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Assistive Technologies for Older Adults in Urban Areas: A Literature Review

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Abstract Assistive technologies have the potential to address problems that older adults encounter when living alone. However, challenges arise when technologies are embedded into urban areas, e.g., restrictions emerging from networking structures, which potentially influence the success of implementing technologies. The development of such technologies requires the consideration of urban structures, including architectural and spatial environments as well as social factors. The goal of this contribution is to analyze the impact of Ambient Assisted Living systems on urban areas and point out challenges for future research. We investigated literature on assistive technology of the past decade, focusing on their potential application in urban areas, and propose a set of categories to classify the extracted approaches. While many contributions support individual users or social interaction, few consider urban structures. Future research is explored, with challenges emerging from novel network technologies, market uptake or adaptation, and the support of social neighborhood structures.

Keywords Gerontechnology · Assistive technology · Urban areas · Literature review

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Introduction

The rapidly changing population in urban areas and the increasing distances between family members and friends result in a higher degree of isolation among older adults living in single-person households. Globally, 40 % of older adults, defined as people aged 60 and above, live independently [1], and there is a high tendency of social withdrawal and social isolation among older adults in social and built environments [2]. Changes in life expectancy will create a higher percentage of older adults with age-related impairments and a growing gap in healthcare services. The percentage of older adults among the world population is expected to grow from 841 million people in 2013 to over 2 billion people in 2050 [1]. The population group of older adults is characterized by heterogeneous abilities and requirements—not all are frail and in constant need of help, as some research approaches suggest; but instead many are living autonomously, engaged in and contributing to social structures [3]. Despite this, age-related impairments still affect a growing number of older adults, e.g., in Germany, the likelihood of people with health problems living independently increases for ages 65 and above [4]. These impairments are influenced by many factors, including social and environmental determinants [4], which may differ within rural or urban areas.

With the aim of improving and maintaining living conditions for this population group, research in the field of Ambient Assisted Living (AAL) introduces assistive technologies which address older adults, nursing staff, and family members in various contexts. These contexts include care facilities, medical applications in hospitals and rehabilitation clinics, as well as everyday-life activities in home environments [5]. With the goal of supporting older adults to organize their daily life, many AAL systems

implement intelligent algorithms, inspired by human cognition, to process gathered sensor data and generate information [6]. To maintain physical and cognitive abilities and thereby reduce future care needs, specific AAL systems concentrate on prevention and intervention for age-related impairments [7]. Some approaches also consider social factors—by implementing social network technologies or sharing information about the user and their situation, assistive technologies connect peers, support communication, and create spaces for social interaction [8, 9].

Cognitively Inspired Computing for Gerontechnology in AAL Approaches

Gerontechnology, an interdisciplinary field of combining gerontology and technology, covers central aspects of AAL approaches. Within this field, cognitively inspired computing contributes in creating assistive technologies for older adults. One example of a novel approach in gerontechnology is the automatic diagnosis of Alzheimer's disease by means of novel technologies and biomarkers. Lopez-de-Ipiña et al. [10] investigate how machine learning algorithms can be used to support the detection of Alzheimer's and determine the severity. Moreover, machine learning for activity recognition, as presented by Zhao et al. [11], can be implemented into AAL systems to provide context-based support. Additionally, cognitive computing and intelligent systems also contribute to supporting older adults in urban areas, e.g., socially believable robots that support older adults in urban areas by assisting in delivering groceries and collecting garbage [12]. Thus, cognitive computing and intelligent systems are crucial for AAL technology in urban areas.

Scope of this Contribution

Even if pursuing similar goals, assistive technologies differ in their possible effect on social structures and on urban environments. When embedded into urban areas, this effect has not yet been analyzed. Many challenges and research questions arise, including how to consider existing local structures and face issues arising with novel technologies. To develop a suitable support for older adults in urban areas, future research should take into account the possible impact on urban structures. Within the scope of this contribution, the term urban structures refers to both spatial structures (e.g., the separation of public and private space or the building arrangement) and social structures (e.g., neighborhood organizations or established ways of social interaction), since they differ from rural areas and have an influence on the life of older adults.

I order to address these aspects in more detail and identify the impact of AAL systems on urban areas, this work presents an extensive literature review. We aim to identify new research questions as input for AAL research and highlight approaches which have the potential to impact urban structures in the near future. The developed classification will help future research identify the type of system being created and map those developments to problems arising in other work. In "Literature Review of Assistive Technologies for Older Adults" section, we present prevention and intervention systems and classify these by categories regarding the support of older adults and the influence on urban areas. We do not declare the completeness of this set, but show that all literature investigated can be matched to at least one of these categories. Based on this categorization, we point out what challenges research faces when creating technologies for older adults in urban areas and show the potential of considering the location and related social structures in the development of tomorrow's assistive systems ("Assisting Older Adults in Urban Areas: Challenges for Future Research" section). We identified four central challenges that should be discussed in future research on AAL systems for older adults living in urban areas. By those means, this contribution benefits researchers and developers from the fields of gerontechnology, cognitive psychology and artificial intelligence. This work is based on a former article presented in the Workshop on Ambient Intelligence for Urban Areas (AmIUA), co-located with the International Work conference on Ambient Assisted Living (IWAAL) [13].

Literature Review of Assistive Technologies for Older Adults

Society is confronted with a growing number of older adults living alone and lack social contacts, which affects economic and social systems in urban areas [14]. Hence, authorities need to adjust and facilitate existing structures for community interaction and urban planning [15]. As policy-makers increase their focus on these issues, research on gerontechnology has become a growing field, with research focuses ranging from assistive technologies for individual support to fostering of local community services. In order to overview the state of the art and point out upcoming challenges and potentials, we differentiated user involvement as a determining element to structure the approaches of AAL technology regarding the life of older adults.

Research Questions

As presented in "Introduction" section, assistive technologies may have a different influence on urban structures. Challenges of implementing assistive technologies into urban areas should be embraced by looking into

existing research and the possible impact on older adults living in urban areas. Since different aspects of urban lifestyle have an influence on the quality of life in older adults [1, 2], and AAL approaches aim to improve these aspects by different means [5], we discuss the role of AAL technologies in urban areas. Therefore, we focus on the following questions in our literature review:

1. What potential influences do assistive technologies have on older adults in urban areas?
2. What challenges and potential opportunities arise when implementing assistive technologies for older adults into urban areas?

