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Mapping the landscape of Hospital at home (HaH) care: a validated taxonomy for HaH care model classification

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Abstract

Background Hospital at home (HaH) care models have gained significant attention due to their potential to reduce healthcare costs, improve patient satisfaction, and lower readmission rates. However, the lack of a standardized classification system has hindered systematic evaluation and comparison of these models. Taxonomies serve as classification systems that simplify complexity and enhance understanding within a specific domain.

Objective This paper introduces a comprehensive taxonomy of HaH care models, aiming to categorize and compare the various ways HaH services are delivered as an alternative to traditional hospital care.

Methods We developed a taxonomy of characteristics for HaH care models based on scientific literature and by applying a taxonomy development framework. To validate the taxonomy, and to analyze the current landscape of HaH models we matched the taxonomy to HaH care models described in literature. Finally, to identify types of HaH care implementations, we applied the k-means clustering method to care models represented using the taxonomy.

Results Our taxonomy consists of 12 unique dimensions structured into 5 perspectives following the progression from triaging, through care delivery, operational processes, and metrics for success: Persons and roles (2 dimensions), Target population (1 dimension), Service delivery and care model (6 dimensions), outcomes and quality metrics (2 dimensions), and training and education (1 dimension). Cluster analysis of 34 HaH care models revealed three distinct types: One cluster (50%, 17/34) focuses on patient eligibility and home environment suitability, a care model to be chosen for clinically complex patients. A second cluster (29.4%, 10/34) aggregates technology-enabled models using telemedicine and remote monitoring that are adaptable across settings. This type could be chosen for generalizable care. The third cluster (20.6%, 7/34) includes complex interventions involving informal caregivers and advanced medical devices, requiring caregiver training, supportive policies, and user-friendly technology to reduce caregiver burden and improve safety.

Conclusions The clusters identified highlight practical considerations for adapting HaH care approaches to patient and contextual needs. These findings can guide policymakers in developing guidelines and assist practitioners in tailoring HaH care models to specific patient populations. The challenges encountered in collecting information on different characteristics of the taxonomy underscore the urgent need for more comprehensive and standardized reporting in scientific papers on HaH interventions.

Keywords Hospital at home, Care model, Taxonomy, Validation

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Introduction

According to the definition of the World Hospital at Home Community, "Hospital at Home/ Hospital in the Home (HaH) is an acute clinical service that takes staff, equipment, technologies, medication and skills usually provided in hospitals and delivers that hospital care to selected people in their homes or in nursing homes. It substitutes for acute inpatient hospital care" [1]. Although already well established in the United States, Spain and other countries since years [2], HaH care models gained in interest as reaction to the restrictions during the COVID-19 pandemic [3], and the related need for reducing hospital admissions to limit the risk of infections. HaH, also known as home hospitalization, is a model of care where patients are treated in their own homes rather than in a hospital bed, managed by a dedicated team with clear clinical responsibilities [4]. HaH care operates within a time frame ranging from days to weeks [5]. It requires specialized multidisciplinary teams trained to provide treatment and care at home.

Despite increased interest due to recent technological advances and the COVID-19 pandemic [3], the implementation of HaH care models still faces significant challenges. In previous work considering publications published before June 2022, we found that technology is still rarely used in HaH care models. Out of the broad range of technological means available in the context of digital health and eHealth, basically communication technology is involved to realize 24/7 support at home. A recently published Cochrane Review on HaH care approaches gathered qualitative research evidence on the factors that influence the implementation of admission avoidance HaH and early discharge HaH care, taking into account the perspectives of different stakeholders, including policy makers, health service managers, health professionals, patients and carers [6]. The identified factors motivate the development of a taxonomy for HaH care models. For example, the findings of the review highlight multiple factors influencing implementation, from stakeholder engagement to safety concerns to workforce requirements. A taxonomy could help organize and classify these various implementation factors. Different criteria for patient eligibility and referral were specified for individual HaH care approaches which could be standardized by a taxonomy. With HaH services expanding, a taxonomy could provide a common language and framework to describe different service models. It would allow to more easily compare different models of HaH care, assess their effectiveness, and identify which models work best for specific patient populations or conditions. Healthcare providers can use the taxonomy to plan and implement HaH care models more effectively. It can provide a framework for understanding the necessary components, potential challenges and best practices, facilitating smoother implementation and operation. Once applied as reporting standard for HaH care models, it will allow for better understanding the differences of the care models and identify gaps.

Ankuda et al. developed a taxonomy of Medicare-funded home-based clinical care using fee-for-service Medicare claims [7]. The resulting taxonomy consists of five dimensions: home-based medical care (physician, physician assistant, or nurse practitioner visits), home-based podiatry, skilled home health care, hospice, and other fee-for-service home-based care. This taxonomy provides a classification schema for home-based services and assesses the size and scope of the population they reach. Saba presents in her paper an overview of the Home Health Care Classification (HHCC) System, highlighting its two interconnected taxonomies: the HHCC of Nursing Diagnoses and the HHCC of Nursing Interventions, both organized under 20 Care Components [8]. Valentijin et al. developed a taxonomy for integrated care [9]. Their taxonomy considers dimensions representing different levels of integration, e.g. clinical integration, professional integration or organizational integration. None of these taxonomies captures the complex and multifaceted services of HaH care.

