New perspectives from technology adoption in senior cohousing facilities

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Abstract

Purpose – The purpose of this paper is to analyse the integration of industry 4.0 related technologies of telehealth within innovative housing models addressed to senior population, in order to facing the growing issue of a sustainable management of the population ageing.

Design/methodology/approach – A qualitative exploratory analysis of four case studies of senior cohousing facilities located in different countries was performed. The cases analysed were selected as pioneering cases in the adoption of innovative and economically sustainable organizational solutions.

Findings – The study made it possible to identify which are the common characters that successful experiences have highlighted. Although each facility needs to adapt to the social, cultural, demographic and economic context in which it is located, there are some recurring aspects, which have proved to be key success factors.

Research limitations/implications – This research analyses only four cases. This suggests that the sample does not provide an exhaustive representation of the models adopted in this field. However, the study is an exploratory research and it can provide a basis for further analyses.

Practical implications – This study provides valuable indications for the design and management of senior cohousing facilities, as regards the services to be offered, the network of services and facilities that can be complementary to the residences, the activities to be conducted and organized, the degree of involvement of the elderly in the planning of activities and services. With regard to the adoption of telehealth-related technologies, the study provides indications on which new technologies resulting from the industry 4.0 revolution are going to be adopted, that is, remote surveillance, remote diagnostics and the use of sensors and video. These technologies, thanks to the artificial intelligence, can detect anomalies and provide predictive analyses on the behaviour and health of the elderly.

Originality/value – The study made it possible to identify the key success factors for senior cohousing facilities regardless of the characteristics of the context in which they are located. In addition, it provides a first analysis of the potential of telehealth-related technological solutions, paving the way for further studies aimed at assessing how, thanks to new technologies, the level of economic sustainability of senior cohousing solutions can be improved.

Keywords Population ageing, Senior cohousing, Telehealth, Quality management, Healthcare, Industry 4.0

Paper type Research paper

Introduction

Nowadays, world population is ageing at a faster rhythm than in the past. Due to the increase in life expectancy and the reduction of demographic growth, all countries are reporting an increase in the number and proportion of elderly people in their population. According to the United Nations' Twenty-sixth World Population Report (2019), by 2050, one in six people in the world will be over 65, being one in eleven in 2019, and the number of people aged 80 years (and over) is expected to triple, from 143 million in 2019 to 426 million in 2050.

Population ageing is one of the most significant social transformations of the 21st century. This implies a rethinking of all sectors of society, including labour and financial markets (Williams, 2005). The increase in ageing also leads to a transformation in the demand for goods and services, such as housing (Brown, 2004; Jarvis, 2011; Chatterton, 2013), transport, health and social protection (Kingston *et al.*, 2001; Field, 2004; Bouma and Voorbij, 2009; Wells and Laquatra, 2010), as well as family structures and inter-generational ties (Musso *et al.*, 2017).

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Furthermore, the health conditions of the elderly will have an impact on the economic system. In the last 20 years, many researchers (Cooper and Hagan, 1999; Dormont *et al.*, 2006; Kildemoes *et al.*, 2006; Breyer *et al.*, 2010; Tchoe and Nam, 2010) have examined the relationship between ageing and healthcare expenditure in different countries around the world. Although with differences due to country specific factors, the results of all these studies showed that healthcare costs rise with increasing age of people. Forecasts for future years are in line with past trends, and the governments' decision-makers have to take into account the effects of the ageing and the impact that their decisions will produce on the quality of life.

In the existing literature, some studies focused on the technological innovations in healthcare, such as telehealth that reduces transmitted and processing data time, with a view to continuous improvement (ScottHanson and ScottHanson, 2005; Mazzocato *et al.*, 2016; Graban and Swartz, 2018; Pace *et al.*, 2019). Other scholars focused on innovative housing models, such as senior cohousing that improves the quality of life for the residents and reduces the risk of isolation and depression for older people (Sorkin, 2002; Paul *et al.*, 2006; Glass, 2009; Glass and Vander Plaats, 2013). Lastly, Gomes and Lott Dare (2009) investigated the importance of telemedicine in senior cohousing placed in rural areas. However, the literature lacks studies related to the impact of the use of new technologies, particularly those related to the so-called industry 4.0, in senior housing facilities connected to the management of the problem of population ageing. Indeed, industry 4.0 is playing an important role in many different industries, and it can certainly be crucial also in the healthcare sector. Thus, the main research question of this work is whether a healthcare management using both the opportunities made available by industry 4.0, and innovative senior cohousing models, can improve people's quality of life (both of the elderly and their families) and make healthcare expenditure sustainable in the long term. In order to respond to this question, a qualitative exploratory study of four case studies of senior cohousing facilities located in different countries was conducted, with the aim of identifying emerging models of assistance to elder people that could ensure financial sustainability, both for families and national healthcare systems, and preserve people's quality of life.