Review Process

The assessment and aggregation of prior research in this contribution was achieved by conducting a systematic literature review in combination with a proposed classification of the presented work. This method of reviewing literature was realized in accordance with the steps proposed for the software engineering review process [16] and was adapted to the area of gerontechnology as follows:

- The aim was transferred into answerable questions ("Research Questions" section).
- Literature providing the best evidence was extracted from relevant databases.
- Evidence for relevance and impact of these contributions was given by proposing classification categories and validating them according to a scenario ("Levels of Assistive Technology with an Influence on Urban Areas," "Classification Categories," and "Scenario" sections).
- We integrated relevant outcome of the review into our proposed categories ("Results" section).
- Finally, we discuss ways to improve the former steps ("Assisting Older Adults in Urban Areas: Challenges for Future Research" and "Conclusion" section).

To answer the research questions, we investigated existing literature from 2004 to 2014, focused mainly on computer science literature as we regard AAL as a computer science discipline. Contributions were extracted from four databases: ACM Digital Library, IEEE Xplore Digital Library, DBLP Computer Science Bibliography, and SpringerLink, the main literature resources in computer science. The search is based on the appearance of the keywords "assisted living," "senior," "older adult," "aging," or "intergenerational" in headline or abstract, which have been incrementally extracted as relevant keywords in the addressed context. This set of keywords was derived form informal interviews with experts as well as information from various workshops we conducted in the last years. We also added keywords while searching for relevant publications. In addition, we filtered the proceedings of IWAAL, UCAmI, PETRA, ASSETS, CHI, CSCW, as well as the AAL Forum, AAL Congress, and the German Conference on Human–Computer Interaction (MuC), due to their relevance for the field. With a focus on user involvement of novel technologies and the possible impact on the older adults in urban areas, end-user applications designed for and studies evaluating the use of systems by older adults were included. Consequently, middleware systems and design studies without use cases were not included. After eliminating duplications, 643 relevant systems, studies and services were extracted out of 941 scientific contributions.

We first read the abstracts and identified categories based on the information. These categories and different characteristics of each category were extracted by the identification of similar keywords and topics in the papers ("Classification Categories" section). For each contribution, we sorted the given information into the proposed categories. Finally, we conducted a scenario-based reflection of the presented systems, which allowed the identification of a possible influence on urban areas. The proposed categories and results are presented in the following sections.

Levels of Assistive Technology with an Influence on Urban Areas

Based on information found in the examined literature, we propose a three-level model of potential support for older adults. We argue that potential support also determines the influence on urban social structures by reacting to an existing infrastructure and focusing on a different level of user involvement in AAL systems. The three levels of support can be differentiated: (1) *Single-user applications*, (2) *co-located or virtual multi-user applications*, and (3) *applications supporting community structures*. Figure 1 shows these levels of support and their possible influence on community interaction and urban areas.

The first level is comprised of *single-user applications*. These applications have the goal of enabling older adults to participate in social life. They can reduce expenses for care by supporting prevention and intervention through analyzing individual behavior and providing services for older adults, families, and care personnel. These applications encourage physical and cognitive activity among dedicated older adults and change the way older adults are able to move and interact autonomously within their environment. Consequently, these applications indirectly affect urban areas. Examples of single-user applications are systems that provide reminders or specific task support, which help older adults to retain their autonomy and engage in social

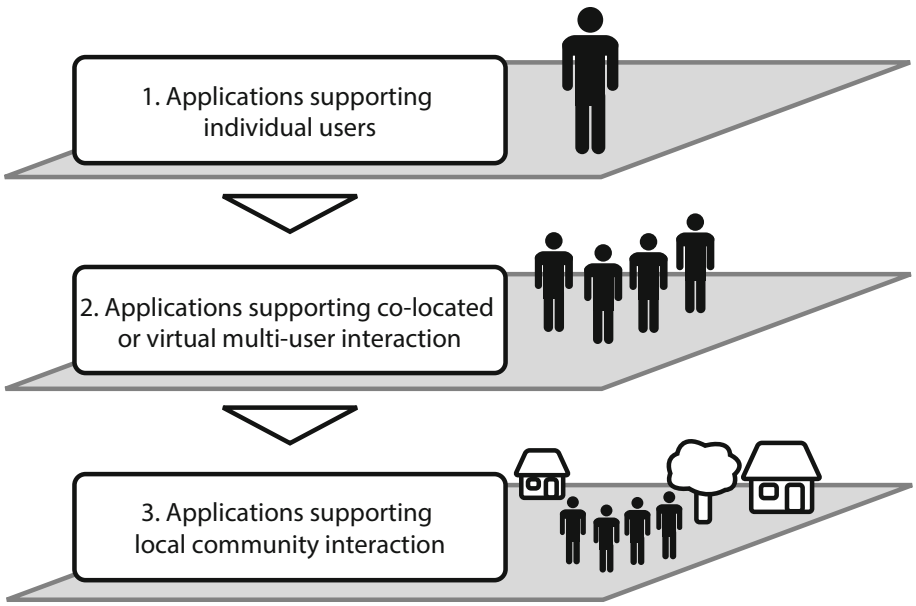

Fig. 1 Three levels of influence of applied assistive technologies on urban structures

interaction, e.g., by relieving the fear of forgetting an actual task or losing their path while talking to a neighbor.

Co-located or virtual multi-user applications as well as *single-user applications for community interaction* represent the second level. This level includes technologies that provide virtual spaces, e.g., community platforms or virtual meeting rooms, and facilitate opportunities to share experiences or enrich social structures. These applications connect older adults to relatives and enable them to share messages, photos and videos at any time, or provide topics of conversation for people with different demographics [17]. Accordingly, these applications indirectly influence urban structures by enhancing or facilitating social interaction in (inter-)generational contexts. However, applications on this level do not take into consideration boundaries arising from their application in urban areas. Even if technologies support social interaction, they are confronted with challenges when implemented into neighborhood communities, if they do not take into account the specific social and spatial requirements arising in deployment. Applications on this level have the potential to connect older adults and thus, indirectly influence urban structures, but do not have a direct influence on urban areas.