Thus, the objective of this study is to develop and validate a taxonomy for HaH care models**.** In particular, we are focused on the following research questions: 1) What are the characteristics of HaH care models? 2) Which cluster of HaH care models can be identified using the characteristics in the taxonomy?, and 3) Which distinctive properties exist to characterize HaH models of care?

Methods

To answer our research questions, we applied the three steps shown in Fig. 1. We developed a taxonomy based on HaH care approaches described in scientific literature. To validate the taxonomy and form clusters, we applied the taxonomy to HaH care models reported in literature in the last two years. We deployed a cluster analysis and identified 3 HaH care model archetypes. The contributions of this work are to present a taxonomy of HaH care models for describing basic characteristics of these models of care and to identify archetypes of HaH care models.

Taxonomy development procedure

This first step aims to develop a taxonomy that captures the complex and multifaceted services of HaH care. For this purpose, we applied a formalized taxonomy-building approach as outlined by Nickerson et al. [10]. This method is particularly well-suited for our objectives because it outlines essential steps and incorporates two optional, iterative processes for both the conceptual

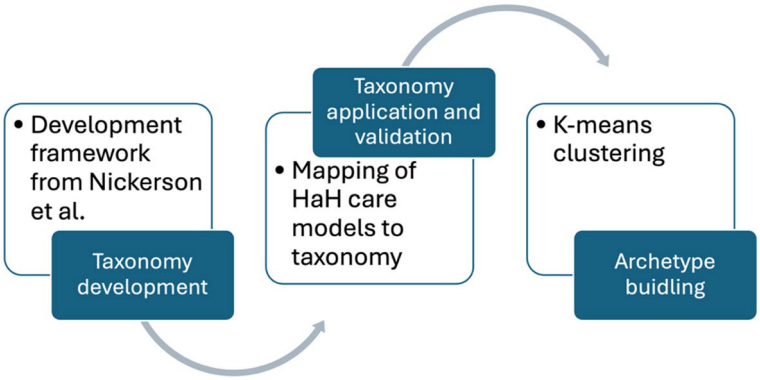

Fig. 1 Overview of the research steps; HaH: Hospital at Home

construction and empirical evaluation of our taxonomy. Nickerson et al. define a taxonomy T as a set of n dimensions D_i (i = 1, ..., n), with each dimension consisting of k_i ($k_i \geq 2$) mutually exclusive and collectively exhaustive characteristics C_{ij} (j = 1, ..., k_i) [10]. Table 1 shows how we adapted the taxonomy development process of Nickerson et al.

First, we established the meta characteristic. As defined by Nickerson et al., the meta characteristic is the "most comprehensive characteristic that will serve as the basis for the choice of characteristics in the taxonomy" [10]. For our study, we identified the meta characteristic as: The intervention characteristics of HaH care models. The choice was made for several reasons:

- Comprehensiveness: Intervention characteristics define and differentiate HaH care models.
- Relevance: These characteristics are essential for describing the intervention in detail, providing a foundation for understanding how different HaH models operate.
- Comparability: This meta characteristic allows for meaningful comparisons between different HaH models, highlighting similarities and differences in their approach to care.

The second step involved defining the ending conditions. We adopted the five subjective ending conditions proposed by Nickerson et al.: the taxonomy should be concise, robust, comprehensive, extendable, and explanatory [10]. In the third step, we decided on the approach to taxonomy development, which we determined to be conceptual to empirical. In the fourth step, we abstracted a preliminary conceptual taxonomy structure based on a previously conducted literature review [11]. That review was conducted in June 2022 considering publications from the past 10 years and was based on the preferred items for systematic review and meta-analysis (PRISMA) statements. It considered 42 articles from 2013–2022 describing HaH care models. The review's objective was to identify strengths and weaknesses, opportunities, and threats associated with HaH models of care; and to suggest a research agenda. PubMed was searched for papers

Table 1 The 7 steps of the Nickerson et al. framework for taxonomy development and its adaptation in this study