Literature review

Senior cohousing: living together to improve the quality of life

Senior cohousing is a form of group living, for age-peer over the age of 50 or so, which clusters individual homes around a common house (Brenton, 2013). The basis for the success of the senior cohousing model, like in a basic model of cohousing community, is necessarily in 'intentionality' of people to live together and deal with several daily activities (Field, 2004). The priority of the senior cohousing residents is to aging well together (Critchlow Rodman, 2013). Durrett (2009) argued that 'senior cohousing revolves around custom-built neighbourhoods organized by the seniors themselves in order to fit in with their real needs, wants, and aspirations for health, longevity and quality of life'.

Compared to the first senior cohousing facilities appeared in Denmark in the 1970s (Lietaert, 2011), nowadays senior cohousing is much more advanced. Currently, many cases of advanced experiences of senior cohousing facilities in different countries can be observed. About them, in the last 15 years the literature started to analyse characteristics, critical issues, development opportunities and implications for society of cohousing solutions for the elderly (Brenton, 2013; Critchlow Rodman, 2013; Durrett, 2009; Glass and Vander Plaats, 2013; Guan Hong, 2017; Musso *et al.*, 2017; Quigley, 2010; Rhoades, 2018; Ribbe *et al.*, 1997; Rinnan *et al.*, 2018; Roberts and Adams, 2018; Rowles, 2018; ScottHanson and ScottHanson, 2005; Zupančič, 2014; Wells and Laquatra, 2010; Williams, 2005). One of the most significant experiences is that of the Lewes Community, Delaware (USA) (O'Hanlon, 2019; Ferrara, 2019), which hosts a variety of community-based supports and resources offered by local senior centres, cooperative networks, and other non-profits. The presence of a favourable natural environment combined with a wide range of services dedicated to the elderly has made this area a particularly attractive environment for them. The result is that currently in the area over 50% of the population is over 65 years old (O'Hanlon, 2019).

More recently, innovative technological solutions, such as domotic, sensors and telehealth started to be introduced in senior housing facilities (Morris *et al.*, 2013; Pacis *et al.*, 2018; Ponce *et al.*, 2019; van Hoof *et al.*, 2011). These technologies are connected to the industry 4.0 revolution; therefore, they are still in progress. However, they are already expected to bring considerable benefits in favouring autonomy, health, security, mobility and inclusion of vulnerable people regarding motor and cognitive functions (Ponce *et al.*, 2019).

The development of industry 4.0

Industry 4.0, more commonly known as industry 4.0, was officially announced for the first time in 2013 by the Germany Trade and Invest (GTAI), the economic development agency of the Federal Republic of Germany, as a strategic initiative to take a pioneering role in industries which are currently revolutionizing the manufacturing sector (Xu *et al.*, 2018).

Today, industry 4.0 is considered the Fourth Industrial Revolution. At the end of the 18th century and early 19th century, the First Industrial Revolution (Industry 1.0) started with the introduction of mechanical manufacturing systems based on water and steam power. The Second Industrial Revolution (Industry 2.0) began in the late 19th century, after the introduction of mass production using electrical power. Later on, in the middle of the 20th century, the Third Industrial Revolution (Industry 3.0) introduced electronic and information and communication technology (ICT) systems for automation. These new technologies made flexible manufacturing systems (FMSs) possible through the widespread adoption of computer numerical control (CNC) machinery and industrial robots. Furthermore, the technologies for computer-aided manufacturing (CAM), computer-aided design (CAD) and computer-aided processing planning (CAPP) led to computer integrated manufacturing (CIM) (Feng *et al.*, 2001; Xu *et al.*, 2018). The Fourth Industrial Revolution (Industry 4.0) is mainly represented by the introduction of Cyber Physical Systems (CPS), Cloud Computing (CC) and Internet of Things (IoT) (Jasperneite, 2012; Kagermann *et al.*, 2013; Lasi *et al.*, 2014; Hermann *et al.*, 2016; Qin *et al.*, 2016; Li, 2017; Kumari *et al.*, 2018). More in detail, at first IoT included radio-frequency identification (RFID) technology. Internet-connected RFID readers can automatically identify and track linked objects with tags in real time (Xu *et al.*, 2014). Afterwards, other technologies such as sensors, actuators, the Global Positioning System (GPS) and mobile devices that are operated via Wi-Fi, Bluetooth or near field communication (NFC) were used with IoT technology (Xu *et al.*, 2018).