Applications on the third level may include applications on the first and second level. Nevertheless, these technologies take into account the requirements of urban areas, making it more likely to have an influence on the existing environment. Technologies on this level directly influence urban areas by *reacting to information gathered in the relevant area and about its population*. The goal of these approaches is to enable and support the connection of people with similar areas of interest or people living in the same region and to foster social support. Location-based services and social networks use algorithms to analyze personal information and match-making algorithms to connect people with similar interests or problems living in the same area. These approaches take up existing structures in urban environments, or develop technologies to increase the acceptance and usage of those structures. Thus, these technologies not only influence urban areas but are integral part of them. An example of such an application might be a local community, which gathers information on the living situation of a user and connects people living within the same vicinity who share a common social background, e.g., people who have just moved to a cit, and suggests shared activities.

Classification Categories

We also identified different aspects not directly related to the support of assistive technologies in urban structures by means of the 3-level model, but help classify systems to point out challenges and future trends in AAL research (Table 1). These categories were extracted from the content of the reviewed contributions and incrementally subjoined. The classification itself was used as a means of validation. For each category, we could assign at least one contribution to every characteristic.

In addition to the three levels of influence on urban structures (classification category 0 in Table 1), we propose seven classification categories. The most basic category, type of contribution, includes "systems," "services" and "studies." The application context covers a range of topics grouped into 23 characteristics (see Table 1). Within

Table 1 Classification categories and characteristics as described above

Classification category							
0. Level of support	1. Type	2. Context	3. User	4. Information	5. Technology	6. Adaptation	7. Status
Individual (level 1)	System	Navigation	Older adults	Location	Sensors	Situation-based	Prototype
Community (level 2)	Service	Monitoring	Care personnel	Movement	Wireless sensor Networks (WSN)	User-based	Concept
Location (level 3)	Study	Intervention	Caregivers	Intention	Camera	Automatic	Market-ready
		Playful	Intergenerational	Activities	Logging	Manual	Ongoing
		Physical	Helpers	Health	Global Positioning Systems (GPS)	Route	Completed
		Task support	Friends	Situation	Manual	Interface	
		Mobility		User information	Radio frequency	Content	
		Social interaction		Communication	Laser	Behavior	
		Communication		Device			
		Shared content					
		Presence					
		Learning					
		Social networking services (SNS)					
		Video communication					
		Social support					
		Activity support					
		Matchmaking					
		Information system					
		Home automation					
		Mobile devices					
		Services					
		Accident management					
		Tools					

this category, "intervention" includes measurements for care, prevention and rehabilitation; "communication support" includes measurements to help an individual person to communicate (e.g., language translation); "presence" includes virtual and actual presence; "activity support" includes means to engage people in performing more activities or helps them in the performance; and "tools" includes frameworks, middleware technologies or results that help to create solutions for supporting older adults. Even when aiming to support older adults, applications differ in the focused user group including "older adults," "care personnel," "caregivers," "intergenerational" groups, "helpers" and services, and "friends" and family. Systems require or gather various information in order to achieve system functionality, like the "location," "performed activities," "health," or "situation information," of the user. These aspects can be transferred into the system by different technology including "sensors," such as motion, pressure, biofeedback, or acoustic sensors; connection and activity "logging" when using a system; information "manually" typed in, interaction via touch gestures recorded by "cameras," or radio "frequency technologies" like RFID or NCF. Systems also use different means of adaptation, classified into "situation-" or "user-based" adaptation, "route," "interface," "content," and "behavior" adaptation as well as "automatic" or "manual" adaptation. Finally, the literature includes systems, studies, and services in certain stages (status), which can be grouped into "prototypes," "concepts," products on the "market," and "ongoing" or "completed" research.

Objectives, measurements, user interaction mechanisms, and evaluation methods were examined, but were too diverse to be clearly classified. Through the presented classification, the proposed categories are implicitly validated because we were able to match all contributions to at least one category. The proposed three-level model of influence on urban areas will be validated by this using a scenario-based approach. Due to the high volume of contributions, we focused on a limited number of representative approaches, which illustrate the work on assistive technologies for older adults for each level.

Scenario

The following scenario was created to explain the impact of the derived classification categories on urban areas and provide an insight into the presentation of research. Our scenario involves Margret, a woman living alone in the city of Essen in Germany: Margret is a widow of 72 years. She does not have any children, but often talks to her brother and his family living in Munich, about 650 km away. She was also closely connected to her neighborhood and work colleagues. However, this contact decreased when her husband died. Taking care of herself became a challenging task, which changed for the worse with first indicators of mild cognitive impairments. She feels embarrassed to keep forgetting the date and where she put things in her home. All these factors make increasingly hard for her to stay in contact with friends, resulting in a feeling of loneliness and helplessness.

This scenario provides a context for possible benefits when applying the presented approaches to analyzed literature, with a focus on the three levels of support on urban structures. Our persona Margret suffers cognitive impairments, which makes the usage of technologies on the first level meaningful, because they support her (mental and physical fitness) individually by enabling her to participate in social life. Being a sociable person who is decreasingly involved in social interaction, co-located or virtual multi-user applications and applications for community interaction (second level) can support Margret through existing community structures or creating new contacts. Because she lives in an urban environment, she is especially affected by technologies on the third level that react to information gathered in her neighborhood and its population. Our scenario refers to all presented assistive technologies and helps to understand their impact on urban structures.

Results

Using the Margret scenario, we were able to sort the extracted technologies in one of the three levels of support. Figure 2 provides an overview on the general differences in characteristics regarding AAL systems sorted to the three levels. Note that some contributions were sorted to multiple characteristics in one category according to the information provided by the authors. In the following sections, we present the results of our literature review. Due to the high number of contributions included, only a few are explicitly mentioned, selected to reflect the range of all 941 reviewed contributions.

Level 1: Support of Individual Users

Table 2 lists an extract of approaches that support individual users. A total of 562 contributions were assigned to this category, ranging from the support of physical or cognitive activities [18], performing everyday tasks in private [19, 20] or work environments [21], help coping with impairments [22, 23] and care support. Due to a missing focus on the user group of older adults, supportive technologies for peers or care givers, e.g., management tools for hospitals, were not considered. Most approaches focus on accident management by monitoring (274 contributions) the healthcare status [24], analyzing activities [25], or predicting behavior [26]. All technologies included in category five ("technology") gathered information for individual user support. A high number of monitoring systems leads to an increased usage of sensors (e.g., pressure mats), wireless sensor networks (WSN), camera-based, and radio frequency tracking to track information on the location, movement and health of the user and thus, predict intention and activities.

