A Community Based Activity Center to Promote Social Engagement and Counteract Decline of Elders Living Independently*

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Abstract. Global ageing of the population is deeply affecting the everyday lives of the frailest, by exposing them to increasing isolation and loneliness that, in turn, can cause or accelerate cognitive decline. The use of digital technologies and, in particular, social networks can be an effective tool to mitigate this phenomenon, by helping older age people to stay connected and be stimulated in the cognitive and physical sphere. In this work, we present a platform called Community-Based Activity Center (CBAC) a central tool developed within the scope of the European project Movecare, an effort to leverage intelligent Ambient-Assisted Living technologies to promote active well-being for the elderly. CBAC conveys cross-domain stimulation in the cognitive, physical, and social scopes by providing a virtual community where different types of activities can be carried out alone or together with caregivers, members of the family, friends, and peers. We followed a modular approach, developing a flexible platform that be integrated with AI-based recommendations and that allows for transparent monitoring. The effectiveness of our platform has been extensively tested in a preliminary usability test and in a pilot experimental campaign that involved 25 selected seniors on a time span of 10 weeks.

Keywords: community based activity center · AAL · active ageing · ICT for ageing

1 Introduction

Modern societies are rapidly ageing, and this is leading to changes and consequences in both healthcare and society at large [1], due to the constantly increasing proportion of elder population [2]. Moreover, because of looser family bonds, elders are left living alone more often than it has happened in the past [3]. As a result, this is leading to an increase in the number of *frail people* [4], who are people at risk of abrupt decline in health and function. Therefore, counteracting physical and cognitive decline is becoming one of the top priorities of Health and Social providers, such that the longer life that we are currently enjoying, can go hand in hand with a good life.

Three areas of intervention can be identified. They are monitoring (to early detect decline and to detect hazards and critical events), assistance (to let elders be at ease in their own houses), and stimulation (to promote an active lifestyle and counteract social isolation). In particular, *social isolation* is a key risk factor, as it is shown to be linked to a decrease in physical activity, depression, and, ultimately, to physical and cognitive decline [5,6]. Indeed, elders who have an extensive network of friends are shown to live longer and with a positive outcome in their life quality [7]. The recent pandemic, and the consequent change in the lifestyle, has substantially increased the risks connected to such factors [8].

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In recent years, ICT, with the development of social communities, has been proven particularly successful in providing tools to connect together people with shared needs by developing networks of social support [9,10,11]. Virtual communities can create social support that positively affects stress levels and, in turn, improve the physical and psychological states [12]. Social networks and virtual communities increase social support by connecting together people who share a common condition, such as fighting a similar disease [13], allowing such people to find both emotional and informative support by sharing their experience and receiving feedback from people similar to them [14]. Within these frameworks, different forms of communication emerge [15]: on one side sharing past experiences allows users to identify with other members of the community and to be part of a group [16]. On the other side, this form of communication allows the creation of interpersonal bonds with other members [16]. The trend of using social networks for such a purpose emerged particularly across homogeneous groups of people [17], as young people and adolescents, who were already active users of social networks and for whom was easy to form clusters of social communities related to social support and information sharing about a common condition by using technologies that they already know.

Although beneficial, the development of social communities tailored to elders' needs is difficult, since elders are often not comfortable in learning new functionalities and technologies [18]. Several works investigated the opportunity to facilitate elders in using existing social networks and communication tools (like Skype or Facebook). As an example, the work of [19] shows how the use of ICT-based social intervention based on Skype increased the number of social contacts and total communication time. Interestingly, a follow-up of such work allowed to discover that variation in the time spent in socializing through ICT is a valid indicator to unobtrusively detect mild cognitive impairment (MCI)[20]. However, these approaches suffer from a major limitation, namely that elders often do not find interesting social networks as a method of communication [21] per se and they do not find a motivation to engage in such online social network [22].

An alternative approach tries to improve motivation by developing new social communities around the elders' needs, similarly to what we propose in this work. In this approach the social community is designed and developed around activities and functionalities designed specifically to engage users and to stimulate them, thus leveraging on such motivation to foster socialization. As an example, the work of [23,24] shows how the development of digital activities specifically targeted to elders (as a digital card game) can be effectively used for such a purpose. The technology barrier is lowered by developing a simple and intuitive interface for a tablet and television. However, the framework proposed in these works is based on single activities, it was tested in controlled environments and in a preliminary controlled deployment. Moreover, no monitoring data are derived.

Another common limitation is that most approaches are aimed only to improve one of the three aforementioned target areas (monitoring, assistance, and stimulation) at once. Only a few of them offered a wider perspective on how to really improve later life quality by jointly addressing them [18]. However, these approaches are often limited as they are more designed as a social network to connect elders with their relatives while also sharing health-related monitoring data[25]. In this paper, we aim to tackle these limitations.

We propose an ICT framework to promote social engagement and an active lifestyle to pre-frail elders living alone. This is achieved through a Community Based Activity Center (CBAC), a social engagement platform based on virtual rooms that provide a set of diverse physical or cognitive *activities* with the underlying goal of fostering socialization. Through the CBAC, the elder interacts with a virtual community of users directly from home and carries out social activities with the support of audio-video communication. At the same time, activities provide valuable quantitative monitoring data.

The platform was tested for a period of three-months on 11 elders living in Milan (Italy) and 14 living in Badajoz (Spain). All elders were living alone and were independent. The evaluation shows how, overall, people found the system easy to use, they felt confident and they would have liked to keep the system also after the pilot; moreover, the proposed platform allowed the user to develop new social connections, whom several of them maintained also after the end of the study.

This paper is an extended and revised version of the contribution presented at [26], which presented a preliminary version of the proposed framework. The proposed framework is integrated within a broader project, MoveCare [27,28], that had the goal to integrate several ICT components (as a service robot, smart objects, and an IoT network) to provide a heterogeneous, modular, and integrated AAL platform.

2 A Community Based Activity Center

The design of an effective Community Based activity center has to start from elders' needs. And we did follow this tenet [29]. Elders were actively involved in the development of the platform along with caregivers to suggest activities and scenarios; these were then prioritized according to their impact and implementation feasibility.

The final set of activities implemented comprehends several social games: Puzzle, Words, Draw & Guess (a drawing game), two card games (named Scopa and Briscola), and a set of physical activities. The choice of the particular card games was motivated by their diffusion in the south of Europe, where our system was evaluated. We have also developed gentle exercises to train body mobility and strength and an application to promote outdoor activities with peers.

Activities are the building blocks of the CBAC. Each activity has been designed following two desiderata, a) the activity should be engaging so that users are motivated in using the platform, and b) the tasks performed by the user during the activities should be useful to themselves by providing proper physical and cognitive stimulation. They were conceived to encourage socialization and are performed jointly by more than one user.

To this aim, the concept of **virtual room** has been introduced. In a virtual room, players can talk to each other while participating in the same activity, similarly to what would happen if they were all inside the same physical room, around a table. To achieve this, the interface of the activities has been conceived as split into two parts (See Figure 1). The left side of the interface contains the **activity board**, where the activity takes place. (e.g., card deck, drawing board, a trainer for the exercise). Its content is synchronized in real-time for the different users who see at the same time the same content.

The right side of the interface contains the **social panel** that allows all the attendees to participate in the activity session and to communicate with each other using both audio and video. We limited the number of players participating together to the same virtual room to four so that each user can easily understand and communicate with all the others without the need of silencing their microphone or experiencing communication issues. The two modules are activated concurrently inside the same window. From the technological point of view, the activity board and the social panel are two modular web pages combined into a single one by means of HTML iframes (Figure 1 depicts the obtained page) that is visualized as a single WEB page. The activity board exchanges commands and data with its activity server through a WebSocket connection. On the other side, the social panel provides real-time audio-video communication through a peer-to-peer network using a protocol based on the WebRTC standard. In particular, the social panel has been developed exploiting the EasyRTC[5] open-source toolkit.

[5] `https://easyrtc.com/`

Fig. 1: Activities interface is split into two parts: an activity board on the left and a social panel on the right. In this particular case, the activity is constituted of a Scopa card-game match

This graphical design was the result of progressive refinement through two pre-pilot testing rounds which involved 16 end-users (see Section 3.1). The CBAC does not provide only stimulation through activities, but it offers also monitoring capabilities. The CBAC collects both system usage statistics and the actions of the players that are evaluated and scored. These data could be used to infer a possible decline in cognitive and physical state. Its design is highly modular: each activity has its own activity server and clients that share the same communication mechanism, authentication mechanism, and interfaces. This makes it very easy to add new activities.