According to Xu *et al.* (2014), the advances in both RFID and wireless sensor networks (WSN) have contributed significantly to the development of IoT, with a significant impact on new ICT and CPS, thus opening the way to the industry 4.0 revolution. Therefore, Industry 4.0 combines data analytics, intelligent sensors and artificial intelligence in order to optimize each kind of process in real time.

Nowadays, these technologies are applied in many different industries, included the healthcare sector. In the IoT era, also the healthcare industry has grown-up from 1.0 to 4.0 generation (Kumari *et al.*, 2018). According to Anya and Tawfik (2017), a huge set of IoT based medical devices (such as wearables, sensors and smartphones) empowers the patient-driven healthcare 4.0 system to monitor the real time health status of patients. The potential areas where industry 4.0 plays an important role to provide health services to hospital, clinics and remote healthcare is known as telehealth (Farahani *et al.*, 2018).

More recently, developments in computing capabilities are giving rise to new developments in artificial intelligence, with new applications in the field of telemedicine, including the possibility of making predictive assessments based on remotely collected data on vital parameters, position, actions and movements and of remote assisted patients (Szolovits, 2019; Pacis *et al.*, 2018).

The importance of telehealth in the healthcare system

There is no universally accepted definition of telehealth. The literal meaning is 'healthcare at a distance'. In the early 1900s, inspired by radio's sudden prominence in every field, someone was already imagining how doctors could attend to their patients over the radio (Wotton, 1999). The cover of a *Radio News Magazine* from 1924 showed an illustration of a doctor attending to a patient via live video feed, under the headline 'The Radio Doctor – Maybe!'. In that period, it was only a vision of an editor on future technologies. Some decades later, in Pennsylvania, radiology images were sent 24 miles between two towns via telephone line; the University of Nebraska established a two-way television setup to transmit information to medical students across campus, and later linked with a state hospital to perform video consultations (National Academy of Science, 1996). Telehealth technology was born to serve many rural communities without local physician access, but in the 1960s, it appeared in urban communities as support to the emergency medicine (Nickelson, 1998).

Today, telehealth is one aspect of the use of ICT. It is widely believed that ICT generally has the potential to improve clinical care and public health (Wotton, 2008). According to Wotton *et al.* (2009), in addition to facilitating medical education, administration and research, appropriate use of ICT may:

(1) increase and improve access to healthcare;

(2) enhance the quality of service delivery;

(3) improve the effectiveness of public health and primary care interventions;

(4) improve the global shortage of health professionals through collaboration.

More recently, the California National Telehealth Resource Center (2019) highlighted how telehealth is emerging as a critical component of the healthcare crisis solution. Indeed, patients diagnosed and treated with the support of telehealth have substantially reduced mortality rates, reduced complications, and reduced hospital stays. Furthermore, telehealth reduces healthcare costs when home monitoring programs can replace high-cost hospital care. Telehealth also provides support in addressing shortages and misdistribution of healthcare providers. On the one hand, specialists can serve more patients using telehealth technologies, and on the other hand, nursing shortages can be addressed using telehealth technologies. In addition, telehealth supports clinical education programs. Rural clinicians can more easily obtain continuous training and they can more easily consult with specialists.

Many telehealth applications empower patients to play an active role in their healthcare. Furthermore, this technology improves organizational productivity, thanks to the optimization in the use of specialized medical personnel and the possibility of making relevant skills available regardless of distances.

Lastly, telehealth helps the environment since it reduces travelling to obtain necessary care, thus reducing the related carbon footprint.

What is worth to be analysed, and which has so far been little investigated, is how the senior cohousing model may be affected by the developments in telehealth, especially those related to industry 4.0 technologies. Although this is a constantly evolving theme, it is appropriate to investigate if advanced experiences are being conducted at the international level within senior cohousing facilities, in order to identify which are the most relevant changes that are going to be introduced in this field, and which consequences are expected in terms of economic sustainability of cohousing facilities.

Methodology

For this research, a methodology based on case studies was adopted. This method is suitable for the development of theoretical/practical hypotheses based on empirical evidence (Eisenhardt, 1989; Miles and Huberman, 1994), allowing to compare results with those emerged from previous studies, and identify new theoretical developments and advances on a given topic (Chetty and Blankenburg Holm, 2000). Four cases have been analysed. According to the literature, although it is not possible to define an ideal number of cases to be considered, the optimal number is between four and ten cases (Eisenhardt, 1989). With less than four cases it is difficult to extract theoretical elements that can be generalized, and more than ten cases would provide a volume of information difficult to manage.

