravação audio-visual da sessão.

Nome do(a) participante: _____ Idade: _____

Nº de anos de atividade profissional: _____

Utiliza algum sistema digital de informação na sua prática profissional diária? Sim Não

Se sim, qual/quais? _____

Com que finalidade(s)? _____

Data: ____/____/____

O(a) participante:

O(a) investigador(a)

Appendix I. Usability scenario and guide (Portuguese)

João Gonçalves é profissional de desporto num ginásio orientado para a população sénior. O João é responsável por avaliar os utentes do ginásio e prescrever exercício físico de acordo com as necessidades de cada um. No seu dia-a-dia, o João tem ao seu dispôr uma plataforma móvel de Exergames que os utentes usufruem como forma de complemento dos seus treinos habituais. Essa plataforma permite-lhe gerir a informação referente aos utentes, criar planos de treino e sessões de avaliação, bem como acompanhar a evolução do desempenho de cada utente.

Neste teste de usabilidade irá desempenhar o papel de João Gonçalves e realizar duas atividades:

Atividade 1

Neste preciso dia, há uma nova utente do ginásio (Teresa Teixeira) que necessita de ser avaliada para posteriormente criar um plano de treino:

1 – Faça login no sistema com as suas credenciais:

ID do utilizador: id99

Palavra-passe: 1234

2 – Verifique se a utente Teresa Teixeira já está inserida no sistema. Se sim, escolha a utente, caso contrário, crie um novo utilizador.

3 – Crie uma nova sessão para a Teresa.

4 – Adicione a rotina de avaliação geral usada no ginásio.

5 – Edite a data da sessão para o dia de amanhã.

6 – Guarde a sessão.

Atividade 2

Nesse mesmo dia, a Joana Fonseca, utente do ginásio que foi avaliada no início desta semana, vem ter consigo à hora combinada para que lhe informe do seu plano de treino com Exergames:

1 – Selecione a utente Joana Fonseca.

2 – Abra o perfil da Joana para visualizar os seus detalhes.

3 – Crie um plano de treino para a Joana com os seguintes detalhes:

Data de início: 1/11/2018

Data de fim: 31/01/2019

A frequência será 1 vez por semana, com 1 momento de avaliação ao fim de cada mês.

As sessões terão a duração de 30 minutos.

Os testes de avaliação a usar serão o Senior Fitness Test e o Fullerton.

A Joana necessita de trabalhar o equilíbrio pois o seu desempenho no teste de Fullerton foi muito baixo, altere o valor do treino de equilíbrio para 30%.

No final, guarde o plano.

Parabéns, o teste de usabilidade está concluído com sucesso. Sinta-se à vontade para explorar a ferramenta e fazer as questões ou sugestões que achar necessárias. 😊

Appendix J. Micro-tasks details

MICRO-TASKS DETAILS/COMPLEXITY

A1.1	Touch the username inputfield
	Type username
	Touch password inputfield
	type password
	Press login button
A1.2	Swipe to find user
	Press the user
A1.3	Press create new session button
A1.4	Press "+" button
	Swipe to scroll down to find routine
	Press routine button
A1.5	Touch date inputfield
	Touch the next day
A1.6	Press save session button
A2.1	Press Home button
	Press the user
A2.2	Press user photo
A2.3	Press start date inputfield
	Press next month button
	Press the correct day
	Press end date inputfield
	Press next month button till reach the correct month
	Press the correct day
	Press the frequency inputfield
	type the frequency
	Press the recurrence dropdown
	Select weekly
	Press the assessment moments input field
	Type the number of moments
	Press the second recurrence dropdown
	Select monthly
	Press the duration inputfield
	Type 30
	Press the "+" button to add assessments
	Select one of the assessments
	Press the "+" button to add assessments
	Select the other assessment
Slide the balance slider to change the percentage	
Save plan	

Appendix K. USE questionnaire (Portuguese)

Código de identificação:

Questionário USE: Utilidade, Satisfação e Facilidade de Utilização

Sistema:

Utilidade

1 Ajuda-me a ser mais eficaz.

Discordo totalmente 1 2 3 4 5 6 7 Concordo totalmente NA

2 Ajuda-me a ser mais produtivo.

Discordo totalmente 1 2 3 4 5 6 7 Concordo totalmente NA

3 É útil.