2.1 The CBAC Architecture

The CBAC has been designed according to a modular paradigm in which different applications, each responsible for a specific functionality, are designed and work together according to the controller model defined. Each functionality is implemented as a standalone application, which is part of a shared network that constitutes the backbone of the CBAC. To allow using the platform on different devices, the software has been developed as a web application using the SaaS (Software As A Service) model. It is largely based on Open standards (e.g. WebRTC for video-communication). The platform is configured as a classical client-server application of Web-applications, where the view of an activity is provided on the **client side** while the data model and the controller logic are deployed on the **server side**, following the Model View Controller architectural Paradigm (MVC), as illustrated in Figure 2.

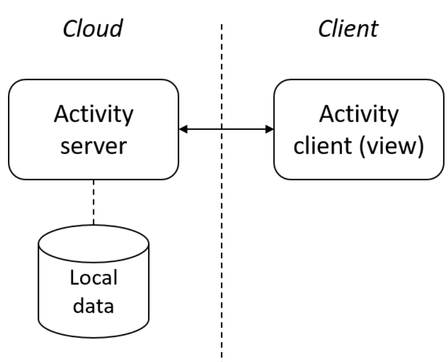


Fig. 2: The software achitecture of the CBAC server. Activities are constituted of an Activity Server and its client.

The entire platform software architecture is designed as federated architecture where activities can be independently deployed on the platform at any time. Substantially, an activity is designed as a real-time web application that provides on its front-end and interactive Graphical User Interface (GUI) for users to do things like playing a game, being guided during workouts, and socializing. Activities are devised as independent units, they contain arbitrary business logic enveloped in a container that must comply with specific interfacing requirements so that the platform can handle their instantiation and support interoperability as well as data-exchange functionalities.

The client and the server communicate either through HTTPS requests/responses and by keeping a constant communication channel among them by using encrypted WebSockets. Websockets are also used to stream users' activity to the servers, who are responsible for storing usage data for monitoring purposes. The video communication is based on WebRTC[6] W3C standard, as it is supported by most popular browsers, and it supports multi-party real-time, synchronous, audio-video communication and data transmission.

2.2 The Client Side

The architecture above allows providing the user with simple and effective interfaces and interfacing modalities.

From the user's point of view, the CBAC appears as a single web application that can be accessed with any device that supports a web browser such as Google Chrome (Fig. 5). The client presents to the user the current view of an activity that is synchronized with the view of all other users who are carrying out that same activity. It has been realized as a standard web page served by the activity server. Such pages are configured according to the user state and device used. They have been realized through the Bootstrap framework[7], based on a graphical layout defined through style sheets (CSS). Modifications to the Document Object Model (DOM) implementing the logic activity, which ensures a dynamical behaviour, is implemented through client-side JavaScript. Each client traps user actions (e.g. dragging an icon, tapping, and so forth) and transmits this event to the server that, in turn, modifies the activity board accordingly for all users, by using WebSockets as a communication mechanism. At the same time, JavaScript is used to log user activities and to transfer such data (through WebSockets) to the dedicated server for monitoring and analysis.

Interfaces are both responsive to the device used and to the user needs; moreover, DOM elements can be rearranged by the Artificial Intelligence (Section 2.3) according to elders' preferences. Card games have been implemented starting from an open-source available library specific for cards[8].

The CBAC has been embedded as an Android application. It has been released on Google Play Store (private link). This allows easy installation and maintenance to all clients: any time a new release is uploaded to the store, it is automatically downloaded to all clients (automatic updates).

2.3 The Server Side

The CBAC system logic and data management is resident on the server side, that is hosted in the cloud platform.

[6] `https://webrtc.org/`
[7] `https://getbootstrap.com/`
[8] `https://github.com/deck-of-cards/deck-of-cards`

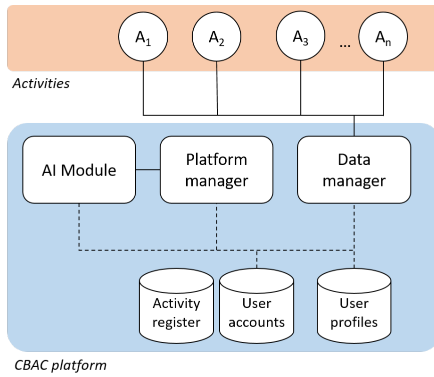


Fig. 3: The platform architecture

Figure 3, depicts the general architecture formed by *activity units* (denoted as A_1, A_2, ..., A_n) and the CBAC platform that includes an application and a data layer. The application layer is composed of three modules that concur in gluing together a system that is more than the sum of its single parts. Indeed, the system is not merely composed of a list of independent activities but provides a number of user-centric cross features like providing access by means of user accounts, gathering data, and maintaining profiles to be used for suggestions and reminders, enabling socialization by allowing users to see who is online at the moment and to send them an invite to join an activity. In the following, we provide a short technical description of each module on the platform, by briefly discussing the services it provides.

Activity units Activities are implemented as independent **Activity units**. Each activity unit corresponds to a web application implemented according to a classical Model-View-Controller paradigm (see Figure 2), as described in Section 2.1.

The activity server is the component responsible for providing the activity business logic as well as serving the view that allows the user to perform the activity from his client. The server also interacts with the aforementioned platform components, advertising its presence and entry point, as well as interacting with the data manager to collect data that users generated by doing the activity. Being implemented as web applications, activities provide a versatile client view that can be tailored for different types of user devices.

The main technologies adopted for the development of the whole platform and activity units are based on NodeJS and MongoDB.

The platform manager The platform manager is the central actor covering the role of the orchestrator by keeping track of the activities deployed at the moment and ruling the users' accesses. It provides the following basic services.

Activity management Each time an activity module is loaded on the platform and starts, it announces itself to the platform manager who, from that moment on, keeps track of its status and maintains an updated list of available activities inside a DB called *activity register*. The activity register acts as a sort of "white-pages" service for activities and allows for smooth management of start/stop events for the activity units. If, for example, an activity stops due to a problem or is taken down for maintenance, the platform manager will update the activity register accordingly and will no longer present that activity in the user's choice menus. This service is achieved by means of HTTP REST internal APIs that allow activities to advertise their status to the platform manager, and the manager to query their status periodically.

Accounts and accesses User accesses to the platform must be granted in a centralized way. This is required for allowing users to provide their access credentials only once at the entry point, without having to re-post them each time they access a specific activity. For this reason, the platform manager acts as an authentication authority. A public web page is provided as the main entry point for the user. From such a web page, the user can register a new account on the platform and/or login into it. During account creation, the users are requested to provide, besides a username and a password to access the system, some personal information and some basic preferences over types of activities they might enjoy. These data will form the users' account containing theirs access credentials, personal data, and a profile (given by preferences collected during the registration phase) to be subsequently integrated and refined with usage data. The system login is performed by inserting the user name and password in the form provided by the entry page. Upon credentials validation, the platform manager creates a session for the user and releases a token to the client. Such a token shall be used by the client to access the activities without re-posting the credentials so that the user can be tracked and recognized in each activity.

Presence and messages Once users are logged into the system, they can choose an activity from the list of available ones and, upon selection, the user's client is redirected to the corresponding activity unit where the related web application is served. From the login moment on, the platform manager keeps track of the user presence on the system by assigning it a status:

- on-line and available: the user is logged into the system and has not initiated an activity yet;
- on-line and not available: the user is logged into the system and is conducting some specific activity;
- off-line: the user is not logged into the system at the moment.

By keeping track of user presence, the platform manager can maintain a list of online users. This list is key for enabling social interactions between users and multi-player activities. Moreover, the list of online users is also exploited by a message delivery system that the platform manager coordinates. User-to-user messages (for example, invitations for joining an activity) or system-to-user notifications (for example, reminders to play an activity) can be forwarded. Each message is qualified by a priority while a delivery policy establishes rules for deciding how messages should be displayed under a given level of priority and user presence status. For example, high priority messages can override the non-availability of on-line users, temporarily preempting an activity. Low priority messages, instead, will be placed in a queue and shown to the user as soon as he becomes available. Both presence tracking and message delivery are based on the WebSocket application protocol.

Administration The platform manager also features an administration dashboard to provide monitoring and situation-awareness of the system. From such a panel, administrators can inspect the list of registered users and moderate accounts (enabling or disabling them). Also, a data visualization functionality provides a live interface where usage stats concerning activities and users can be analyzed.

The data manager The data manager is the component responsible for collecting and maintaining the usage data generated by user activity. The bulk of data coming from a user defines his profile. During the execution of an activity and after its completion, usage and performance data will be pushed to the data manager that will store them inside a DB. The data manager also provides an access interface to the data to the other components of the platform. Some advanced functionalities have been developed to extract from such data performance indicators and statistics describing the users' behavior.