The cases analysed have been identified by taking into consideration the existing literature on Senior Cohousing, Senior Living Facilities and Nursing Homes, making a selection based on the analysis framework proposed by Tomita and Nochajski (2015) and Morris *et al.* (2013) in their literature reviews.

The selection was made by identifying those contributions reporting information from case studies where innovative experiences were reported and discussed (Guan Hong, 2017; Rowles, 2018; Roberts and Adams, 2018; Rhoades, 2018; Rinnan *et al.*, 2018; Ribbe *et al.*, 1997; Burke and Werner, 2019; Konetzka and Werner, 2010). Once cases have been selected, data have been collected from secondary sources, included company reports, websites, documentation available online and additional information from technical reports, specialized press and previous studies (Guan Hong, 2017; Morris *et al.*, 2013; Zupančič, 2014; Quigley, 2010).

To retrieve and classify the relevant information, a text extraction analysis was performed using the TextAnalyst™ software. Then, the information emerged have been discussed with experts on the field and specialists in residential facilities for the elderly, with the aim of identifying the most significant cases to be considered. Data collection, analysis and discussion with experts were carried out from May to September 2019.

Findings and discussion

Case study A

The facility is located in Osaka, Japan, and is part of a chain of residential facilities for the elderly managed by a private company. The property is located in a central urban location, served by public transport and close to two hospitals. It is also close to supermarkets and commercial areas with shops, and is connected with pedestrian paths to a large public park.

The residential compound, built in the late 1990s, was conceived after a long debate, which lasted a year and a half, with the resident elderly population of the area, whose needs and expectations were analysed and discussed.

The facility has 53 housing units and is home to both self-sufficient couples and single senior citizens. Housing unit sizes range from 30 square meters to 60 square meters. The age of the residents must be over 60 years and the average age is 75 years, of which 60% are females.

Each unit consists of a small kitchen, a bedroom and a bathroom. The bathroom is fully furnished and the kitchen is equipped with all the appliances, and the residents must take care of the purchase of the remaining furniture for furnishing of the units.

Each unit is free of architectural barriers, accessible to disabled people and equipped with emergency bells in every room. A project is under evaluation for more advanced solutions including motion detectors and sensors that can allow anomalies to be detected and automatic alarms to be triggered. According to the property, these solutions would allow a more efficient organization, providing more timely and accurate responses to the needs of residents and ensuring considerable savings in staff costs, both for nursing care and for medical staff.

The shared facilities include a cafeteria, which is also open to outside customers, a common kitchen used by residents, a library, also open to outsiders. The fact that both the cafeteria and the library are open to outsiders is an instrument of interaction between the elderly and the external community, which has proved to be very effective in avoiding isolation. In addition, a surrounding garden is available for gardening, which demonstrated to be very popular among elderly residents.

The staff is composed of nine employees, with a guarantee to always have three staff members on duty and available day and night.

Among the services provided, a 24/7 monitoring and assistance is ensured. In addition are also provided: first aid, psychological counselling, assistance for the management of daily life, such as reading correspondence and reminders for taking prescriptions, entertainment programs and social activities.

The economic model is based on private contributions and partially on government contributions, being the centre recognized as a 'service apartment for seniors'.

The elderly who have access acquire the right to live until the end of life and can choose to rent or own their own housing units. If an elder chooses to rent, the basic cost of living, including management fees and support services, is around US$520 for one person and US$800 for two persons. For a single average resident, the total monthly expense, including meals and personal expenses, is approximately US$1,400–1,500.

A key feature that characterizes this facility is the fact that all the services and above all the activities have not been set *a priori*, but are organized according to the needs and aspirations of the elderly, discussing with them the activities and programs to which they would like to participate. Their involvement has always been a fundamental point of reference since the design of the residence, and it seems to be the main success factor of this model. The goal is to create a family environment with which seniors are familiar, ensuring that their previous lifestyle, before entering the facility, could be maintained. For this reason, pets are also allowed. The result is a high level of satisfaction witnessed by very low turnover, mostly due to passing away of the residents.

As the elderly enter with the intention of remaining until the end of life, it is important that the organization is able to meet their changing needs and health state. Although not all services can be provided within the compound, the location in a neighbourhood well served with key services and facilities such as hospitals, clinics, dentists, supermarkets and public transportation systems, ensures that seniors can access not only to medical care but also to the social programs they need.

Intergenerational contact is another important factor in planning a structure for the elderly. The opening of the cafeteria and library to the external public has encouraged interaction, especially with children attending the library, thanks also to the proximity to a primary school. Elderly people like to watch children going to school, and interact with them when they have an opportunity.