Discordo totalmente 1 2 3 4 5 6 7 Concordo totalmente NA

4 Permite-me um melhor controlo das atividades da minha vida.

Discordo totalmente 1 2 3 4 5 6 7 Concordo totalmente NA

5 Torna as coisas que eu quero concretizar mais fáceis de serem feitas.

Discordo totalmente 1 2 3 4 5 6 7 Concordo totalmente NA

6 Poupa-me tempo quando o uso.

Discordo totalmente 1 2 3 4 5 6 7 Concordo totalmente NA

7 Satisfaz as minhas necessidades.

Discordo totalmente 1 2 3 4 5 6 7 Concordo totalmente NA

8 Faz tudo o que eu esperaria que fizesse.

Discordo totalmente 1 2 3 4 5 6 7 Concordo totalmente NA

Código de identificação:

Facilidade de Utilização

9	É fácil de usar.									
	Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
10	É simples de usar.									
	Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
11	É intuitivo.									
	Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
12	Requer o mínimo possível de passos para alcançar o meu objetivo quando o uso.									
	Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
13	É flexível.									
	Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
14	O seu uso não requer esforço.									
	Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
15	Eu consigo usá-lo sem instruções escritas.									
	Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
16	Eu não noto quaisquer inconsistências quando o uso.									
	Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
17	Tanto os utilizadores ocasionais como os regulares gostariam dele.									
	Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
18	Eu consigo corrigir erros de forma rápida e fácil.									
	Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
19	Eu consigo usá-lo todas as vezes com sucesso.									
	Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA

Código de identificação:
_____**Facilidade de Aprendizagem**

20 Eu aprendi rapidamente a usá-lo.

Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
---------------------	---	---	---	---	---	---	---	---------------------	----

21 Eu lembro-me facilmente como o usar.

Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
---------------------	---	---	---	---	---	---	---	---------------------	----

22 É fácil aprender a usá-lo.

Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
---------------------	---	---	---	---	---	---	---	---------------------	----

23 Eu tornei-me rapidamente competente a usá-lo.

Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
---------------------	---	---	---	---	---	---	---	---------------------	----

Satisfação

24 Eu estou satisfeito com o seu uso.

Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
---------------------	---	---	---	---	---	---	---	---------------------	----

25 Eu recomendá-lo-ia a um amigo.

Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
---------------------	---	---	---	---	---	---	---	---------------------	----

26 É divertido de usar.

Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
---------------------	---	---	---	---	---	---	---	---------------------	----

27 Funciona da forma que eu quero que funcione.

Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
---------------------	---	---	---	---	---	---	---	---------------------	----

28 É maravilhoso.

Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
---------------------	---	---	---	---	---	---	---	---------------------	----

29 Eu sinto que preciso de tê-lo.

Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
---------------------	---	---	---	---	---	---	---	---------------------	----

30 É agradável de usar.

Discordo totalmente	1	2	3	4	5	6	7	Concordo totalmente	NA
---------------------	---	---	---	---	---	---	---	---------------------	----

Código de identificação:

Quais os aspetos mais negativos?

1 _____

2 _____

3 _____

Quais os aspetos mais positivos?

1 _____

2 _____

3 _____

Appendix L. Usability logging per user

ID1

Task	Duration (mm:ss)	Number of occurrences	Accomplishment (*)
A1.1	00:17	0	2
A1.2	00:03	0	2
A1.3	00:53	0	2
A1.4	02:27	9	2
A1.5	00:07	0	2
A1.6	00:03	0	2
A2.1	00:16	1	2
A2.2	00:47	2	0
A2.3	01:12	1	2

ID2

Task	Duration (mm:ss)	Number of occurrences	Accomplishment (*)
A1.1	00:27	1	2
A1.2	00:15	0	2
A1.3	00:02	0	2
A1.4	00:24	1	2
A1.5	00:10	0	2
A1.6	00:05	0	2
A2.1	00:29	0	2
A2.2	00:09	1	0
A2.3	02:43	5	2