The 7 steps by Nickerson et al.	Adaptation to our work
1. Determine meta-characteristics	1. The meta characteristic is the intervention characteristics, i.e. we only include characteristics related to the intervention
2. Determine ending conditions	2. We consider 5 subjective ending conditions: taxonomy should be concise, robust, comprehensive, extendable, and explanatory (Table 2)
3. Decide on approach (empirical to conceptual or conceptual to empirical)	3. We follow a conceptual to empirical approach
4. Conceptualize (new) characteristics and dimensions of objects	4. A preliminary conceptual taxonomic structure is abstracted based on a literature review conducted by the author on HaH care models [11]
5. Examine objects for these characteristics and dimensions	5. Characteristics and dimensions are added to the taxonomic structure based on a Cochrane review [6]
6. Create (revised) taxonomy	6. A revised taxonomy is developed and reported in this work
7. Check whether ending conditions are met	7. Ending conditions are tested by applying the taxonomy to additional care models found in literature. Revisions to the taxonomy are made as needed. Ending conditions are confirmed

reporting on concrete concepts and implementations of HaH care using the keywords "hospital at home" OR "care at home" OR "patient at home". Out of the 1371 identified papers, 143 full texts were assessed for eligibility. 42 papers were considered for taxonomy development. They included papers published between January 2013 and July 2022. The resulting initial taxonomy structure was discussed with the research community at the pHealth conference 2024 [12]. Additionally, we extended the initial version by characteristics of HaH care models that were considered in a Cochrane review on factors influencing implementation of HaH that was published in 2024 [6]. The review describes the HaH care models included in their review. For extracting characteristics from this publication, we applied OpenAI's GPT4 with the prompt "Extract a taxonomy to describe hospital at home care models from the paper". The result was used to add additional dimensions and characteristics to the previously created taxonomy structure when needed.

To determine whether the ending conditions (see Table 2) were met, we applied the initial taxonomy to the HaH care models identified through a literature review (see section Taxonomy application). We considered the taxonomy to be robust and comprehensive if no additional characteristics or dimensions needed to be added. The taxonomy meets the condition of extendibility if new dimensions and characteristics can be incorporated during the validation process. The descriptions of the dimensions and characteristics have been carefully crafted to ensure that they are explanatory, and all of them are detailed in this paper. To maintain conciseness, we avoided adding a new characteristic for each new item, but instead checked whether it could be integrated into an existing characteristic.

Taxonomy application

To validate the proposed taxonomy, we identified HaH care models reported in literature by conducting a literature review based on the PRISMA statements [13]. The full search strategy is provided as Appendix 1. We considered the time between July 2022 (the time when the previous review stopped) and June 2024, which covers the time after the review that formed the basis for the initial taxonomy development. This specific timeframe was chosen because it encompasses the period immediately following the acute phase of the COVID-19 pandemic, during which numerous HaH care approaches were rapidly implemented in real-world settings. By including publications detailing care approaches developed and refined during this time, we aimed to capture a diverse set of methodologies that reflect the varying restrictions and adaptations necessitated by the pandemic. This focus on a recent and dynamic period ensures that our taxonomy is grounded in contemporary practices and is adaptable to evolving healthcare needs.

We applied the same search strategy as in the previous review [11]. Specifically, we searched PubMed with a *search string, consisting of "hospital@home" and its most prominent synonyms: "hospital at home" OR "care at home" OR "patient at home"* OR "hospital in the home" OR "home Hospitalization". We applied the following eligibility criteria:

1. The publication is written in English.
2. The publication is a peer-reviewed conference paper or journal article.
3. The publication has been published between June 2022 and June 2024.
4. The publication has at least 5 pages.
5. The publication presents a concrete HaH care model implementation.

We excluded publications with less than 5 pages to ensure a certain quality of the paper assuming that a publication with a minimum number of pages provides enough details to describe a care model. The search was conducted on June 12, 2024 and resulted in 360 results. 96/360 papers (26.6%) were included after title-abstract screening. 62/96 additional papers (64.6%) were filtered out during the full text assessment due

Table 2 Subjective ending conditions for a taxonomy for H@H care models

Subjective ending condition	Description
It should be concise	The taxonomy should avoid having an excessive number of dimensions or characteristics within each dimension, as this could make it overly complex and challenging to understand and implement
It should be robust	The taxonomy should offer a comprehensive set of dimensions and characteristics to maintain relevance. Additionally, these dimensions and characteristics should enable effective differentiation among HaH care models
It should be comprehensive	The taxonomy should include all dimensions and characteristics to classify all HaH care models of interest
It should be extendible	The taxonomy should accommodate the inclusion of new dimensions and categories within existing dimensions as new HaH care models emerge
It should be explanatory	The dimensions and characteristics should adequately describe the objects of interest

to unavailability of the full text, not fulfilling the eligibility criteria, i.e. wrong document type (commentary, letter to editor, case report), written in foreign language, no concrete HaH care model described, insufficient information on care model. 34/96 papers (35.4%) were included in the data extraction according to the taxonomy.

For each paper, the information on the HaH care model was reviewed and matched with the characteristics in the taxonomy. The data was filled in a standardized Microsoft Excel (Microsoft Corp) spreadsheet. When necessary, characteristics were added to the taxonomy.

Archetype building

The taxonomy organizes HaH care models into dimensions, but we also aim to uncover latent relationships and patterns among the care approaches. These patterns manifest as archetypes, which are high-level representations that encapsulate commonalities across care approaches. Such archetypes can guide stakeholders in recognizing and categorizing their HaH models within a broader landscape.