Three key points of this case can be summarized as: involvement of the elderly in the entire process of designing spaces, services and activities; the inclusion of the structure in a well-balanced environmental context between the offer of services, natural features and relations with the local community; presence of a significant intergenerational interaction.

In this case, the adoption of solutions connected to industry 4.0 is poorly implemented. However, the introduction of sensors to monitor the residents and their actions inside the homes is being planned. Consequently, an efficiency gain in the organization of care services is expected, and this should bring to lower management costs, and ultimately, lower costs for the elderly and the public health care system. Nevertheless, the extent of these savings has not been quantified.

Case study B

The second case study is located in the Algarve, Portugal. The cohousing facility was started in the mid-1990s within an area of approximately 20,000 square meters owned by a local parish. The main goal of its establishment was to provide a response to a segment of elderly and low-income population located in a peripheral region. Such a region, with poor employment perspectives for young people, was at risk of demographic desertification.

The cohousing compound was designed to accommodate old and poor people, both single and couples, who face difficulties in living alone, taking into account the fact that, given the economic and demographic conditions of the region, the sense of incapacity and loneliness of the elderly had raised the rate of suicides.

The compound includes 52 private residences with a physical layout that encourages a strong sense of neighbourhood. The residences are formed by two circular blocks open on a garden and on pedestrian paths. The layout invites interaction and social exchange. The presence of different open spaces used as small gardens, supports several interaction activities.

The central building is home to the shared facilities and services: a kitchen, a dining room, a guest room, a craft area, a laundry room, a beauty salon, a chapel, personal office spaces and an ambulatory. Outside, there are an amphitheatre and a cafeteria. A wide-open garden is available for gardening and horticulture, and this meets the preference of the residents, since most of them are former farmers.

Medical assistance is provided by a nurse who is always present and by a doctor who carries out scheduled visits on a weekly basis, assisting people and redirecting to different types of assistance in case of need. The telemedicine and tele-assistance supports are not adopted and the ambulatory is provided with just a basic equipment.

The residential units include living room, kitchen, bathroom and one or two bedrooms depending on the residents. Each unit has sufficient flexibility to change its settings from an active lifestyle function to an accessible function for disabilities. Therefore, all details, such as the size of corridors and ballrooms, are designed to support a more inclusive environment.

Each unit is self-sufficient with a full kitchen, but residents can choose the canteen to have meals without cooking and, in addition, increase the interaction between them.

The compound also includes a building used as a nursery school and a space for hosting children after school; both areas aim to provide support to families with children during working hours. This gives the elderly the opportunity to interact with young people, making themselves useful for carrying out school assignments or organizing entertainment initiatives.

According to the more traditional criteria for the organization of a cohousing, there is not a formally established leadership for managing the facility. However, organization, coordination and management of financial resources are entrusted to a priest designated by the local parish.

From the financial point of view, the necessary resources depend on the contribution of the residents, through their pension, and from the contribution of the parish.

As a general evaluation, it can be stated that the main goal of the initiative has been reached, since following the start-up of the facility, the suicide rate among the elderly in the area dropped to zero. However, the facility lacks of innovative technologies, which would reduce costs and improve efficiency and quality of all the services provided. The possibility of introducing advanced telehealth and tele-diagnostics solutions would allow this structure to lower management costs and at the same time increase the quantity and variety of assistance services. This, in turn, would make it possible to accommodate elderly people who are not self-sufficient or with pathologies that require constant medical supervision. These benefits are particularly evident in cases where geographical isolation and distance from health care centres make it more difficult to ensure the residency of older people in the same places where they always lived.

Case study C

This case is located in California, in the San Francisco Bay Area. The facility was opened in 2014 to cope with housing demand for low-income elderly people searching for accommodation in the region. The structure was previously owned by the municipality that sold it for free to a private company with the aim of building a residence for low-income seniors. The building is located on a surface of half a hectare and it houses 66 apartments each with a bedroom and a bathroom, with surfaces ranging from 50 to 60 square meters. Given the strong demand for residential housing of this type, all the units have been filled since the opening, having received over a thousand applications.

The housing units are reserved to elderly people over 62 years old and assigned on the basis of disposable income, favouring low incomes, in particular those with incomes of 50% lower than the average income of the area. The cost of monthly rents varies according to income: for those with an average income of 30% of the average income, the cost is US$517 per month, for income of 40% the cost is US$690, for income 50% of the average the cost is US$862.