The AI module The AI module runs a reasoner that combines a set of pre-defined rules with the user profiles maintained by the data manager. By reasoning over those two sources of information, it generates recommendations tailored to each specific user. See Section 2.7 and [30] for further details.

2.4 The User Side

Our platform can be accessed through a multimodal interface through a *tablet*, a *TV set-top box*, or a *laptop* allowing technological equivalence - i.e., the possibility to deploy the platform on multiple (and simultaneous) devices adapting it to the user's behaviour and preferences. In this way, the users can choose to use the platform with the device they prefer.

(a) (b)

Fig. 4: On the left the Tablet setup with the support and the pen. On the right the TV set-top box setup: notice the webcam on the top of the TV screen.

The main device to access the CBAC is the tablet (Figure 4a). In particular, for the tablet setup, we have chosen a Samsung Galaxy Tab A (Model 10.1, Wi-Fi, 32GB) for its large screen size. It communicates with the Activity server through a WiFi connection. In our pre-pilot studies, the users reported that they were not comfortable in using the tablet flat on a table and that they felt that the tablet was too heavy to be held in one hand for several minutes, as it happens when the tablet is used. Consequently, following users' suggestions, we complemented the tablet with some accessories: a stand, a case, and a capacitive pen.

The second set-up is based on the home TV using a TV set-top box, a home station that provides a TV-based access through the main television of the user (Figure 4b). In this setting, the CBAC is controlled with a remote wireless mouse (air mouse), similar to a remote controller. The TV set-top box is composed of a mobile computer connected to the television, a webcam placed on top of the television, and a remote controller. The TV is connected through its HMDI port to a NUC Intel® Core™ i5-7260U minicomputer with Windows 10 in kiosk mode. A webcam is placed on top of the TV (Logitech C270 HD) for monitoring users when using the CBAC. This computational power and setting can easily be found inside Smart TV in the next future.

Besides this, we allow users to access the CBAC through a web application accessible from any computer equipped with a webcam. In this way, users who prefer to have a physical keyboard instead of a touch interface (as with the tablet) can use the platform.

The display of the three types of devices is characterized by different screen sizes and resolutions. Therefore to provide the same view of the interface on the different devices, the interface has been fully parameterized such that all interface elements can be scaled and positioned in the same relative position.

Besides providing the activities, the client can also receive notifications from other users even when the client is in stand-by mode.

2.5 Activities

The CBAC main interface is a personalized dashboard (Figure 5) that is presented to the users each time they enter the platform. It shows some custom details for the users (for example, their avatar image, and a personalized welcome message) and showcases a set of buttons to start an activity.

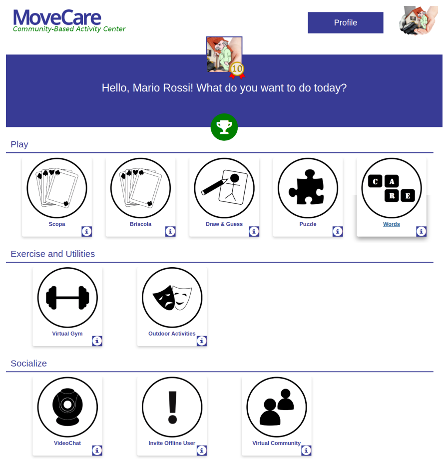


Fig. 5: The CBAC Home Page.

Such a user interface has been designed considering elders as the primary target users. For this reason, it favors a minimal and regular organization of homogeneous buttons, each representing one particular activity that can be carried out in the CBAC. A limited color palette characterized by high contrast was chosen to obtain a neat display style and the number of buttons for side functionalities (like the profile and contact request) have been kept at the minimum to focus the interaction and to maximize the familiarization with the interface. The buttons on the dashboard are organized into three different groups, namely Play, Exercise and Utilities, and Socialize.

The main interface also features a dynamic behavior both in terms of graphical style and content organization. Specifically, to handle the difference between the various devices on which the interface could be displayed, the CBAC dashboard is dynamically reorganized: the size and position of the buttons are automatically rearranged depending on screen size and resolution. This behavior is obtained by exploiting the grid system of the Bootstrap framework used to develop the dashboard page. This provides different and modular grid classes that are associated to the type of device on which the GUI is currently displayed (e.g., tablet, TV set-top box, laptop).

Moreover, the CBAC's dashboard has been designed to accommodate dynamic content organization. For example, a particular activity can be promoted or one or more peers can be suggested as partners for an activity. When one of such directives is received, the CBAC rearranges the interface layout following the intent of the directive: the button of the suggested activity is shifted leftwards from the others and highlighted. Similarly, suggested peers can be put in the first spot of the user list suggested for that activity.

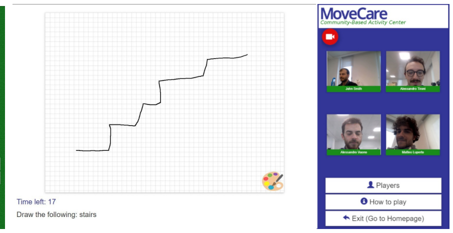
The CBAC dynamic behaviour also extends to the language spoken by the interface using a flexible internationalization functionality. Labels and messages provided by the interface are parametrized by a global variable indicating the current language. Each time a label or a message has to be displayed, the system automatically fetches the translation corresponding to the language indicated in such a parameter.

From this main window, all the activities can be accessed: by clicking on the associated button, the activity window is opened (Figure 5).

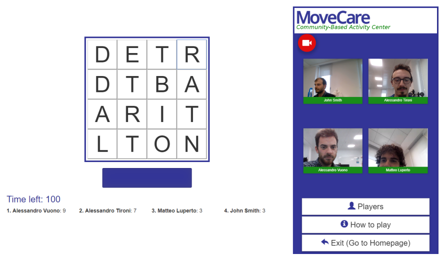
The first line of the home interface contains games that can provide cognitively stimulating activities: a drawing game called Draw& Guess, Words, Puzzle and two cards games popular in South Europe, Scopa and Briscola (Escoba and Brisca in Spanish).

The **card** games can be played by two or four players simultaneously, according to the rules of each game, and they unfold in a sequence of matches within which players take turns. In each match, the allowed moves and the assigned scores are handled by the specific rules and mechanics of the game. An interactive card deck allows the user to drag and drop and rearrange cards on a virtual table resembling the movements that players would undertake with real cards, as can be seen in Figure 6a. As both card games exist with

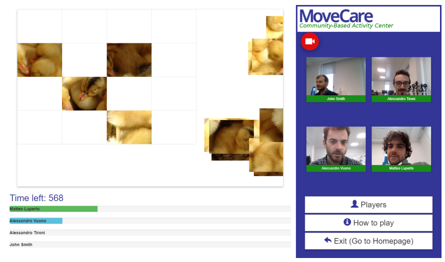
(a) Card Game.



(b) Draw & Guess.



(c) Words.



(d) Puzzle.

Fig. 6: An overview gaming the activities of the CBAC.

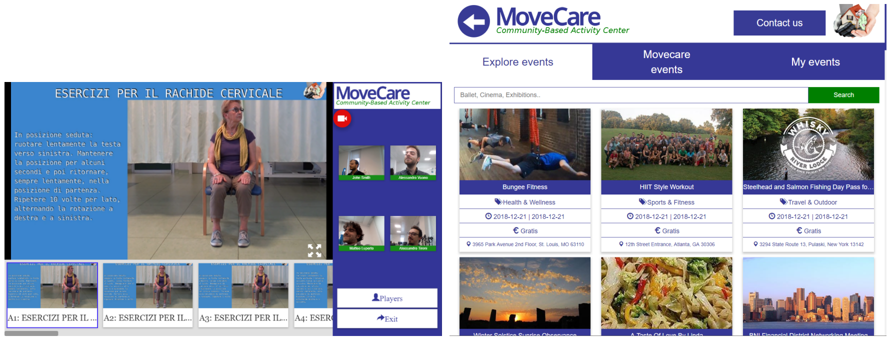
different regional variants, so that those games are played with different rules in the two regions of Europe where this platform was tested, we implemented two slightly different versions of both card games (Scopa and Briscola for Italy, and Escoba and Brisca for Spain, respectively).

Draw and Guess is a turn-based drawing game inspired by the table game Pictionary. At each turn, one player has to draw on an interactive white-board a subject suggested by the game, as can be seen in Figure 6b. Other players have to guess the subject by typing its name on a virtual keyboard. Scores are assigned proportionally to the number of corrected guesses a user managed to make.