To identify these archetypes, we apply an unsupervised clustering algorithm, specifically k-means clustering, implemented using scikit-learn (version 3.10, Python Software Foundation). This algorithm was used to automatically recognize patterns in our extracted features [14] by grouping similar data points into clusters. To determine an appropriate number of clusters as input value for k-means while maximizing the distance between clusters, we used the elbow method [15]. This analysis suggested that three clusters provided the best fit for our data set (see Fig. 2).

Results

Overview

Our taxonomy consists of 12 unique dimensions structured into 5 perspectives following the progression from triaging, through care delivery, operational processes, and metrics for success (Fig. 3): Persons and roles (2 dimensions), Target population (1 dimension), Service delivery and care model (6 dimensions), Outcomes and quality metrics (2 dimensions), Training and education (1 dimension). Each dimension aggregates between 1 and 20 characteristics. The dimensions "Operational model" (with the characteristics hospital-managed programs, third-party providers, insurance driven models) and "Care delivery approach" with its 3 characteristics in-person care, telemedicine care, hybrid care were added based on the information extracted from the Cochrane review [6] using ChatGPT. Two dimensions were renamed based on that input: "Target population" was renamed "Patient selection criteria". Dimension "Service delivery" was changed to "Clinical application". The characteristics of the dimension "Clinical applications" were modified to "Post acute care" (rehabilitation, palliative care), "Acute medical care", "Continuous care for chronic conditions". We replaced the characteristic "Wearables and sensors" by a higher-level concept "Remote monitoring" and rephrased "Patient apps and online audiovisual and communication platforms" to "Digital health tools for patients (incl. audiovisual material online). The

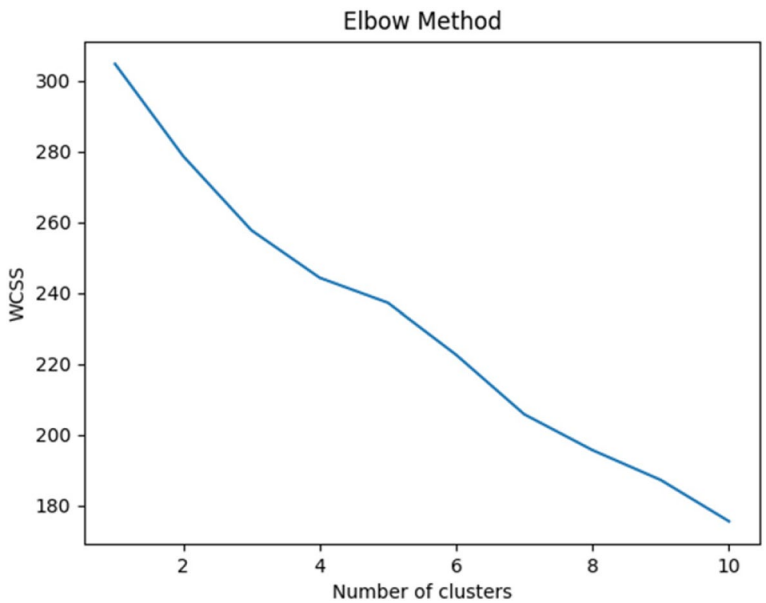

Fig. 2 Elbow plot for selection of number of clusters for k-means clustering

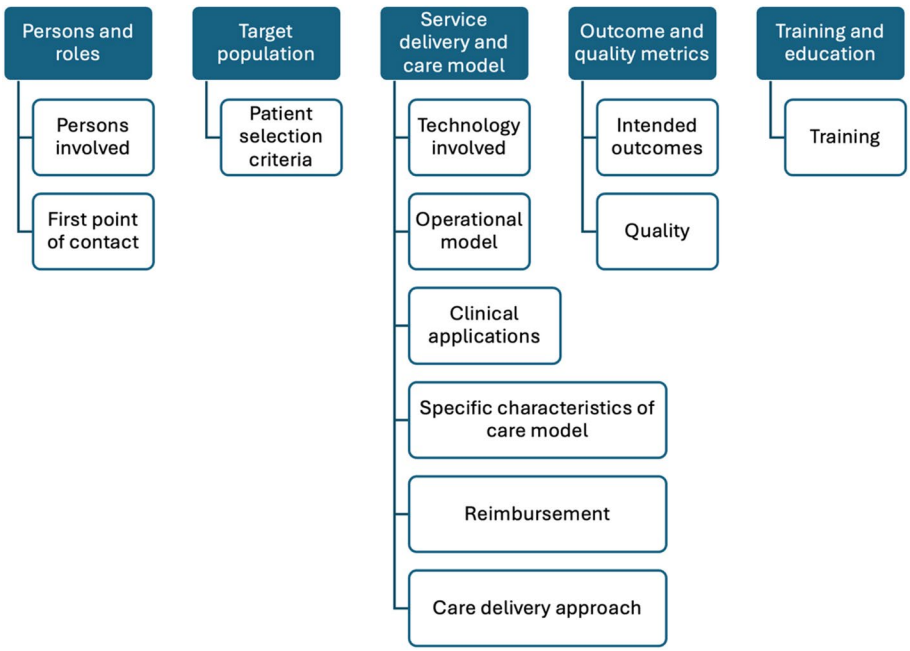

Fig. 3 Taxonomy overview: The HaH taxonomy comprises 5 perspectives (blue boxes) and 12 dimensions

characteristics Clinical eligibility and Technological readiness were added to the dimension "Patient selection criteria". Clinical outcomes and Patient Satisfaction were added to the dimension "Quality". The result from the ChatGPT request is provided in Appendix 3.