The construction criteria of the building have been based on sustainability principles, the entire building was built including solar thermal heating systems and energy-saving appliances. In addition, the relationship with the natural environment was taken care of, for example with the use of native plants resistant to drought and installing high-efficiency irrigation systems. For construction materials, products with recycled materials were used as much as possible, and paints and floors with low emissions of volatile organic parts were used to ensure healthy indoor environments.

The design elements inside the building and in each apartment have been organized to facilitate the maximum independence of residents, even in advanced aging phases. A portion of the apartments has been structured in compliance with disability standards, including some units reserved for those with visual and hearing disabilities.

The common spaces include a library, a computer lab, a gym, a hairdresser, a common room and various rooms for public use.

The services offered include free health services provided by external specialists, such as annual vaccinations, blood pressure screening, podiatry and diabetes tests. Physical activities, nutrition lessons and budget management lessons are also offered. Finally, in agreement with external specialists, psychological and mental health advice and financial advice are provided.

The building is close to a supermarket, a post office and other retail stores. Public transport is also nearby, with a bus stop a few steps away.

Actually, the management of the residence is actively exploring the use of smart apps and services for the safety, care, comfort and convenience offered to residents. The spectrum of smart home technologies is wide and growing. Advanced solutions range from voice-activated devices to motion/weight sensors and integrated systems that can remotely control lighting, room temperatures and security features. Technology also provides alarms for medication reminders, analytics that measure changes in daily living activities, and communication supports for interacting with staff, family, or caregivers.

A further area of exploration is that of mental illness. As the number of available mental health providers decreases, the demand increases. This is particularly relevant to limited mobility people and those living in rural areas where distance impedes access to quality mental healthcare. Since behavioural health providers often do not need a physical presence with patients, and because many individuals prefer to access behavioural health services discretely, using telehealth technologies to deliver mental health services could be of great usefulness and costs saving. Indeed, tele-behavioural healthcare requires no specialized investments beyond a simple video connection.

In summary, this case reports the adoption of advanced technologies, but mainly limited to applications aimed at facilitating the use of household appliances and lighting systems with sensors and remote controls. The potential of industry 4.0 technologies is not yet exploited, in particular the IoT and the use of data for predictive analyses. Furthermore, no punctual evaluations on the possible economic benefits deriving from the innovations introduced were found in this case.

Case study D

This case reports of facility built ex-novo with 60 housing units located in Alamogordo, New Mexico. The compound comprises 14 buildings with one or two floors containing 24 one-bedroom apartments and 36 two-bed apartments. All the units are reserved for families with elderly people aged 62 or over, and other family members with at least 55 years. Four units are designed for full accessibility for disabled, each projected to be fully adaptable to the characteristics of the family unit that occupies it.

The underlying goal that guided the project was that to offer affordable housing at low prices, without burdening rent and with low public subsidies. The challenge was managed by achieving savings on construction costs, integrating green solutions to minimize operating and managing costs and offering an unusual architectural design, which could appeal to younger, healthier seniors. The housing units were designed on two levels, as it emerged from a focus group that highlighted as the two-levels development would have been more attractive for the elderly, who would have exercised daily and would have enjoyed better views of the landscape. Each apartment has been designed with a patio. The buildings have been arranged to create a sense of security, interaction with neighbours and maximum exposure to the sun, so as to maximize energy efficiency.

The materials used for the construction were all ecological, non-toxic, with recycled materials and natural water-based paints. Wheat-based plywood without formaldehyde were used, and recycled cotton for insulation was installed. The buildings have been designed in coordination with and environment-friendly project to collect rainwater from the roofs and provide irrigation to the plants. These characteristics of green building offer considerable savings in terms of costs for energy and water, contributing to the reduction of operating costs to about 25% – compared to similar properties – on the costs paid by tenants.

All the buildings of the compound are surrounded by large green spaces. The landscape design of the site includes native or drought-resistant plants, shrubs and trees.

The structural features of the complex include a fitness room, a library, a computer room, a common room and a central laundry service. Common spaces include on-site parking, communal gardens, picnic areas and shaded outdoor benches. The housing units are equipped with emergency communication devices directly connected to the city hospital. In the future development, the introduction of technologically advanced solutions for the monitoring of the elderly, through video, tele-diagnostic and sensor devices is planned. These devices will allow making health checks more frequently and regularly, therefore preventing accidents and causes of mortality.