In the other two games, called them **Words** and **Puzzle**, players do not follow a turn-based sequence of moves. Instead of turns, each player is presented with a game board to solve at the same time. The first game, Words, is inspired by the table game Boggle, while the second game is a puzzle game. In the case of Words, the board is a 4×4 matrix of letters where players must identify meaningful words by drawing sequences connecting adjacent cells. In the case of Puzzle, each player has to reconstruct a picture by properly positioning a set of shuffled square tiles on a grid. Each time players perform a correct move (forming a proper word in Words or placing a tile in the right spot in Puzzle) their score is increased. The objective in Words is to find as many words as possible while Puzzle requires solving it as fast as possible (a maximum timeout is imposed at the expiration of which the game ends). Actions are performed by drag and drop of items on the activity board (by selecting multiple letters in Words or by dragging tiles onto a grid in Puzzle). To boost competition during the games, each user can see the current score accrued by others in real-time. Figures 6c and 6d show example screenshots from these activities.

In the second line of the interface, activities that have a prevalent physical stimulation are reported. These activities combine physical and social stimulation: a Virtual Gym where to participate in gentle exercising sessions and a set of Outdoor Activities.

The **Virtual Gym** provides a set virtual rooms where users can follow together home-fitness sessions of gentle workouts. Figure 7a shows the activity's interface. Videos are kept synchronized between all the participants. An explanatory text is shown on the left side by side with the footage of a trainer guiding the workout. In this way, all users can do the exercises altogether. During the training session users can see each other in the social board, just like it happened in the games described above. Workouts are grouped into four different channels, each one containing a different set of exercises divided by type (e.g., exercises



(a) Gentle Exercises. (b) Outdoor Activities.

Fig. 7: An overview the physical activities of the CBAC.

for the upper or lower limbs). During a session, users follow a predefined order as indicated by the domain experts who participated into the development of this activity and in the choice of the exercises. Videos were acquired with an actor performing the exercises and mounted together with a voice explaining the exercise and an explanatory text on the side. We rely on Youtube for hosting videos, while the streaming and synchronization among all users is embedded by our application by using Youtube APIs and websockets.

The second one, called **Outdoor Activities**, provides access to a geolocalized catalog of public events scheduled in the local area (see Figure 7b). By accessing this activity, the user can read the description of the events, localize them on the map, and add them to a personal list of favorites. Participation in events can be advertised to the other members of the platform by means of a shared list. Users can also propose and agree on meeting points on the map to organize a rendezvous for attending a particular event. This activity encourages users to get out of their house and participate in social gatherings. Here, the social interaction carried out on the platform is not performed in real-time: participation in events is shared and advertised in an asynchronous way so that the users are supported in organizing real meetings to be enjoyed in the real world.

The last activity, **Video Chat**, is primarily focused on social interactions. It is a simple video-call application where users can spend time doing conversations together. A set of public rooms is always available for users to enter and exit at any time. Alternatively, users can invite people that are on-line on the platform and form private rooms with them.

Being the CBAC a social platform, a key functionality is the **invitation mechanism** through which each user can invite peers to join an activity. To this aim, the user can choose first an activity and then the users, or choose one or more users and then the activity. We rank users by putting first users with whom an activity was carried out recently. Offline users receive a notification that prompts them to answer the request.

2.6 Data logged by the platform

Besides providing the user with activities, the CBAC performs constant and transparent monitoring: events related to user activities are logged by the Data Collector and processed to derive **indicators** aimed to assess the cognitive/physical skills that the user is employing to play that particular physical or cognitive activity.

The Activity Server logs all the events (e.g., a card moved) and raw data (e.g., a sequence of position/velocity touch events on the tablet interface) of every single move in a game. At the end of each activity, such data are transformed into features that belong to two classes: **high-level features** that do not depend on the particular logic of the activity and **low-level** features that are activity-dependent.

High-level features include general usage statistics and apply to all activities: the *time of access* to a specific activity (a timestamp), the *duration* of the playing session, the peers (in case of multi-player activities) with whom the activity has been performed, and, for competitive games, the *score*. Clearly, this last indicator is present only for those activities where the concept of performance can be properly defined.

Low-level features are indicators whose meaning can only be interpreted within the scope of the particular activity they refer to. To provide a concrete example of low-level features, we provide here the list of those we computed from the raw logs of the cards game Scopa where each match of every single user was considered. Such low level features can be subdivided into **time indicators** and **performance indicators**.

Turn duration (T) is the total time taken by the user to complete a turn, from the moment the turn is assigned to when the action is performed.

The *Time to Action* (TTA) is the total time between the moment the turn is assigned and the moment the user "touches" any card on the deck; such a touch event can be interpreted as the beginning of the execution of a move. During this interval, the player is not physically interacting with the game board and it can be hypothesized that they are reasoning about the current state of the deck and about which card should they play. From those, we compute the *Plan-Act ratio*: the ratio between TTA and T.

Performance indicators describe how good to win the game is the action played. These indicators are related to the player's cognitive strength, by rewarding moves that yield strategic advantages and penalize those that advantage the opponents. For instance, in the word game performance indicators are the number of words identified and the score, in the drawing game the number of guesses, and so forth.

For card games that require a strategy to decide the play, performance indicators are based on *Action efficiency*: for each game board that the user faced during the match, we consider all the possible actions among which he had to undertake a selection and we rank them according to the immediate reward (in terms of score obtained) they would get in the current board; the action efficiency is then defined as the ratio between the reward obtained by the selected action and the reward of the best action. For each action played during the game, its efficiency is defined as the ratio between the score provided by that action and the score of the optimal action that the player could have selected. Computing the optimal action can be computationally expensive, since it requires, in principle, to search among an exponential space of possible game realizations. To ease this task, we compute the optimal action by solving a local *maxmin* problem where the solution is the action that would minimize the highest score of the opponent's next move under the assumption that this last one knows of all the cards that have not been played yet (worst-case assumption).

Low-level features like these can be used to perform a deep and detailed analysis of some performance trends that the user might have achieved in a particular activity. These indicators can be exploited to identify patterns of play or eventually they can be correlated with other validated measures like, for example, clinical cognitive assessments. However, due to their specificity, low-level features can hardly be adopted to improve the user experience at the general platform level. This task will be achieved by exploiting high-level features inside a key functionality provided by the platform: *intelligent recommendations*.

2.7 Recommendations

The CBAC Platform Manager and the AI module produce *Recommendations* to the users. Suggestions can be implemented as direct *reminders* and/or more indirect *interface adaptations* [30,31]. Recommendations represent the main approach of leveraging the data collected on the platform. Recommendations are computed after analyzing the user profile incrementally built from data and maintaining user-specific rankings over elements from two different domains: activities and users. For each user, elements are ranked by suggestion priority. Suggesting an activity means encouraging the user to play it. Similarly, suggesting a peer means encouraging the user to play together with him.

Fig. 8: A suggested activity.

Reminders take the form of system-to-user notifications. For instance, the user can be remembered activities that were not carried out for a long time or new activities introduced in the platform

Interface adaptations apply an advertisement-like approach to the preference ranking over activities and users by changing the order in which these are displayed on the choice menus. Online users that have a high rank will be shown on top of their corresponding selection lists. Similarly, the activity buttons on the home page will be sorted according to their rank and the one that classifies first will be highlighted with a ribbon (see an example in Figure 8).

The activity rank is used also to dynamically rearrange the buttons of the main CBAC interface and the one that classifies first will be highlighted with a ribbon.

2.8 Additional CBAC functionalities

The CBAC provides additional functionalities that go beyond the aim of this paper

One additional functionality that we included in our platform is a suite of single-player *exergames* designed following the principles discussed in [32]. They are specifically tailored to exercise postural control with the aim of counteracting physical decline and can be tuned according to the user's current state thus providing a proper challenge level. Exergames are played by using a balance board positioned in front of the TV with the TV set-top box setup (see Figure 4b) and require the user to control a virtual avatar/tool by moving his center of balance [33]. These need to be achieved by lateral or front-rear and left-right weight shifts performed while standing on the balance board (the exergames are called *Fruit Catcher*,*Bubbles*, *Hay Collect*), by sit-stand movements using a balance board and a chair (*Horse Runner*).

Finally, the CBAC is also used as a monitoring device, serving as a proxy for a set of digital cognitive tests we proposed in [34,35]. These tests can be scheduled by a clinician who, after their completion, can access their quantitative results.

3 Experimental Evaluation

The CBAC is part of a larger system that comprehends also a service robot, smart objects and an IoT subnetwork that was developed inside the H2020 MoveCare[9] project [27,28]. This had the goal to develop, integrate, and test a heterogeneous, modular, and integrated platform for the assistance of elders living independently and alone. We here describe in more detail the results of the CBAC. The CBAC has been tested in two pre-pilot rounds and a final pilot, which was also subdivided into two rounds.