In the process of applying the taxonomy to care models, we added 16 additional characteristics to the dimensions:

- Quality (Family satisfaction, Prescription of drugs, Health-related quality of life, Occurrence of infection, Duration of intervention, Travel time saved, CO_2 reduction, Falls incidents, Services received, Mortality, Adverse effects, Emergency department usage);
- Person involved (Dietician, Pharmacist),
- Clinical Application (Diagnostic), and
- Purpose (Optimize resource utilization).

Further, 2 dimensions were added: Specific characteristics (Risk management), and Training (Patient education, Relative education, Staff training).

Persons and roles

The perspective Persons and Roles comprises 2 dimensions that are "Persons involved" and "First point of contact". The dimension "Persons involved" captures the human resources involved within HaH care models. It includes as characteristics: 1) informal caregivers, relatives and friends (who provide non-professional support), 2) healthcare providers (family doctor, clinicians, specialists), 3) nurses, 4) emergency department staff, 6) paramedics, 7) social workers, 8) mental health support (includes psychologists, psychotherapists), 9) rehabilitation staff (aggregates physiotherapists, occupational therapist, speech therapist…), 10) pharmacists, 11) dietician, 12) technology-related staff. Technology-related staff are professionals who provide technical support for the technologies used such as electronic health records, medical devices, remote monitoring and telehealth devices (i.e., medical/health informatics professionals, information technology professionals, biomedical engineers).

The dimension "First point of contact" refers to the first contact point that the patient is interacting with to decide on inclusion in a HaH care model. These are 1) the emergency department, 2) a hospital ward, 3) an outpatient department, 4) family doctor, or 5) telephone triage.

Target population

The perspective Target population consists of one dimension, the "patient selection criteria". These are criteria checked when admitting a patient to HaH care and therefore focuses on the candidates' eligibility criteria for receiving HaH services. These characteristics are:

- Medical condition(s): The specific health conditions to be managed at home.

- Demographics: Patient characteristics such as age, gender, socio-economic status, etc. that may influence the appropriateness for receiving HaH care.
- Literacy level: Health literacy of patients.
- Social support: Presence or absence of caregivers and a social network that can provide health supports and interact with health professionals providing care.
- Adequate living conditions, e.g. distance to the hospital
- Clinical eligibility (e.g. whether patient is stable, severity of disease).
- Technological readiness of patient.

Service delivery and care model

The Service delivery and care model perspective aggregates 6 dimensions: "Technology involved", "Operational model", "Care delivery approach", "Clinical applications", "Specific characteristics of care model", and "Reimbursement".

The dimension "Technology involved" describes the technological tools used to deliver HaH care or to support care provision including monitoring. We distinguish the following characteristics:

- Communication technologies: These technologies support interaction between patients and care providers for routine and emergency situations.
- Remote monitoring (wearables, sensors, Internet-of-Things technologies): These include sensors in the patient's home to support monitoring of health status. Wearables are sensors worn by patients to collect data for monitoring purposes. Internet-of-Things sensors can monitor activities of the daily life (e.g. cooking by switching on/off the oven).
- Diagnostic instruments: They are used to support patient assessments and monitoring; for example, point-of-care laboratory tests, ultrasound, vital signs monitors.
- Digital health tools for patients: Digital health provides multiple means to support patients at home. This can be for example recommendation systems, skills training apps, or augmented or virtual reality applications for treatment. They support patient engagement, self-management, education, and decision making.
- Tablet/Laptop/PC provided for patient use. To allow the patient to use specific digital tools that are part of the HaH care model, they can be provided with the appropriate technical means.
- Medical devices for treatment. These include specific devices that are required to deliver care and treatment at home (e.g. phototherapy [16]).
- Electronic health records and documentation systems can be used to report patient data.
- Assistive technologies for healthcare professionals help to analyze data collected from sensors or entered manually. Examples include a monitoring dashboard for healthcare professionals, medical alert systems, medication management system, or a decision support system.

The dimension "Operational model" describes who manages and operates the HaH care model. This can be categorized into three main types:

- Hospital-managed: The hospital directly oversees and operates the HaH program.
- Third-party provider managed: An external healthcare organization or company manages the HaH services.
- Insurance-driven: Health insurance companies initiate and manage the HaH program for their policyholders.