While monitoring systems focus on care personnel, some approaches put the older adult into control by allowing adaption of monitoring conditions [27]. Another major theme is digitally supported cognitive or physical therapy (132). The majority of rehabilitation systems support user-based content adaptation in order to provide suitable training for older adults with varying needs. Playful concepts are often used in therapy systems, aiming to increase motivation [28, 29]. Task support systems are also used for individual support (141). Based on the current location or time, they provide reminders, structure activities, and give instructions on how to perform certain activities [30, 31]. Other major contexts are services (89), tools (77), information systems (56), playful approaches (53), home automation (43), and presence measures (41). Also, some systems support navigation (26), physical interaction (38), mobility (24), communication (25), and interaction with mobile devices (25). Automatic adaptation mechanisms mainly include the user- or situation-based selection of services (59). Also, user-based adaptation of user interfaces is a common approach (23), followed by route adaptation in navigation contexts (12). Two contributions also adapted the system behavior based on the user interaction.

While most of the contributions present prototypes (498), some products for individual support were already in the market (19), and some had not yet exceeded a conceptual phase (25). Others present ongoing or completed studies. Evaluations of system efficiency have been conducted for most of the systems [32, 33], while actual (long-term) effects on the user were not included.

All of these contributions share the goal of supporting older adults in one or more aspects of everyday life. An example application supporting individual users is a cognitive and psychomotoric training game [18]. Based on manually inserted preferences and automatic diagnosis via digital geriatric tasks, the health status of the user is

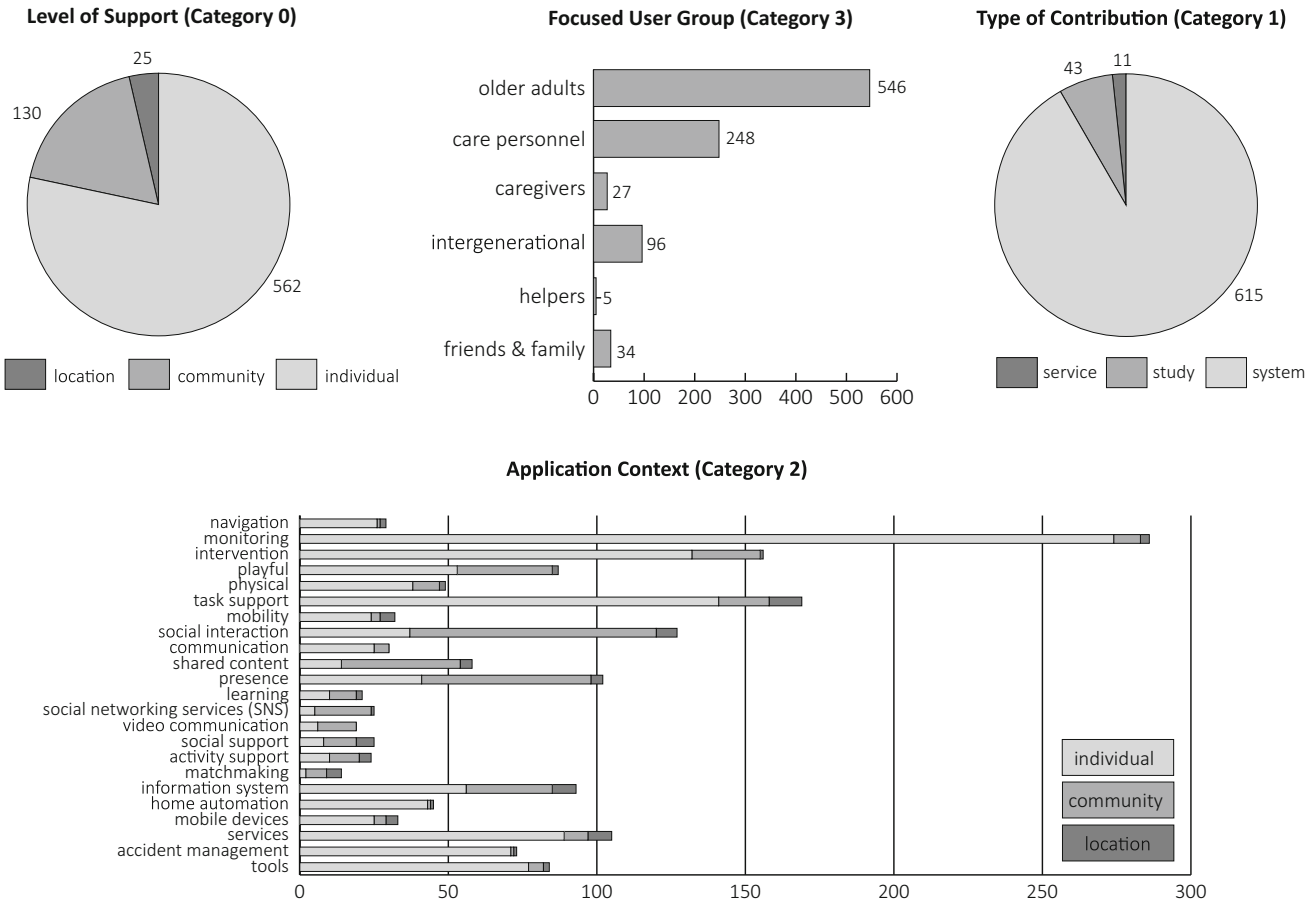

Fig. 2 Overview of the number of contributions classified into (*first row*) level of support (*left*), focused user group (*center*), type of contribution (*right*), and (*second row*) application context

determined. The content and difficulty of trainings are adapted based on the results to be suitable for the individual abilities of a user. The potential influence on urban structures becomes clear when considering the introduced scenario.

When visiting a couple of months ago, Margret's brother brought her a tablet with an application for cognitive training. He explained to her how to use it and she has practiced twice a week ever since. Although the different tasks are sometimes challenging, it is never too hard for her. Somehow, she seems to remember more often where she left her keys or glasses. Maybe the memory training really helps. Margret is really proud of herself, not only for being motivated to practice on a regular basis, but to be able to master everything without help. This feeling of confidence changes her attitude toward living alone. She tries to go out more often and does not feel as helpless as before. At the moment, Margret feels like she can help herself overcome the loneliness.