	Case study A	Case study B	Case study C	Case study D
Location	Central	Peripheral inland	Residential area	Out of town
Property	Private	Local parish	Property	
No. of housing units	65	52	66	60
Age admitted	60 and over	No limit	62 and over	62 and over, and family members at least 55 yo
Income-related admission criteria	No	Yes	Priority for incomes 50% lower than average in the area	Yes
Facilities	Open cafeteria, common kitchen, open library, gardening	Kitchen, dining room, guest room, craft area, laundry, beauty salon, chapel, personal office spaces, amphitheatre, cafeteria, garden, ambulatory	Library, computer lab, gym, hairdresser, common rooms for public use	Fitness room, library, computer room, common room, central laundry service
Medical and nursing assistance	Yes	Nursing, scheduled weekly medical visits	Yes	Yes
Activities and programmes	Discussed with the residents	Gardening and horticulture, financial advice, psychological advice, interaction with children in after-school hours	Physical activities, nutrition lessons and budget management lessons	Fitness courses, craft activities, social events, annual senior Olympics
Operating model	Private contributions and partially government contributions	Contributions from residents and local parish	Contributions from residents and partially public subsidies	Maximum reduction of operating costs (25% lower). Low public subsidies, low rental costs
Costs (monthly)	US$520 1 person US$800 2 persons	N.a	Depending on income: from US$517 to US$862	Cost per unit: US$90,000
4.0 related technologies	No. Some to be introduced (under evaluation)	No	Projects in progress: smart apps, voice-activated devices, motion / weight sensors, security features, remote control of lighting and room temperature	No, just connection with the city hospital. Planned: video, tele-diagnostic and sensor devices
Economic assessment of 4.0 innovation	No	No	No	Partial

Table 1.
Summary of the cases analysed

The services offered include transport services, provision of meals at a centralized canteen, trolley meals served inside the housing units for those who want to have lunch at home, assistance for daily cleaning, health care assistance and fitness courses. In addition, residents participate in a variety of activities such as crafts, bingo, social events and the annual senior Olympics.

What characterizes this case is the use of design and construction solutions that allowed the project to become attractive and at the same time economically viable, with a cost per unit of approximately US$90,000. The use of high-efficiency solutions has also made it possible to contain management costs and therefore reduce the rental costs of the housing units. At the same time, constant attention to innovative technological solutions will further lower the costs of managing and providing support services.

This case, although it represents an avant-garde among the cohousing solutions, does not show a use of industry 4.0 related technologies. Investments in remote monitoring and remote assistance are planned, but a project capable of exploiting advanced technologies such as IoT, artificial intelligence and remote diagnostics is missing.

As a summary of the cases analysed, a table is proposed with the characteristics of the cohousing facilities examined (Table 1). The table shows a substantial homogeneity in the adoption of a functional model where the compatibility between management costs and available income of residents is pursued. However, a complete financial autonomy is not reached, since partial public subsidies are necessary in any case. The level of technology 4.0 adopted is low, and this prevents from exploiting all the cost savings and service quality improvement opportunities that advanced technologies can allow.

Conclusions, limitations and future research

The four cases analysed represent an example of housing facilities from different countries, having in common a successful model that is strongly adapted and suitable for the specific social, cultural, demographic, urban and economic context in which they are located. The variety of cases analysed made it possible to verify their features and functionality both in urban environments and in peripheral regions, with the latter far from social assistance services.

The average age of residents in a facility fluctuates between 75 and 85 years, and this suggests that a good level of assistance can allow an independent life of the elderly. This, in turn, favours the maintenance of an active lifestyle and psychological conditions that help to preserve good health. In one case, the two-storey layout of the housing units was deliberately designed to stimulate the elderly to carry out more physical activity, according to a view addressed to offer continuous stimuli to the residents. Among these stimuli, the presence of green spaces for horticulture and gardening has proved to be particularly effective both physically and psychologically.

While the services provided are differentiated in the models adopted, in all cases basic services such as general assistance, barrier-free accessibility and 24-hour monitoring are guaranteed. In the case of the Japanese housing facility, other aspects have also been given weight: security, psychological counselling and possibility to participate in the planning of activities, with a strong involvement of the elderly residents in decisions.

Other aspects that emerged from the cases analysed are: (1) the creation of an assistance ecosystem (in addition to the assisted living facilities), where the structures are located near or have created networks with complementary social and health services, such as public hospitals and emergency services; (2) empowerment of the elderly: in all cases, privacy and independence have been respected and the previous daily life of the elderly has not been changed. Even in cases where the elderly are in wheelchairs, they have individual rooms and can choose whether to prepare their own meals or consume them in common areas taking advantage of the canteen service; (3) enabling inter-generational interaction: solutions in which the presence of children has been favoured (such as cafeteria and library open to the public, nursery schools and after-school for workers' children) have proved to be particularly effective in motivating and involving the seniors in interaction activities with children.