The "Clinical Applications" dimension encompasses five key characteristics of care provided in the HaH setting:

- Post-acute care: Includes rehabilitation services and palliative care for patients transitioning from hospital to home.
- Preventive care: Focuses on proactive health measurements to prevent hospitalizations or complications.
- Acute medical care: Provides hospital-level care for acute conditions that can be safely managed at home.
- Continuous care for chronic conditions: Offers ongoing support and management for patients with long-term health issues.
- Diagnostic services: Enables various medical tests and assessments to be conducted in the home environment.

The "Reimbursement" dimension refers to the payment model underlying the HaH care approach. Several reimbursement models can be used to finance HaH care models programs [17]: Health insurance coverage can be realized for example by traditional fee-for-service payment or within value-based care models. Bundled payments can be realized as condition-specific bundled payments, global budgets for HaH services or episode-based care payments.

The "Care delivery approach" dimension refers to the methods used to provide care in the HaH setting. In-person care includes home visits by healthcare professionals

including physical examinations and treatments. Telemedicine care are virtual consultations with physicians, specialists or nurses or also remote patient education and counseling. Telemonitoring means continuous monitoring of vital signs which could be realized by wearable devices or home-based medical equipment. Hybrid care are any combinations of the above mentioned approaches.

For the dimension "Specific characteristics of the HaH care model" we found one characteristic, which is emergency handling. This means whether the HaH care model implements specific emergency handling strategies to ensure patient safety.

Outcomes and quality metrics

The Outcomes and quality metrics perspective encompasses the "Intended outcomes / purpose" dimension and the "Quality/Outcome metrics" dimension.

HaH care models are designed for a specific purpose or intended outcome. These can include:

- Early discharge,
- Avoidance of admission,
- Improving care outcomes,
- Economic efficiency of care,
- Improving patient safety,
- Improving patient satisfaction,
- Optimizing resource utilization.

The "Quality/Outcome Metrics" dimension encompasses various aspects used to evaluate the effectiveness, safety, and overall performance of the HaH care model. These metrics can be categorized as clinical outcomes, effectiveness and efficiency, patient experience, provide impact, and environmental impact.

Clinical outcomes are: mortality rate, readmission rate, frequency of return to hospital, adverse events, occurrence of infections, falls incidents, health-related quality of life. Effectiveness and efficiency comprise: Clinical effectiveness, cost-effectiveness, duration of intervention, number of services received, resource utilization, emergency department usage, number of drug prescriptions.

Regarding patient experience, we distinguish patient satisfaction, patient safety (perceived), Patient trust (perceived), acceptability, and family satisfaction. Then, we have provider satisfaction and reduction of workload for healthcare providers as metrics for provider impact. Finally, the environmental impact can be quantified by kilogram CO_2 saved or travel times saved.

Training and education

From the perspective Training and education, we consider the "Training" dimension, which encompasses patient education, informal caregiver training, and staff development. Patient education empowers patients with knowledge about their condition and treatment. Further, self-management techniques are trained or the use of medical devices. Informal caregiver training equips informal caregivers with skills to support patient care. This also includes safety protocols or basic medical procedures or use of medical devices. Staff training can include training on telehealth technologies and remote monitoring systems.

Application of the taxonomy to HaH care models: characterization of HaH care models

In the following, we describe the 34 HaH care models included into the validation process of the taxonomy. The mapping result of the care models to the taxonomy can be found in Appendix 2.

Nurses and healthcare professionals are the most frequently involved persons. Informal care givers and rehabilitation staff play a role in around one third of the care models. The target population is described by the medical condition, clinical eligibility and demographics, but also adequate living conditions and availability of social support play an important role for selecting patients for being admitted to HaH care.

Most of the HaH care models are hospital-managed and are delivering acute medical care. Reimbursement models (insurance covered, bundled payment) are only mentioned once each. HaH care is delivered in person, as telemedicine care and in this way as hybrid care. Telemonitoring is applied in 9/34 cases. An emergency handling is only in place in 4/34 of the care models. 22/34 HaH care models apply communication technologies. Medical devices for treatment are used frequently. Remote monitoring, digital health tools for patients, and assistive technologies for healthcare professionals are applied in a limited number of HaH care approaches. Corresponding technical devices such as tablets to interact with the digital tool are provided rarely to the patient.

Purpose of applying HaH care is basically avoidance of admission; early discharge is reported in 12/34 cases as purpose. The main outcome metrics are the effectiveness of the care approach, the readmission rate, patient satisfaction, duration of interventions as well as adverse events. Training was rarely reported: patient education and training of informal caregivers was reported in 6/34 cases each. Staff training was only mentioned for 3/34 of the HaH care models. The complete mapping is provided as Appendix 2.