In an optimized use case, as presented, applications on level one have the potential to support the maintenance of cognitive and motor skills and thus, provide the basis for interacting with the environment. Consequently, these technologies indirectly influence urban living structures by enabling older adults to participate in social living activities.

Level 2: Support of Community Interaction

We matched 130 of the analyzed approaches to level two, where approaches support community interaction, co-located or virtual multi-user applications and single-user applications for community interaction. These systems or studies aim at enhancing or facilitating social interaction by providing shared spaces for exchanging information with peers and relatives [34, 35], or tools for mediated synchronous interaction, e.g., video communication [36]. They foster co-located activities by providing challenging or cooperative multi-user interaction [37, 38]. Examples of different approaches are listed in Table 3. Many systems focus on asynchronous or synchronous social interaction (83), social presence (57), information sharing (40), playful

Table 2 Examples of technologies supporting individual users, classified into the categories presented in "Classification Categories" section

Ref	Type	Context	User	Information	Tracking	Adaption	Status
[21]	System	Navigation	Older adults	Location, situation	Sensors, WSN, camera	N/A	Ongoing
[48]	System	Intervention	Older adults, care personnel	Situation, user information	Manual	Content	Prototype
[49]	System	Monitoring, accident management	Older adults, care personnel	Movement	Sensors, camera	N/A	Prototype
[28]	Study	Task support	Older adults	Movement, communication	Sensors, camera	N/A	Prototype
[50]	System	Intervention, task support	Older adults	Activities, user information	N/A	N/A	Concept
[51]	System	Monitoring, task support, automation, services	Older adults, care personnel	Activities, user information	Sensors, radio frequency	N/A	Prototype
[52]	System	Monitoring, information system, accident management, services	Older adults, care personnel	User information	Sensors, WSN	N/A	Market-ready
[53]	System	Intervention, mobility, accident management, tools	Older adults, care personnel	User information	Manual	User-based, interface, manual	Prototype
[19]	System	Task support, tools	Older adults	Location, activities	Sensors, camera, GPS	User-based, route, interface, content	Concept
[42]	System	Task support, mobility	Older adults	User information	Manual	Situation-based, user-based	Concept
[27]	System	Intervention, playful, tools	Older adults	Movement	Camera	N/A	Prototype
[54]	System	Navigation, task support, information system, mobile devices	Older adults	Location, movement, situation, user information	N/A	Situation-based, user-based, route, content	Concept
[55]	System	Task support, home automation, services	Older adults	Movement	N/A	User-based, interface	Prototype
[56]	System	Monitoring, task support	Older adults, care personnel	Location, movement	Camera	User-based, content	Prototype
[29]	System	Intervention, task support	Older adults	User information	Manual	N/A	Prototype
[24]	Study	Monitoring	Older adults, care personnel	User information	Sensors, manual	N/A	Completed
[7]	System	Intervention, playful, mobile devices, services	Older adults	User information	Logging, manual	User-based, content, automatic	Prototype
[57]	System	Navigation, task support, services	Older adults	Situation, device	Sensors, camera	Situation-based, user-based, interface, content	Concept
[58]	System	Intervention, playful, task support	Older adults	Movement, activities, situation, user information	Camera, logging, manual	User-based, automatic	Prototype
[59]	System	Tools	Older adults	User information	Manual	User-based, interface	Prototype
[60]	System	Monitoring, accident management, services	Older adults, care personnel	Location, movement	Sensors	N/A	Prototype
[31]	Service, system	Services	Older adults	User information	Manual	User-based	Prototype
[61]	System	Task support, communication, services	Older adults	Activities, health, user information	Sensors, manual	N/A	Prototype

Table 2 continued

Ref	Type	Context	User	Information	Tracking	Adaption	Status
[62]	System	Monitoring, task support, social support, services	Older adults, care personnel	Movement, health, situation	Sensors	User-based, content	Prototype
[63]	System	Home automation, services	Older adults	User intention	Manual	N/A	Prototype
[64]	Study	Intervention, home automation	Older adults	User information	N/A	Manual	Completed
[65]	System	Monitoring, task support, home automation, services	Older adults, care personnel	User information	Sensors	User-based, automatic	Prototype
[66]	System	Monitoring, intervention	Older adults, care personnel	User information	Sensors	N/A	Prototype
[67]	System	Monitoring, task support, information system, home automation	Older adults, friends	Location, movement, health	Sensors	N/A	Prototype
[68]	System, study	Monitoring, communication, information system, accident management	Older adults, care personnel	Location, movement	Sensors	User-based	Prototype

applications (32), information systems (29), and intervention measurements (23), while fewer approaches foster social network interaction (19), task support (17), video communication (13), social support (11), or activity support (10).

Most technologies are in a prototypical (116), or conceptual state (12). One service and two healthcare portals on the market were presented. Furthermore, most of the systems were evaluated considering social presence.

Gameinsam [37] is an example of an application supporting community interaction. This shared TV game uses information on a TV program to create a meta-quiz game for family members and peers to play together either in one location or online. The interface is optimized for people with visual impairments, making it suitable for older adults. The optimized Margret scenario can be applied to this system as follows:

On Mondays, Margret watches "Who wants to be a millionaire" on TV. By using Gameinsam with her niece and her family in Munich, they can watch and guess together. Her niece's husband always knows the answers to financial question, and her niece is an expert in chemistry and biology, but when there are questions on history, no one can compare with Margret. She can answer every question. At the next family reunion, her niece's children ask Margret why she knows all of these historic facts.

While supporting a shared activity, community presence is enhanced. Watching the same show and answering questions together provides a common topic, which encourages communication. These systems connect peers and provide spaces for shared and co-located activities. Even when living at a distance, family members and peers can engage in social interaction. Technologies on this level have an indirect impact on urban structures, because they enable interaction over distances and influence social behavior in (inter-)generational contexts.

Level 3: Support of Local Community Structures

The contributions listed in Table 4 represent different approaches supporting local communities and structures within urban areas (level three). Twenty-five applications were assigned to this level. Despite the small number of results, the presented approaches show a wide variation of measurements. Technologies focus on the accessibility [39], as well as localization and mapping [40, 41], of services and technologies for older adults. They connect peer groups [39], match user objectives, encourage location-based meetings [41], and connect people in need with assistive services [42], thereby creating new local community structures. Interaction measures reach from playful approaches [43, 44] to location-based user ratings [45, 46]. All technologies allow for at least content adaption, based on the user location. Research projects developed prototypes (13) or concepts (7), whereas socio-technological support services have been successfully implemented into local communities [47] and some contributions present ongoing (2) or completed research (3). Supported user groups include older adults, care personnel, voluntary helpers, service facilities, and peer groups. The approaches have been evaluated in terms of contributing to social structures or are derived from qualitative and quantitative research.