ID3

Task	Duration (mm:ss)	Number of occurrences	Accomplishment (*)
A1.1	00:13	0	2
A1.2	00:23	1	2
A1.3	00:09	0	2
A1.4	02:18	9	2
A1.5	00:03	0	2
A1.6	00:45	6	2
A2.1	00:13	0	2
A2.2	00:11	1	0
A2.3	02:20	7	2

ID4

Task	Duration (mm:ss)	Number of occurrences	Accomplishment (*)
A1.1	00:24	0	2
A1.2	00:14	0	2
A1.3	00:05	0	2
A1.4	02:35	6	1
A1.5	00:09	0	2
A1.6	00:03	0	2
A2.1	00:32	1	2
A2.2	00:08	1	1
A2.3	02:40	2	2

ID5

Task	Duration (mm:ss)	Number of occurrences	Accomplishment (*)
A1.1	00:16	0	2
A1.2	00:29	0	2
A1.3	00:02	0	2
A1.4	01:00	1	2
A1.5	00:18	0	2
A1.6	00:03	0	2
A2.1	00:55	3	2
A2.2	00:20	3	0
A2.3	02:42	9	2

ID6

Task	Duration (mm:ss)	Number of occurrences	Accomplishment (*)
A1.1	00:25	0	2
A1.2	00:45	4	2
A1.3	00:02	0	2
A1.4	00:30	1	2
A1.5	00:45	6	2
A1.6	00:05	0	2
A2.1	00:04	0	2
A2.2	00:25	4	2
A2.3	02:43	7	1

ID7

Task	Duration (mm:ss)	Number of occurrences	Accomplishment (*)
A1.1	00:21	0	2
A1.2	00:21	2	2
A1.3	00:04	0	2
A1.4	00:43	2	2
A1.5	00:17	0	2
A1.6	00:04	0	2
A2.1	00:07	0	2
A2.2	00:10	1	0
A2.3	02:18	3	2

ID8

Task	Duration (mm:ss)	Number of occurrences	Accomplishment (*)
A1.1	00:17	0	2
A1.2	00:29	2	2
A1.3	00:03	0	2
A1.4	00:14	0	2
A1.5	00:11	1	2
A1.6	00:02	0	2
A2.1	00:10	0	2
A2.2	00:15	1	0
A2.3	01:59	2	1

ID9

Task	Duration (mm:ss)	Number of occurrences	Accomplishment (*)
A1.1	00:25	1	2
A1.2	00:12	0	2
A1.3	00:06	0	2
A1.4	00:45	2	1
A1.5	00:21	0	2
A1.6	00:08	0	2
A2.1	00:13	0	2
A2.2	02:23	6	2
A2.3	04:00	8	2

ID10

Task	Duration (mm:ss)	Number of occurrences	Accomplishment (*)
A1.1	00:16	1	2
A1.2	01:08	5	2
A1.3	00:02	0	2
A1.4	00:23	2	1
A1.5	00:03	0	2
A1.6	00:02	0	2
A2.1	00:06	0	2
A2.2	00:08	1	2
A2.3	01:52	3	2

Appendix M. Negative and positive aspects mentioned by the participants

NEGATIVE ASPECTS	POSITIVE ASPECTS
Some tabs are not very intuitive	Easy to learn
Too much information appears on the beginning making it difficult to use without external help	Possibility to store data from multiple users
Missing categorization of users, such as alphabetical or per classes	Possibility to do long-term planning
Can be difficult to be used by older people or with limitations	Controlling physical activity and its evolution
Should allow using it by big groups	Easy registration to later use
To be used in digital support only	Easy to use (mentioned by 3 participants)
Vulnerable to technical failures	Highly intuitive (mentioned by 2 participants)
Difficult with big groups	Excellent assessment tool
Does not consider pathologies and precedents	Another training tool
Should consider how the person feels on the day of the activity	Enables working effectively physical capacities
	Innovation and entertainment
	Fast visualization of results
	Easy of use
	Motivating and intuitive
	Different and innovative
	Dynamic and very practical
	It is a good idea for the senior population because it stimulates body and mind
	Valuable for seniors in nursing homes and day centers
	Saves time
	Ease of use
	Better control of each user
	Enables personalized work
	Interaction with multiple data
	Allow specific cases with users
	Management of multiple users
	Management and storing training plans
	Adaptation of the training plans according to assessment results