[9] `http://www.movecare-project.eu/`

3.1 Pre-Pilot

Two preliminary experimental campaigns on sixteen independently living elders, eight for each round, have been carried out. The first round (1R) was conducted in May 2018; the second round (2R) in November 2018. During the two phases, we improved the system by implementing suggestions received at 1R, and by increasing the number of activities available to the users. Each pilot round, where the participants tested the CBAC, lasted three weeks.

During the first round only the first three activities implemented were used by the elderly, namely: Draw & Guess, Scopa, and Video-Chat. In the second round, the remaining activities were added to the initial three activities (which were improved following suggestions by users at the end of 1R). Moreover, the stand and the tablet pen were also provided.

In these two rounds of pre-pilot elders were tightly followed by two researchers: a computer scientist who participated in the implementation of the activities and a researcher in social sciences with previous research experience with elderly users. They explained in detail each activity and trained the elder to play several matches with them. Moreover, they were available throughout the pre-pilot period to answer questions, support elders, and collect feedback.

In the first round, one Tablet was delivered to each participant; in the second round, in addition to the Tablet, a tablet stylus/pen and a tablet stand were provided too, to ease the use of the tablet touch interface. The setup of the system (connectivity to the router and user registration) was performed by the researchers. When delivering the technological devices, the second researcher administered to the users the Mini-Mental State Examination (MMSE) [36], in order to evaluate their cognitive abilities. At the end of this period, the second researcher returned to the home of each participant to collect answers to a structured questionnaire for each activity and to collect opinions and comments regarding the usability and enjoyment of the games and activities performed. Moreover, 6 months after the first round all the participants (1R) were contacted by telephone for the administration of a follow-up questionnaire. This study was approved by the Ethics Committee of the University of Milan on May 25, 2018. All participants signed informed consent, containing clear and standardized information on the objectives and procedures of the research.

Sampling The participants were recruited thanks to the help of ANTEAS (a local association in Milan) among older people aged 65 or older who lived in their home in the city of Milan and who had familiarity with one or more of the common technological devices, have a Wi-Fi internet at home, and were able to give their consent. First, we identified a set of 75 potential participants from which, according to their availability, 16 persons were then invited to take part in the study.

The first session of the study included 6 females (F) and 2 males (M). Their average age was 73.5 years (S.D: 4,47; Range: 66-80; Median: 74). The level of education of the participants was medium/high: 6 of them attended high school and 2 university. Regarding the housing situation, 5 lived with their partner, 2 with their own child, and 1 alone. Regarding their cognitive screening, the MMSE average score was 29.2/30 (S.D.: 0,83; Range: 28-30; Median: 29).

The second session of the study included 5 F and 3 M. Their average age was 75.1 years (S.D.: 3,72; Range: 71-82; Median: 74). The level of education of the participants was medium/high. Regarding the housing situation, 5 lived with their partner, 2 alone, and 1 with their own child. Their MMSE average score was 28,9/30 (S.D.: 0,83; Range: 27-30; Median: 29).

Data collection Structured questionnaires were used as data collection instruments for each game/activity of the CBAC. They were created ad hoc, starting from the System Usability Scale questionnaire, available in the literature [37], and for each questionnaire the content validation was made, according to [38]. For the content validity, which includes face validity, six experts were involved that evaluated the clarity (face validity) and relevance (content validity). Questions that did not met content validity were modified according to the indication provided by the experts' feedback. Questionnaires include single-choice closed questions (Likert scale from 1 = certainly no to 5 = certainly yes, plus the "not used" answer option), and open questions; the number of both types of questions changes on the basis of the game/activity. As users participating at 1R and to 2R experienced different setups of the system, data have been evaluated separately.

Data analysis A descriptive analysis of the data collected through the questionnaire was carried out. The results obtained through the open responses have been processed with methods of content analysis [39]. The results of the questionnaire were analyzed in order to gather information regarding the usability, clarity, and satisfaction of the CBAC. Moreover, we have investigated their level of confidence about the use of technology, as only two of them (1R) and one of them (2R) said they had a Tablet.

Overall, participants provided positive feedback regarding the proposed activities and the technology proposed to them. Users appreciated the tablet interface and the list of activities proposed, while also they enjoyed the social components embedded in each activity. However, despite this consideration, in 1R four users reported issues in understanding how to use the tablet touch interface and they felt some difficulties in performing some actions, like drawing, that they were used to do with a pen. For that reason, a tablet stylus/pen and a tablet stand were provided to the users.

From the answers to closed questions regarding the CBAC activities proposed to 1R, it emerged that overall the activities were perceived as simple, clear, and pleasing to the users. Interestingly, it emerged that Video Chat was used only by 5/8; a user that did not used the Video-Chat considered it as "superfluous" because during the two games there was a box in which to see and hear the other participants. From the answers to open questions emerged that the principal difficulty was the "use of the touch interface" and how to "moving the cards in the card game". Regarding the main positive aspects, it was signaled that users "like the video chat and (to) socialize while playing", while the negative aspects/critics concerned the "interruption of the video chat", that was due to internet issue related to the house set up.

In the 2R, more activities were made available to the user, who provided positive feedback similar to those reported in 1R. Activities were considered, overall, as simple, clear, and pleasing to the users. Six users (over 8) enjoyed the possibility to talk and Video-Chat while playing, indicating that this was a good method to "Feel in company" and to "Socialize (3/6)". Five users enjoyed also the possibility to turn on/off the video component of the chat to preserve privacy. However, the other three users reported that the possibility to turn-off/on the video chat while playing could be "unpleasant/rude" towards the other players. Overall, all users enjoyed the possibility to play with the tablet, while two users reported some issues in understanding the invitation mechanism used to start an activity.

The activity most appreciated in the Second round was Words. Words and Puzzle were the only games that were used by all participants, while no user used Video Chat; among all users, two participants considered it as "superfluous" as during the games there was the same possibility. The main positive aspect signaled was in the fact that the users liked to video chat while playing.

From the comparison between the two rounds (1R and 2R), it is possible to detect a homogeneity between the samples. Comparing the responses that emerged in the two rounds, the positive recurring aspect is in the fact that the users enjoyed the possibility to talk through a video chat while playing and, consequently to socialize. In 2R, compared to 1R, the main disagreement concerned the fact that no user has detected the difficulty in using the touch (reported, instead, from 50% in 1R). It is interesting to note that in the 2R a stylus and a tablet stand were provided.

A follow-up questionnaire administered to participants (1R) after 6 months from the experiment does not detect any significant variation in the use of technologies. However, this survey reported that 1 participant had remained in contact with two other participants (1R). The participant reported how he kept staying in touch periodically by phone and by occasional encounters in presence.

3.2 Final Pilot

In this Section, we present the main evaluation phase, where all the developed framework described in Section 2 was tested. The system was improved following the insights obtained through the preliminary assessment described in the previous section. This pilot study was performed in two rounds; half of the participants in the study were located in the city of Milan (Italy), while the other half of the participants were located in the city of Badajoz (Extremadura, Spain).

The CBAC was integrated within the Movecare platform and the data collected by the IoT platform was provided, along with the data collected from the CBAC, to the AI module. The Giraff robot provided some assistive functionalities to the user, as searching for lost objects inside the house or establishing a teleoperation session with a caregiver in case of an emergency. The AI module could ask the robot to perform a reminder, that was used to suggest the user to do an activity (as, for example, to interact with the other components of the whole system). See [30,40] for more details. Only half of the users were provided with the robot. During the two rounds, the system was installed inside the house of elders living independently and freely available for 10 weeks.

The entire system was set up and configured by researchers (computer scientists who participated in the implementation of the platform). Each user was provided with a tablet, a home TV set-top box kit (with a webcam). The TV set-top box kit was connected to the main television in the house, usually in the living room or in the kitchen. Besides this, as part of the project, a set of IoT sensors were placed in every room and at the door entrance to detect the presence and activities performed by the user in the house. However, data recorded by IoT sensors were not used by the CBAC.

During the setup phase, a researcher with experience with elders provided instructions on the use of the tablet and the home TV set-top box and showed to the user all functionalities and activities. As the system was complex and involved several components, the training phase was divided into two sessions, lasting one to two hours, for each user. If needed, the users could request further training sessions with the researchers. During the selection phase of the user, the same researcher administered to the users the MMSE [36], to evaluate their cognitive abilities.

As the team that was available for the system's setup was one, and as each setup required one day, the duration of the pilot was slightly different across different users.