One approach of supporting local community structures is the InDago HelpMe application [39]. The prototype aims to locate support nearby, to enhance mobility for older

Table 3 Examples of technologies supporting community interaction, classified into the categories presented in "Classification Categories" section

Ref	Type	Context	User	Information	Tracking	Adaption	Status
[69]	System	Social interaction, presence	Older adults	Location	Sensors, WSN	N/A	Prototype
[17]	System	Intervention, playful, social interaction	Intergenerational	Activities	Camera	N/A	Prototype
[70]	System	Social interaction, presence, information system	Older adults	N/A	N/A	N/A	Prototype
[71]	System	Communication	Older adults	Communication	Sensors	N/A	Prototype
[32]	System	Social interaction, shared content, presence, information system	Older adults, intergenerational	Movement, activities	Sensors	N/A	Prototype
[72]	System	Presence	Older adults, care personnel	Activities, user information	Sensors, manual	N/A	Prototype
[73]	System	Social interaction, presence, learning	Intergenerational	Activities, communication	Manual	N/A	Prototype
[74]	System	Presence, video communication	Older adults, friends	User information	Camera, logging	N/A	Prototype
[75]	System	Social interaction, SNS	Older adults, friends	N/A	N/A	N/A	Prototype
[33]	system	Social interaction, shared content, presence, SNS	Older adults	User information	Manual	User-based, content	Prototype
[34]	System, study	Intervention, playful, physical	Intergenerational	User information	Manual	N/A	Prototype
[76]	System	Social interaction, shared content, information system, presence	Older adults	User information	N/A	N/A	Prototype
[35]	System	Information system, task support, presence	Intergenerational	Activities, user information	Camera, manual	N/A	Prototype
[8]	System	Shared content, presence, social interaction, activity support	Older adults	N/A	N/A	N/A	Prototype
[77]	System, study	Playful, social interaction, task support	Older adults	User information	Camera, manual	User-based	Concept
[78]	System	Presence, monitoring, social interaction	Older adults	Location, movement, activities, user information	Sensors, WSN, manual	Situation-based, content	Prototype
[79]	System	Shared content, activity support, social support	Older adults	User information	Manual	N/A	Prototype
[9]	System	Playful, learning, shared content, social support	Intergenerational	Activities, user information	Manual	N/A	Prototype
[30]	System, study	Video communication, social interaction, presence	Older adults	User information	Camera, manual	N/A	Prototype
[80]	System	Social interaction, matchmaking, SNS, shared content	Older adults	Location, movement, intention, user information	Sensors, camera, manual	User-based, content	Prototype
[81]	System	Information system, community interaction, activity support, presence	Older adults	Location, movement	Sensors, camera	User-based, interface	Prototype
[82]	System	Social interaction	Older adults	Activities, user information	Sensors, manual	N/A	Prototype
[83]	System	Communication, social interaction, shared content, presence, services	Older adults	User information, device	Sensors, manual	N/A	Prototype
[84]	System	Learning, social interaction, SNS, information system	Intergenerational	User information	Manual	N/A	Prototype

Table 3 continued

Ref	Type	Context	User	Information	Tracking	Adaption	Status
[85]	System	Social interaction, presence, video communication, information system	Older adults	Health, situation	Sensors	Situation-based, user-based, content, behavior	Prototype
[86]	System	Playful, shared content, social interaction	Intergenerational	Activities, user information	Camera, manual	N/A	Prototype
[87]	System	SNS, shared content, social interaction, information system, presence	Intergenerational, friends	Activities, user information	Logging, manual	N/A	Prototype
[88]	System	Presence, shared content	Older adults, caregivers, friends	Activities	Sensors	N/A	Prototype
[89]	System	Social interaction, presence	Friends	Activities	Manual	N/A	Prototype
[90]	System	Communication, monitoring	Intergenerational	User information, communication	Sensors	Situation-based, interface, behavior	Prototype

adults without the fear of getting lost. The smartphone app tracks the position of the user and connects older adults to voluntary helpers who could carry groceries, help to find the way home or just accompany older adults on a walk.

When being alone at home, housekeeping is always exerting for Margret. Her husband used to buy groceries by car, but Margret feels increasingly insecure when driving—especially during rush hour. Therefore, she always goes to the supermarket by bus. Because the weather is really great today, Margret decides to walk. After paying and leaving the supermarket, she notices how tiring the walk was. She can barely carry her bags to the bus station. She uses the HelpMe application on her mobile phone and searches for someone to help her with her groceries. Fortunately, a young man is waiting for the bus. He is notified and walks toward Margret in order to help her out. They have a nice conversation on their bus ride, and the young man even carries the bags right to Margret's front door. When she offers him a financial reward, he refuses. But he accepts an apple that Margret just bought.

Through such systems, there is a large potential to support social bonding and overall mobility and flexibility of older adults. By leveraging existing structures (e.g., the close distances in neighborhood communities), systems on this level directly influence urban areas and the people living in them. This may be achieved by simple technologies, like community platforms and SNS that foster special neighborhood groups [48], or raise community activity awareness on ambient displays [49]. There is also a large potential in the use of existing technologies for applications in urban areas. By including further information on a certain area, the experience of activities can be enriched, e.g., when applying geo-caching in a location-based family story [41], asking questions on the surrounding area for cognitive training [43], or using augmented reality in sharing experiences connected to points of interest [46]. In addition, local mobility and care structures can be enhanced, e.g., by providing technologies for ridesharing [50] and connecting older adults with aid services [51]. For the success of such concepts, existing urban structures play a crucial role. To reach target user groups and motivate the usage of novel technologies, interdisciplinary interaction should be intensified and socio-technological systems should be focused. For example the implementation of an ambient display [49] may reach older adults in community centers or local restaurants better than in shopping malls.