Archetypes of HaH care models

For the clustering, we removed all characteristics that were found in no or only one paper in our dataset to rely

the clustering only on features that contribute meaning to the formation of clusters. Specifically, we ignored: Patient selection criteria (literacy level, technological readiness), Clinical application (Prevention, Continuous care for chronic conditions), Intended outcome / purpose (Economic efficiency of care), Telephone triage, Reimbursement (Insurance coverage, Bundled Payment), Data management, Outcomes (Patient acceptability, Reduction of workload (Provider), Falls incidents, kg CO2 saved, travel time saved, health-related quality of life, prescription of drugs, family satisfaction), Operational model (Insurance driven models), Persons involved (Emergency department staff), Clinical application (Diagnostic).

Three clusters were formed. Table 3 shows the top 10 features per cluster while Fig. 4 visualizes the clusters as heat map. Cluster 1 has as unique characteristics two patient selection criteria (Adequate living situation at home, Clinical eligibility) and the quality metric Frequency of return / readmission. Unique characteristic of cluster 2 is communication technology. It differs from the first cluster in the patient selection criteria, and technology involved. From the third cluster, cluster 2 differs from the persons involved, first point of contact and technology involved. Cluster 3 has unique characteristics that distinguish it from the other clusters: Informal caregivers or hospital ward as first point of contact. Medical devices are involved in the care approaches of cluster 3. It distinguishes from cluster 1 by persons involved, first point of contact, patient selection criteria, and technology involved. Most papers have been assigned to the second cluster (17/34 papers, 50%). 10/34 (29.4%) papers were assigned to cluster 3 and 7/34 (20.6%) were assigned to cluster 1.

Discussion

Principal results

This paper introduced a taxonomy for describing and categorizing HaH care models. It was validated by application to 34 care models described in scientific literature. We can distinguish three types of care model variations. The most frequent HaH care model variation is a care model aiming at avoiding hospital admission, providing hybrid care supported by communication technology (Cluster 2). Care is delivered by healthcare professionals and nurses. The second most frequent care model type (Cluster 3) exploits medical devices and involves informal care giver in a care process that is delivered also as hybrid care. The third type (Cluster 1) aims to avoid hospital admission, delivers care as hybrid care, and is not supported by specific technology. Care is provided by healthcare professionals and nurses. Patients are specifically checked for appropriate living conditions and clinical eligibility.

Interpretation of the clusters

In the following, we describe what practitioners and policy makers could learn from the cluster results.

Since cluster 1 represents HaH care models that prioritize patient eligibility and home environment suitability, practitioners could learn from this to prioritize detailed pre-admission assessments to ensure patients meet medical and social eligibility criteria to minimize the risk of safety risks at home. They could also conclude that robust discharge planning and follow-up protocols should be incorporated to reduce readmission rates. Policy makers could conclude from this cluster that guidelines are needed for assessing home environments as part of HaH care delivery and patient's

Table 3 Clusters and their top 10 features grouped by dimensions

Dimension	Characteristics Cluster 1	Characteristics Cluster 2	Characteristics Cluster 3
Persons involved	Healthcare professionals, Nurses	Healthcare professionals, Nurses	Nurses, Informal caregivers
First point of contact			Hospital ward
Patient selection criteria	Adequate living situation at home, Clinical eligibility	Medical condition	Medical condition
Technology involved		Communication technologies	Medical devices for treatment
Operational model	Hospital managed programs	Hospital managed programs	Hospital managed programs
Clinical applications	Acute medical care	Acute medical care	Acute medical care
Care delivery approach	Telemedicine care, Hybrid care	Telemedicine care, In person care, Hybrid care	In person care, Telemedicine care, Hybrid care
Intended outcomes / purpose	Avoidance of admission	Avoidance of admission	
Quality/Outcome Metrics	Frequency of return / readmission		
Papers that have been assigned to the cluster	[18–24]	[25–41]	[16, 42–50]