At the end of each pilot round, the researchers returned to the home of each participant to collect the devices left on loan for use and, on the same occasion, interviewed the user by administering a structured questionnaire, created ad hoc and validated. The questionnaire, focusing on each component of the system, collected opinions and comments regarding the usability and enjoyment of the games and activities performed (the content validation of the questionnaires was the same of the pre-pilot). As the system was composed of multiple functionalities, the questionnaires used for evaluation were less detailed and specific if compared with those used for a preliminary assessment, as they were developed to evaluate the entire framework. Nevertheless, they allowed a thorough evaluation of the CBAC.

Sampling The elders enrolled in experiment were outside the frailty state. The participants have been chosen according to the following inclusion criteria

a) ≥ 65 years old;
b) living alone, receiving assistance in activity of daily living for no more than 1 h/day;
c) MMSE [36] ≥ 26;
d) maximum 1 or 2 points in Fried criteria [4] or robust people: 0 points in Fried criteria but with GDS (Geriatric Depression Scale) ≥ 9 or UCLA loneliness scale > 35 [41];
e) keen to use technology;
f) owning and using a smartphone;
g) Internet connection with at least 8 Mbps available at home.

Evaluation is performed by using standardized questionnaires administered to the user at the beginning and at the end of the participation to the pilot. Moreover, sensorial deficit (deafness, blindness) or motorial disability (paraplegia) that precludes the interaction with the system were considered as exclusion criteria.

A total of 25 different elders were recruited: 14 in Badajoz (Spain) and 11 in Milan (Italy). In Milan, 7 people were recruited among the local association of older volunteers and the patients afferent to the Day Hospital and the Ambulatory of the Geriatric Unit of Policlinico Cà Granda and 4 users among the residents of an Assisted Living (AL) facilities. The pilot was organized in two rounds of 15 elders each (first round September 2019-December 2019; second round: January 2020-March 2020). Five users of the first round (1R) decided to continue the experimentation in the second round (2R). During the study, only 1 participant from Spain dropped out during the pilot, because did not feel confident with the service robot included in the full system.

The two communities, in Italy and Spain, were separated (each participant could play games only with people in the same nation/community). The average age was 76.7 years (S.D:7.2; Range: 65-92; Median:

78.5). The participants in Italy were slightly older (average age 79.1 years) than the Spanish participants (average age 74.7 years). This is due to the fact that the users living in the AL facility were older than the other participants and lived in an independent apartment inside the facility (average age 84.8 years). Their MMSE average score was 28.75/30 (S.D:1.42; Range: 26-30; Median: 29). Users in the AL facility had a lower MMSE score (average of 27/30).

Participants were encouraged to promote the use of the CBAC among friends, caregivers, and members of their families, in order to increase their social network and the opportunities of play.

Data collection At the end of each pilot round, users were requested to evaluate their experience through the defined questionnaires. All the questionnaires analyzed here have been filled by the participants at the end of either the first round or the second round of the pilot, according to which one they have been part of. Participants who took part in both rounds filled the questionnaires at the end of the second round. Participants filled various questionnaires on the proposed system, its usability, and their satisfaction, the MoveCare components, the MoveCare high-level scenarios, and functionalities.

Questionnaires are divided into a series of topics. We administered a general satisfaction questionnaire, System Usability Questionnaires (SUS [37]), and a System Validation Questionnaire, where the entire system was evaluated. Moreover, we provided component-specific questionnaires where single functionalities and interfaces were evaluated independently. Questionnaires include single-choice closed questions (Likert scale from 1 = certainly no to 5 = certainly yes, plus the "not used" answer option), and open questions; the number of both types of questions changes on the base of the component evaluated.

The results discussed here are related to the CBAC, the detailed questionnaires with all their average responses can be found in Table 1.

As one of the 25 participants participant (from Spain) dropped out during the pilot, because did not feel confident with the system, a total of 24 participants completed the questionnaires.

As users participating in 1R and 2R experimented the same system setup, data acquired in both rounds are jointly evaluated. Moreover, we collected and analyzed the total usage time of the CBAC accrued by each pilot user in the two system installations (Italy and Spain), divided per activity. Finally, to evaluate socialization, we collected data about the interactions among users using the activities proposed by the CBAC.

Qualitative analysis Answers to the questionnaires were evaluated using descriptive analysis in order to organize and adequately summarize all the information collected on the different variables considered in the questionnaires. They are mostly ordinal qualitative variables in a 1 to 5 Likert scale using 1 for "strongly disagree" and 5 for "strongly agree". The median M and interquartile ranges IQ have been calculated for each variable. M and IQ of all questions are reported in Table 1.

Overall, participants enjoyed the use of the CBAC and found it stimulating. If we look to the question regarding the usability of the whole CBAC platform, users provided particularly positive remarks. The answer to the question if they found "the available games useful and stimulating" obtained $M = 4, IQ = 1.25$. Users stated that they "enjoyed being able to interact through video and voice with users during the activities" ($M = 4, IQ = 1$) and that they "would, if possible frequently use the cognitive games in the future" ($M = 4, IQ = 2.5$). The users appreciated fact that it was "easy to understand how to play each activity" ($M = 4, IQ = 2.25$).

Technological equivalence is also assessed. The users appreciated the fact that it was "easy to learn to use the platform to perform the required activities" both on the tablet interface ($M = 4, IQ = 1.5$) and for the TV set-top box ($M = 4, IQ = 1.5$). They provided similar answers when asked about the fact that the interface was "easy to interpret" ($M = 3, IQ = 2$ for both tablet and TV set-top box setup). However, they felt that the tablet interface was "more responsive to their inputs" when compared to the TV set-top box ($M = 4, IQ = 2.5$ and $M = 3.5, IQ = 2$, respectively).

On the negative side, the user signaled that the air mouse used to control the TV set-top box was difficult to be used and that sometimes it was not easy to recover the system if a wrong action was performed (both on the tablet and the TV set-top box). Overall, both setups were appreciated and equally used by the users.

When asked if the system was useful to socialize, users provided polarized answers; when asked if "using the CBAC [they] enjoyed the company of new friends online" and if they "hung out with new friends met on the CBAC" their answer was, respectively, $M = 1, IQ = 3$ and $M = 1, IQ = 3.75$. However, we remark here that the evaluation of the first question is the result of the computation of the median of two different sub-populations as shown by the large IQ range: 13 users answered 1, while 6 users answered 4 or 5. This clearly reflects the different attitude of the users as for some of them the CBAC turned out an effective mean to make new acquaintances. Similar observations apply to the answers to Question CBAC5 (see Table 1).

The analysis of how cognitive games have been received was done by administering 11 questions. Users reported how they "enjoyed playing the cognitive games" ($M = 4, IQ = 1.25$) that were also "easy to play" ($M = 4, IQ = 1.25$). The social component of the games was particularly appreciated: when asked if the users "enjoyed being able to interact while playing with peers" they replied with a high score ($M = 4, IQ = 1$).

The users particularly appreciated activities that addressed the physical domain, as E1-5 and A3. More precisely they stated that they "enjoyed practicing the gentle exercising" ($M = 4, IQ = 0.25$), found them "easy to use" ($M = 5, IQ = 2$) and that they would frequently play with them in the future ($M = 4, IQ = 2$).

Overall people found the system easy to use, they felt confident and they would have liked to keep the system also after the pilot, with an average score close to 4 over 5 on a Likert scale. The 72.7% of the participants rated positively the use of the system and 68.2% rated positively the satisfaction with the experience.

Quantitative Analysis Figure 10 reports the total usage time of the CBAC accrued by each participant in the two system installations (Italy and Spain) in both rounds of the pilot experiment.

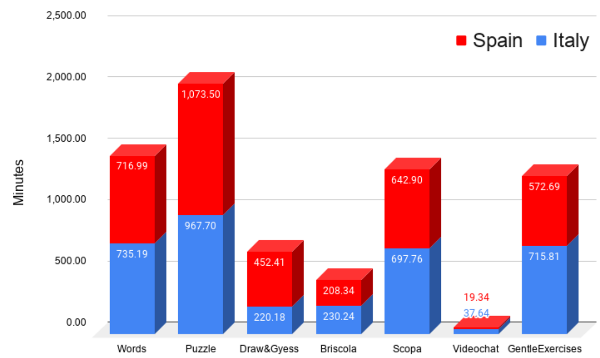


Fig. 9: The platform usage for each activity.

For the Spanish pilot, the rate at which the line grows in the first round of pilot (before 15-12-2019) is roughly the same as that observed in the second round. In the case of Italy, the rate is slow at the beginning but then it grows faster in the second round due to the greater involvement of users and some improvements made to the system that have been suggested by users during the first round. The flat part of the curve reflects the Christmas break where the system was put in stand-by mode (CBAC was still active but no assistance was provided in that period).