Assisting Older Adults in Urban Areas: Challenges for Future Research

In order to identify future challenges in gerontechnology, we explored the potential influence of assistive technologies on older adults living in urban areas (research question 1). Based on the results, we distinguished three levels of influence of assistive technologies. While single-user applications and co-located or virtual multi-user applications can indirectly influence urban areas, applications supporting community structures have a direct impact on urban structures. Based on a categorization of the extracted literature, the means of implementing this direct or indirect influence can be analyzed. Our proposed set of categories allowed the differentiation of the contribution type,

Table 4 Examples of technologies supporting community interaction, classified into the categories presented in "Classification Categories" section

Ref	Type	Context	User	Information	Tracking	Adaption	Status
[37]	System	Monitoring	Older adults, care personnel	Activities	Logging	User-based, route	Concept
[36]	System	Mobility, playful, social support, matchmaking, mobile devices, services	Older adults, helpers	Location, user information	GPS, manual	User-based, interface	Prototype
[38]	System	Playful, task support, social interaction, activity support, mobile devices	Intergenerational	Location, user information	GPS, manual	Content	Prototype
[45]	System	Navigation, mobility, intervention, activity support	Older adults	Location, user information	GPS, manual	Route	Prototype
[79]	System, study	Task support, social interaction, information system, services	Older adults, friends	N/A	N/A	N/A	Concept
[47]	System	Monitoring, services	Older adults, care personnel	Location, movement, health	Sensors, GPS	User-based	Prototype
[40]	System	Navigation, task support, information system, mobile devices, services, tools	Older adults	Location, activities, situation	Sensors, GPS, manual, radio frequency	User-based, route, interface, content, automatic	Prototype
[91]	System	Monitoring, accident management	Older adults, care personnel	Location, movement, health	Sensors, GPS	N/A	Prototype
[42]	System	Physical, SNS, activity support	Older adults	N/A	N/A	N/A	Concept
[42]	System	Physical, shared content, information system	Older adults	N/A	N/A	N/A	Concept
[41]	Service	Task support, presence, learning, services	Older adults	N/A	N/A	N/A	Market-ready
[92]	Study	Home automation, services	Older adults	N/A	N/A	N/A	Completed
[39]	System	Social interaction, shared content, activity support, matchmaking	Older adults	Activities, user information	Manual	User, content	Activities, user information
[93]	System	Task support, information system, mobile devices	Older adults	Location, activities	Radio frequency	Content	Prototype
[94]	Service	Task support, learning	Older adults	User information	N/A	N/A	Ongoing
[95]	Study	Services, tools	Older adults	User information	Manual	N/A	Completed, concept
[43]	System	Task support, mobility, social interaction, information system	Older adults	User information, activities	Logging, manual	User-based, content	Prototype
[96]	System	Social interaction, shared content, presence, social support, matchmaking	Older adults	Location, activities, user information	Manual	User-based, content	Prototype
[46]	Study	Mobility, social support, matchmaking, services	Intergenerational	Location, intention user information	N/A	N/A	Completed
[97]	System	Task support, social support	Older adults	Situation, user information	Manual	N/A	Prototype
[98]	System	Social interaction, presence	Older adults	N/A	N/A	N/A	Prototype
[99]	System	Task support, communication, social support, matchmaking, information system	Intergenerational	Intention, communication	Sensors, manual	User-based, content, automatic	Concept
[100]	System	Task support, social interaction, presence, social support	Intergenerational	User information	Manual	N/A	Prototype

Table 4 continued

Ref	Type	Context	User	Information	Tracking	Adaption	Status
[101]	system, study	Task support, mobility, information system	Older adults	Location, intention, situation, user information	Sensors, manual	User-based	Concept
[44]	System	Shared content, information system	Older adults	N/A	N/A	N/A	Prototype

application context, user group, gathered information, tracking technology, system adaptation, and status of the approach, and thus, provided an overview of the state of the art.

The results of the categorization make it possible to point out what aspects of assisting older adults in urban areas have been intensively investigated and what aspects provide major challenges and potentials for future research (research question 2). In the following sections, the classification results are discussed and summarized into potential research topics when focusing on urban areas.

Potentials of Current Approaches

Existing literature addresses many challenges arising from a growing number of older adults living alone in urban areas. Age-related impairments, social isolation, and a growing need of social and financial support are addressed by technologies that support older adults in maintaining an autonomous and socially included life.

Single-user applications mainly provide highly specialized solutions for one or more specific tasks, mostly in everyday settings. Studies point out significant positive effects on the autonomy and well-being of older adults achieved by cognitively inspired computing systems, e.g., monitoring older adults, analyzing activities, and predicting behavior. In addition, a wide range of sensor technology is used to gather information on the user and their usage situation. Based on gathered information, an increasing amount of research uses adaptive technology to create suitable navigation, interfaces and system behavior. Systems are able to automatically choose suitable services based on the situation. While preferences of the provided applications also have the potential to be automatically adapted, most approaches apply manual adaptations. Many of the analyzed contributions present prototypes that have been used to investigate socio-technological research questions. However, an increasing number of prototypes consider requirements for implementing technologies for older adults and thus have the potential to be introduced to the market.

To deal with global demographic development and the consequently changing situation for older adults in urban areas, it becomes crucial for older adults to retain the basic precondition to engage in social interaction within their neighborhood structure. When taking into account the heterogeneous requirements of an older user group, single-user applications bear the potential to support this process, by monitoring and reflecting conditions, enhancing abilities through individualized cognitive therapy, or providing individual task support. A major potential of single-user applications for older adults emerges with their knowledge of and integration in the local area. Urban areas usually offer a variety of structures, e.g., cultural, educational, or touristic locations and events, which provide useful content for applications and, furthermore, may be used to analyze the lifestyle of an individual person.

Likewise, applications that support community interaction have the potential to be improved using this information. Assistive technologies on this level provide tools for synchronous or asynchronous explicit and implicit communication, or systems for multi-user interaction. By those means, older adults are enabled to partake in social interaction with a specific group of people. Nevertheless, most of the presented applications refer to home or work environment solutions. While an increasing number of approaches addresses mobility, the potentials connected to urban structures, e.g., extensive public transportation networks, exceed the mobility reflected in current research. In addition, information on the urban location and usage context can be used to support communication by providing ad hoc conversation topics and thus encouraging older adults to engage in social interaction and connect with peers.