In the cases examined, advanced technologies linked to industry 4.0 are not used and most of innovative solutions are in a planning phase. Since the cases observed are avant-garde examples, it means that the potential of telehealth, home automation and remote assistance technologies, even if already recognized, requires a long time for being exploited, being the adoption of these technologies gradual and expensive.

As previous studies highlighted (Morris *et al.*, 2013), the wide range of smart home technologies currently available can support older people in cohousing facilities. Passive and active sensors, monitoring systems, environmental control systems and electronic devices can provide an effective support for an independent living. Projects to introduce such technologies have always been reported, the benefits of which have been recognized in terms of: improved quality of assistance, increased safety, greater autonomy of the elderly, cost savings and therefore greater access to facilities for low-income people. Above all, cost savings associated with nursing and health care represent an important factor capable of deeply modifying the financial balance of housing structures, opening up new and important prospects for their diffusion and sustainability. Indeed, one of the main factors to be addressed is the high cost of nursing and medical care, where direct human presence has a significant impact. Therefore, all the solutions that can allow remote interactions (for analysis, diagnostics, psychological assistance, surveillance) represent a powerful support to the development of senior housing as a form that allows ensuring dignity and quality of life for the elderly in the final part of life.

Taking into account the size of the cases considered, it must be noted that the possible savings from 4.0 related solutions are limited, given the small size of the residential structures and the small number of staff employed. Greater savings would be possible if the facilities were connected in a network with other similar structures, with a telehealth system that through a centralized monitoring and diagnostics centre would allow the control of a large number of residents, thus significantly reducing costs. On the other hand, further commercialization of smart home technologies will make it possible that their cost will reduce, thereby increasing their availability and utilization in home environments.

A further point that emerged from the cases studied is that the potential of industry 4.0 technologies is not still considered in the variety of solutions, since the projects reported refer only to individual technological applications, such as remote assistance and sensors, without being part of a connected system of medical devices, control systems and data analysis systems supported by artificial intelligence and machine learning. Even the use of robotics for carrying out some assistance operations, also in this case carried by IoT systems, represents a frontier not yet taken into consideration.

All this indicates that the most significant changes coming from industry 4.0 technologies have not yet occurred and their realization requires the adoption of a different organization model capable to ensure advantages in terms of efficiency and cost reduction much greater than those envisaged by single technological applications. Indeed, the greater benefit would be in the creation of a much wider network of assistance structures, connected to central coordination and control units, capable of optimizing resources and ensuring coordination and functionality of decentralized diagnostic/therapeutic devices, thanks to the adoption of artificial intelligence systems. This can make possible much greater savings of specialized human resources thanks also to the availability of databases capable of providing predictive indications on emerging needs and problems. A model of this type also requires logistical planning for ensuring timely interventions facing any type of health need that may concern the elderly residents.

The implications for the design and management of residences for seniors are numerous and the results of this study provide valuable information on: the services to be offered, in addition to the basic ones, the networks of services and facilities that can be complementary to the residences; the activities to be conducted and organized; the degree of involvement of the elderly in the planning of activities and services. Above all, this study proposes a network-based model capable of maximizing the advantages of 4.0 technologies in terms of efficiency, quality of health care and cost savings, opening up the possibility of making cohousing facilities more financially sustainable.

The sector is moving towards the adoption of solutions mainly focused on remote surveillance, remote diagnostics and the use of sensors and video which, thanks to the artificial intelligence, can detect anomalies and provide predictive analyses on the behaviour and health of the elderly.

As a consequence, improvements in safety, security and independence may have a positive impact on their quality of life. However, as several studies highlighted (Rosenberg *et al.*, 2011; van Hoof *et al.*, 2011; Courtney, 2008; Courtney *et al.*, 2008; Demiris *et al.*, 2008), a main barrier to the adoption of smart home technologies by older adults is privacy concerns, and a second issue is related to malfunctioning of technology, and this highlights the importance of contingency systems for events such as power outages.

Future applications will have to take into account of these concerns, by adopting solutions that, thanks an increasing use of robotics based on IoT connected frameworks, will reduce negative perceptions and mistrust.

This study has several limitations, first of all the fact that the main subject of the analysis, i.e. the adoption of industry 4.0 technologies, was not detected in its entirety, since their introduction is only at the design stage. Therefore, it was not possible to analyse and evaluate the economic and financial impact of such technologies.

Future explorative studies are still necessary, aiming at deepening the relationship between costs, efficiency gains and quality of services that the adoption of industry 4.0 technologies can burden, providing valuable information on possible improvements in the economic sustainability of senior cohousing solutions.

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