Roughly around 8-3-2020, the local government in Northern Italy imposed a set of lockdown measures to face the COVID-19 health emergency. It can be seen in the plot how the increasing rate of the curve steepens in this period. This can be an indication of how the system was used as a way to face isolation even if the assistance provided by system administrators could be only from remote, and hence very limited, in this period.

Figure 10 reports a comparison of the usage time accrued by CBAC activities over the Italian (blue bars) and the Spanish (red bars) pilot rounds, divided for each activity.

In general, over both installations, it can be said that the co-existence of activities with social interactions showed a synergy: the activities that featured both those functionalities have received a fair amount of usage from the users. This holds especially true in the second round of the pilot where several improvements have been introduced from the feedback collected after the first round.

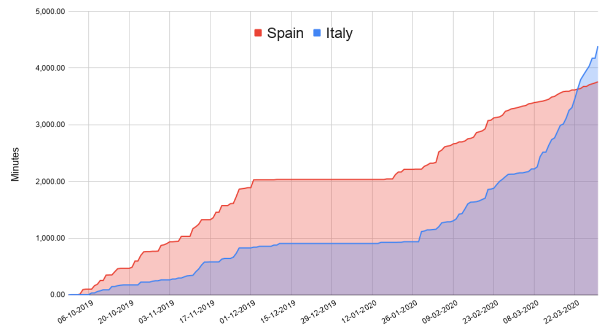


Fig. 10: Timeline of usage of the platform.

4 Discussion

The CBAC integrates a highly heterogeneous set of activities targeted at cross-domain stimulation; physical, cognitive, and social. Differently from other platforms [23], the CBAC allows the combination of social engagement and physical and cognitive stimulation with monitoring capabilities that are used to provide better stimulation to the elder using engaging activities and leveraging on the concept of virtual rooms. This *transversal* approach, which combines monitoring and simulation, allows mutual benefits across different domains. As an example, a user which is interested in activities that address the physical domain is encouraged through our platform to endow activities that also address the cognitive and, most importantly, the social one.

The CBAC is designed around the concept of virtual rooms inside which users can perform activities and socialize at the same time. Although the idea of a virtual room is not completely new [42,43], we provide here a generalization to generic activities on one side and the support of multi-party social interaction on the other. This is indeed what makes activities attractive to the elders: they do activities to know each other and would never start meeting people in a generic social community like Facebook [22].

The platform has been then developed around the concept of virtual room leading to a federated architecture where activities can be independently deployed on the platform at any time. Activities are devised as independent units, they contain arbitrary business logic enveloped in a container that must comply with specific interfacing requirements so that the platform can handle their instantiation and support interoperability, as well as data-exchange functionalities, [44]. This has allowed developing a very complex system in a relatively simple way. Moreover, this architecture enables several benefits such as

- can be easily extended with newly developed modules that provide new functionalities and new activities,
- allows the integration within the platform of external components that could provide new functionalities, such as sensorized objects/devices [45,46],
- allows technological equivalence - i.e. the possibility to deploy the platform on multiple (and simultaneous) devices adapting them to the user's behaviour and preferences,
- increases the robustness to faults of a single components/object – the system is able to cope with possible failure/errors of a component.

Among these benefits, the most important one is the plasticity of our proposed system with respect to multiple activities, devices, and the integration with external components. For instance, a newly developed

	Question	*M*	*IQ*	N
TI	Tablet Interface			
TI1	I can easily learn to use the interface to perform the required tasks/games.	4	1.5	23
TI2	Interacting with the tablet is easy.	3	2	23
TI3	Functions related to buttons are clear.	4	3	24
TI4	The tablet interface is responsive to my inputs.	3	2	23
TI5	The tablet interface is easy to interpret.	4	2.5	23
T16	Wrong actions can be easily recovered without any external help.	2	2	23
TVI	Tv Set-Top-Box Interface			
TVI1	I can easily learn to use the interface to perform the required tasks/games.	4	1.5	24
TVI2	Interacting with the set-top-box through the airmouse is easy.	2	2	24
TVI3	Functions related to buttons are clear.	3.5	2.25	24
TVI4	The tv set-top-box interface is responsive to my inputs.	3	2	24
TVI5	The tv set-top-box interface is easy to interpret.	3.5	2	24
TVI6	Wrong actions can be easily recovered without any external help.	2	2	23
TVI7	The media station interface is easier and more comfortable to use than the Tablet's one.	2.5	1.25	24
CBAC	Cognitive Based Activity Center			
CBAC1	The available games are useful and stimulating.	4	1.25	24
CBAC2	I can easily interact with peers and other participants.	2	1	23
CBAC3	I easily understand how to play each single game.	4	2.25	24
CBAC4	Using the CBAC I enjoied the company of new friends online.	1	3	20
CBAC5	I hung out with new friends met on the CBAC (or I plan to do so).	1	3.75	18
CG	Cognitive Games			
CG1	I enjoyed playing the cognitive games.	4	1.25	24
CG2	I found the cognitive games easy to play.	4	1.25	24
CG3	I found the cognitive games unnecessarily complex.	2	2	24
CG4	I felt I needed the support of a technical person to be able to play the cognitive games.	2.5	3	24
CG5	Inviting other users to join the cognitive games was easy.	3	2	21
CG6	It was clear how to invite offline users to join the cognitive games.	3	1.5	12
CG7	Accepting game requests from other users was easy.	4	1	21
CG8	It was clear how to accept offline game requests from users.	2	2	12
CG9	I enjoyed being able to interact (through video and voice) with other users during gameplay.	4	1	16
CG10	If I have the possibility, I would frequently use the cognitive games in the future.	4	2.5	23
CG11	I would imagine that most people of my age would learn how to play the cognitive games very quickly.	3	2.25	24
GE	Gentle Exercises			
GE1	I enjoyed practicing the gentle exercises.	4	0.25	17
GE2	I found the gentle exercises easy to use.	5	2	17
GE3	I found the gentle exercises unnecessarily complex.	1	1	17
GE4	I felt I needed the support of a technical person to be able to use the gentle exercises.	1	1.5	17
GE5	I enjoyed being able to interact (through video and voice) with other users during the gentle exercises.	3	2.25	17
GE6	It was clear how to access the virtual room/channels to join the gentle exercises.	2	2.5	17
GE7	The explanation of the gentle exercises was clear	4	1	17
GE8	I would imagine that most people of my age would learn how to use the gentle exercises very quickly.	4	1	17
GE9	If I have the possibility, I would frequently use the gentle exercises in the future.	4	2	17
EG	Outdoor Activities			
EG1	I enjoyed the Outdoor suggestions.	3.5	1	6
EG2	I found the Outdoor suggestions easy to use.	4	0	6
EG3	I found the Outdoor suggestions unnecessarily complex.	2.5	1	6
EG4	I felt I needed the support of a technical person to be able to use the Outdoor suggestions.	1.5	1.75	6
EG5	It was clear how to look for an event.	4	1	6
EG6	It was clear how to choose to participate to an event	3	0	5
EG7	I would imagine that most people of my age would learn how to use the Outdoor suggestions very quickly.	4	0	6
EG8	If I have the possibility, I would frequently use the Outdoor suggestions in the future.	4	1	7

Table 1: Questionnaires about the use of the CBAC, divided per topic, used during the main experimental evaluation. *M* is Median, *IQ* is InterQuartile range, *N* is the number of pilot participants who answered to that question.

module, which requires the use of an external sensor, could be easily added (or removed) from the CBAC by adding/removing it to the catalogue in the list of Activity Units server-side, thus enabling fast integration with new functionalities.

A good example of the modularity and of the capabilities of the proposed platform can be seen in its advanced functionalities (see Section 2.8). Different and heterogeneous activities can be added to the system easily, even if they require additional components. In particular, we added a set of exergames ([33]), played on the TV set-top-box and using a balance board as the main input device; exergames are used to provide physical stimulation as well as a set of activities that could be used for advanced monitoring purposes, as for an exergame called *Anti-stress*, that is played by means of a sensorized anti-stress ball and is focused on monitoring the grip force trends of the user (this is a particularly interesting indicator for detecting early signs of frailty). Further details can be found at[46]. Finally, we integrated within the platform the possibility to perform a set of neuropsychological tests (TMT-A/B and Bells) as additional Activity Units. See [35] for more details.

As an additional feature, data from the activities themselves are logged and then processed to compute a set of indicators that could, in principle, correlate with early physical and cognitive decline [4,47]. The same data is used to provide personalized suggestions by rearranging the layout of the buttons of the activities' main interface and ordering the list of peers available thus providing personalization. This is one of the key elements that is considered to increase user engagement [48,49].