Few approaches already recognize the potential of supporting local urban community structures. They present technologies to enhance accessibility of urban buildings for older adults, point out useful information, or encourage shared activities in the neighborhood. When analyzing these contributions, it becomes clear how innovative technologies that were originally implemented for another purpose can be adapted and used to support and investigate urban structures. By those means, existing assistive technologies for individual support and community interaction may be enhanced in terms of achieving a direct influence on urban areas in addition to the indirect influence. All

presented technologies have the potential to support local community structures and older adults living within. However, in order to directly impact urban structures, there are many challenges that need to be considered in future research.

Challenges of Assisting Older Adults in Urban Areas

Given the existing literature, future research is confronted with a multitude of challenges when developing assistive technology systems for urban environments. Cities are confronted with an increasing number of older adults living in single-person households, a rapidly changing population, increasing distances between family members and friends, and thus a higher degree of isolation of older adults. These trends direct researchers toward seizing opportunities to support social interaction and making use of existing information and services which leads to a *challenge for system integration*. However, spatial conditions must be considered when adapting research prototypes to realistic settings. Many technologies presented in "Results" section do not take boundaries into account that occur when they are operated in-between buildings and heterogeneous network systems, resulting in a challenge for systems being *context-adaptive*. Advanced wireless network and sensor technologies and the integration and interchange of multiple solutions should be considered to avoid connection losses and technology failures.

An increasing number of projects focus on developing middleware solutions for assistive technologies that systematically gather data and allow for interoperability of different services trying to tackle these challenges. Nevertheless, a majority of analyzed contributions do not integrate connection requirements, but develop encapsulated systems, thus not considering the integration challenge very well or ignoring it completely. Standardized interfaces and data security measures must be composed to transfer technologies into real user groups and contexts. Additionally, it is important to *consider heterogeneous abilities and allow for adaptation*. In the reviewed literature, many projects develop technologies according to physical or cognitive impairments of older adults. Most of these technologies still follow a pessimistic view of older adults, while research states that the user group of older adults is characterized by heterogeneous abilities and requirements [3], ranging from people who are in need of care to people who actively shape their surrounding community. Adaptive systems have the potential to provide suitable interfaces and content for older individuals with varying abilities and preferences, when they implement adequate tracking and analysis using methods of cognitively inspired computing.

Another major challenge of future assistive technologies for older adults is the *market uptake* of research results. Though many research projects create suitable technologies for supporting individual capabilities and fostering social interaction, few technologies are actually introduced to the market. One of the barriers mentioned in previously discussed literature is the technology skepticism and the lacking acceptance within the user group of older adults. However, with changing technology literacy of older adults and close living spaces of young and old, future older adults can be characterized by curiosity and interest toward developments.

Considering this change of the attitude toward technology, the implementation of existing approaches and research results into assistive technologies for older adults in urban areas becomes increasingly feasible. When these technologies are designed while *taking into account existing urban structures*, they bear the potential to become an integral part of urban life. The challenges arising with integrating technologies in urban social settings are not yet sufficiently covered by current approaches. Therefore, more research on the impact of such technologies and possible long-term effects should be conducted.

Directions for Future Research

With a growing number of older adults in urban areas, the need for connecting various generations of people to sustain social support has increased. Thus, demographic changes do not only lead to challenges for AAL, but offer great potential for the development of supportive technologies. Suitable assistive systems contribute in connecting neighborhood communities and creating spaces for intergenerational exchange. The support of these structures promises great potentials in terms of coping with care issues and isolation. An increasing number of older adults in urban areas also bring together people with similar interests or problems as well as many retirees willing to contribute to social structures and looking for shared activities. Therefore, community services need to be adapted to older adults helping in the society. Considering these structures, the demand of technologies for social matchmaking will potentially grow. Little of the presented literature takes these structures into account, e.g., systems which connect older adults with voluntary helpers, which finally leads to the challenge of fostering the interaction of social and technical systems.

AAL systems can potentially prevent isolation and decreased mobility that arise from changing urban structures. Although we perceived applications supporting individual users or social interaction to have an indirect influence on urban areas, there is much more potential to directly enhance and assist urban structures by designing and implementing assistive technologies. Furthermore, when

spatial and social environments as well as individual needs are adequately considered, future research can meet the challenges mentioned above and benefit from the opportunities within local communities. In summary, we were able to identify the four major topics for future research on AAL systems for older adults in urban areas, which include, but are not limited to, the following research problems:

1. System integration: Technologies to record information should be integrated within a holistic approach regarding all available information. Furthermore, systems must be able to operate even when certain information is not available. Future research needs to focus on how to support a standardization process and spread results among researchers and developers.
2. Context and user adaptivity: Although adaptation based on the user and their situation has been tackled in various works, issues when focusing on older adults and multi-morbid impairments are still not completely solved. Some research results already point out the importance of adaptation when focusing on older adults and, e.g., present a design space for adaptation [102]. However, this work is not differentiated enough to address the challenges arising with a wide range of abilities and requirements.
3. Market uptake: While there are a variety of approaches in research, only a few are actually introduced to the market. To actually support older adults living in urban areas, attempts to uptake research results for market-ready products should be increased and supported by policymakers. Research questions will address how to deal with established structures (e.g., in healthcare) and how to transfer research outcome into existing products.
4. Interaction of social and technical systems: Many novel technologies have been developed and evaluated. With a minimal effort, these might be introduced into local social contexts in order to be available and visible for older adults, leading to further research on user-centered design and user involvement in creating suitable systems as well as the evaluation of long-term effects of implementing technical systems into urban structures.

The presented aspects provide possible directions for future research when trying to support older adults living in urban areas.

Conclusion

Within this contribution, we classified existing literature of the last decade focusing on assistive technologies for older adults. We examined many technologies that have an impact on older adults living in urban areas by directly or indirectly influencing the utilization of urban structures. By means of sorting these technologies into different categories, potentials and challenges for future research technologies for older adults in urban areas could be identified. However, with the emerging focus on assistive technologies, every publication provides a new insight of potential support for older adults in urban areas. Due to the interdisciplinary character of assistive technologies, the presented literature does not cover all approaches. To receive a complete overview, further databases (e.g., of medical and socio-technical disciplines) should be investigated. Nevertheless, this literature review contributes in achieving an overview of technologies that have been developed from a computer science perspective. The presented classification helps future research to identify potentials when creating novel technologies and thus, provides a benefit for researchers in cognitively inspired gerontechnology. A growing target group living in urban areas will cause upcoming challenges but also high potentials for future work in the area of AAL that focuses on local communities.

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