A critical element that emerged in the pilot is the network connection. In most houses, this was through WiFi and was not always stable. This was especially critical for video communication. In general, elders had the impression that a need for technical personnel was required to overcome transient failures.

The CBAC has been largely evaluated on the field. This has been a continuous process that, especially in the initial stages, was tightly coupled with its development.

For some elders mastering the different functionalities of the CBAC was demanding and felt to need some training. As expected, younger participants enjoyed the games and used them more than the older participants [50]. Moreover, we observed by analyzing the answers by age that older subjects tended to rate the system more difficult to use, less friendly, and less compliant, while younger people were more enthusiastic and effective in using it. This is indeed a manifestation of a digital divide, that is expected to vanish in the next future where seniors will likely be more familiar with the technology.

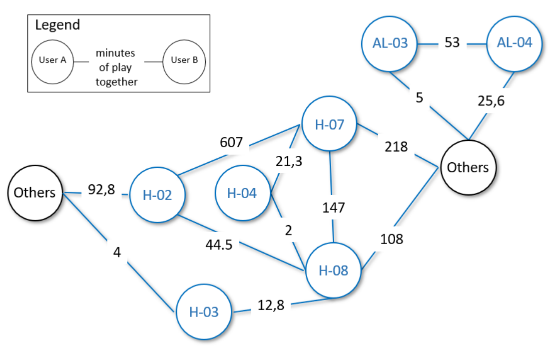
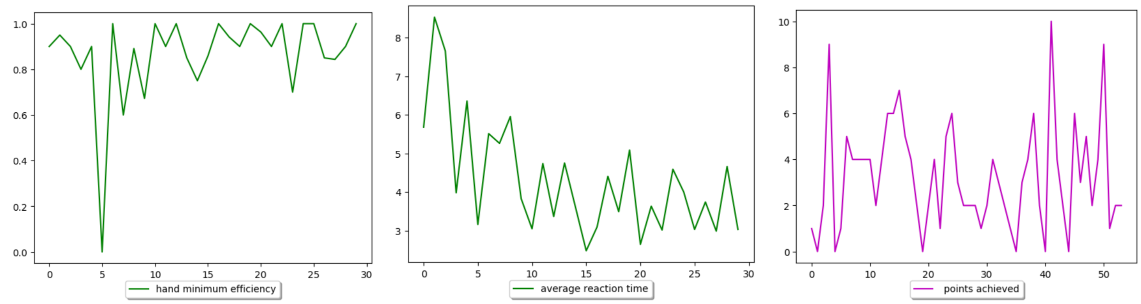


Fig. 11: The graph of how users interacted during the second round of Pilot in Milano, during the national COVID-19 lockdown. Users labeled with an H are those living in their houses, while users labeled AL are those living in the AL structure. Users H02-H07 did an activity together for a total of 607 minutes. A third user, H-08 did activities with both users, although for a more limited amount of time.

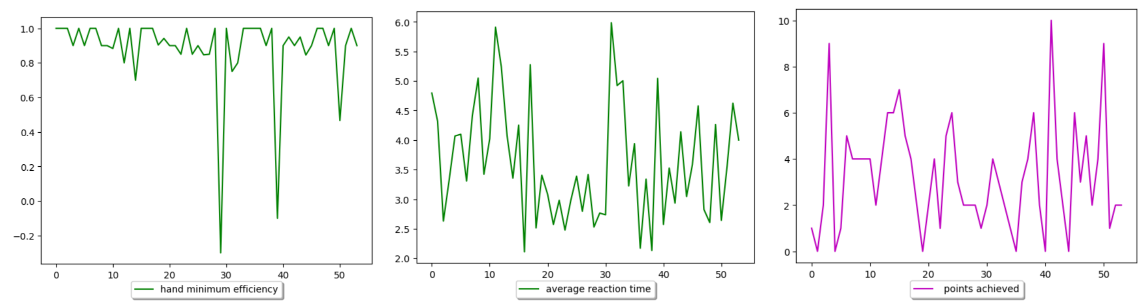
Usage data show a steep increase in the usage of the CBAC during the initial stage of the COVID-19 emergency (Figure 11). Interestingly, looking at the social graph that shows the time spent in activities



(a) Minimum action efficiency per game H-02.

(b) Average game TTA H-02.

(c) Score per game H-02.



(d) Minimum action efficiency per game H-07.

(e) Average game TTA H-07.

(f) Score per game H-07.

Fig. 12: Performance analysis playing the game Scoma for users H-02 and H-07. Time is in seconds. TTA is computed for each *hand* of the game - a turn of the user.

together, two users (H02-H07) did indeed a lot of activity together and, from the final questionnaire, it emerged that they have started to meet and go out together on a regular basis. From this point of view, the CBAC has shown its effectiveness. We remark that also two users of the second round of the pre-pilot met inside the CBAC and started to meet outside on a regular basis. If we compare the platform use between the first and second round, it can be hypothesized that the forced reclusion induced by the COVID-19 pandemic acted as an additional incentive for users to seek and find social interactions through the platform.

Overall two pairs of users, one in the pre-pilot and one in the pilot, met inside the CBAC and started meeting on a regular basis, becoming friends and meeting also beyond the project-related occasions. A third elder of the pilot did a lot of activity with those two thus creating a triplet of people who started to meet virtually. The graph of how users have interacted with each other during the second Pilot phase can be seen in Figure 9.

Data collected by users doing an activity can be used as an indicator about their performance and fed to the reasoning system [30]. Due to the limited duration of the pilot, we do not expect that data acquired could show any significant change into the cognitive abilities of the users. However, we envisage the fact that those data could provide significant insight into the user condition if used for a long time. Interestingly, we identified a mild correlation of the *Turn Duration* feature (see Section 2.6) with the age of the participants and we detected that the two users who played the most games are also the fastest ones. In Figure 13 we report a preliminary analysis in this direction, where the monitoring data collected about the user performance in terms of minimum action efficiency (as described in Section 2.6) are shown.

As we gathered more data from the two most-active users, H-02 and H-07, we can make a more detailed analysis of their performances through the games (Figure 12). This analysis, different from the one presented

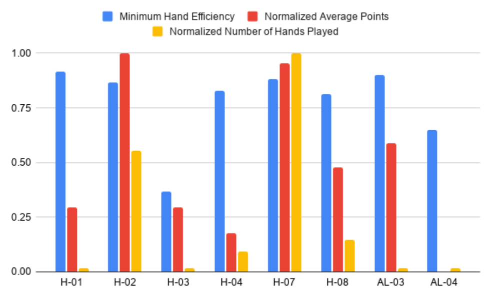


Fig. 13: An example of monitoring data that could be extracted from activities played in the CBAC. Here statistics about how user play at cards game are shown.

above, reports data obtained on each hand played by the user (while above we showed aggregated data from all players' games). On the x-axis of each graph is indicated the number of hands played.
User H-02: We can see how all indicators show that H- 02 has significantly improved especially in the first games becoming a faster player both in terms of TTA and T in the last games. This results also in a decrease, with each match, on the total duration of the match. Such improvement becomes stable in the last games performed. However, this trend is correlated with an increase in terms of performances, as overall the user efficiency is almost stable (besides some oscillations) in all games. The same consideration can be made when we consider the number of points obtained by the user. It can be seen how, despite the fact that the average minimum and average efficiency throughout all hands played by the user is consistent with respect to the average value obtained by the other players, in certain games, this player had a particularly low minimum hand efficiency (i.e., the user made a particularly bad move, as shown in the graph below there is one action with a minimum hand efficiency close to 0). This could be related to the fact that the user, who was an experienced player, has tried to perform a more risky move that could result either in a high revenue or in a high loss or simply that she made a mistake. This points out the fact that outliers can always occur and be considered in the evaluation through robust statistics. Less experienced users, with fewer hands played, show a lower average minimum and they have lower oscillations with respect to their minimum hand efficiency.
User H-07: We can see that the TTA of this user has been consistent for all games, so we are not observing a training effect. Similarly, T has not changed much during the pilot, with oscillations from game to game. Overall, the user seems not to have improved nor decreased his performance over the games.

5 Conclusion

This paper shows how Virtual Communities can be a powerful method to promote socialization when they are combined with activities of interest for the elders. Besides providing engagement and cross-domain stimulation, the platform can acquire activity data that can be valuable to early detect physical and cognitive decline. Such an approach has been further pursued by the H2020 ESSENSE project[10]) aimed to support elders and children at home in the COVID-19 Pandemic in [51].

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[10] `https://www.essence2020.eu/`

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