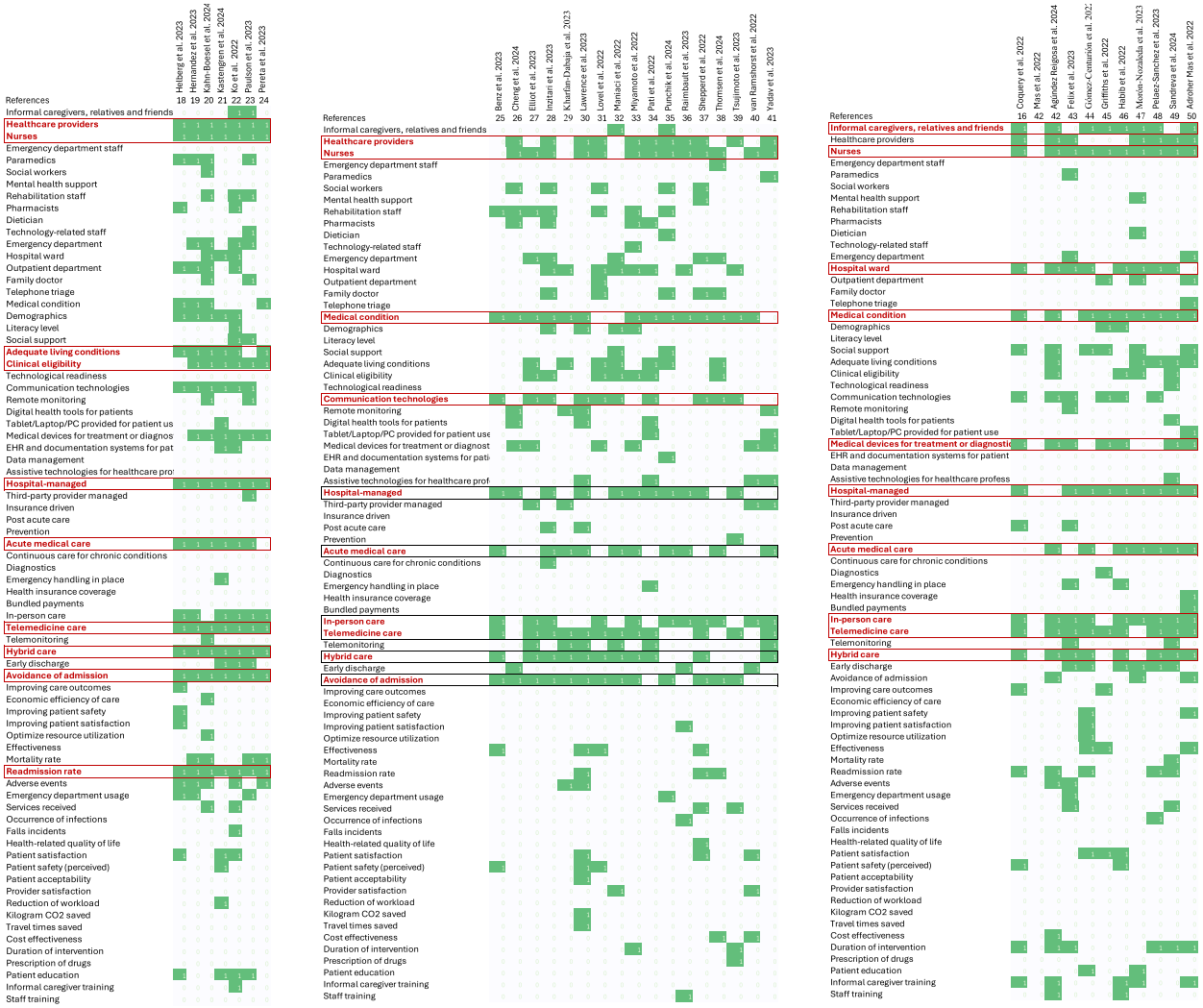

Fig. 4 Heat map of the three clusters. Characteristics are listed top-down while papers assigned to the cluster are listed from left to right. The top features are highlighted by red color. Green cells show when a care model reported this characteristic while white cells show that this care model did not report this characteristic

medical eligibility to standardized admission criteria for HaH care models.

Communication technology (e.g., telemedicine or remote monitoring) plays an important role to deliver care in models of cluster type 2. This cluster is likely to represent generalized models that do not require highly specific first points of contact or patient selection criteria, making them more adaptable to different settings. This cluster indicates that an essential success factor would be to train staff and patients how to effectively use telehealth and communication technology, ensuring continuity of care and timely intervention. Policy makers should create policies that ensure equitable access to telehealth and communication technologies, particularly in underserved or rural communities.

Cluster 3 highlights HaH models that involve informal caregivers (e.g. family members) in the provision of care and use advanced medical devices for monitoring or treatment. This type of model represents more complex interventions, often requiring high levels of caregiver involvement and technological infrastructure. In consequence, this type of HaH care model requires to provide thorough training and support for informal caregivers to enhance their readiness and reduce caregiver burden. Policy makers could support this by developing policies to support caregivers in terms of reducing

burden of work, training and financing models to support informal caregivers. Additionally, progress should be made emphasizing safety and ease of use of medical devices and other technologies that could support HaH care delivery.

Practitioners could use the clusters to match HaH care models to patient needs. A care model falling into cluster 1 could be chosen for clinically complex patients. A model following cluster 2 should be chosen for generalizable care, and a HaH care model of type cluster 3 could be adopted for caregiver-driven or device-intensive cases. Clearly, more evidence is needed that supports the three clusters.

Application of the taxonomy to describe HaH care models

The application of the taxonomy to HaH care models highlights several critical gaps in the current implementation and reporting of these approaches, especially regarding technology integration, patient readiness, and care model transparency. As already recognized by Denecke et al. [11], the use of remote monitoring technologies and digital health tools within HaH care models is still limited. This was again confirmed by our assessment. Although a small proportion of HaH approaches involves remote monitoring technologies (7/34, 20.6%) and digital health tools for patients (4/34, 11.8%), there is a lack of consideration for technological readiness and literacy levels as eligibility criteria. An example where remote patient monitoring by a cloud-based monitoring system and telemetry monitoring has been applied was presented by Kahn-Boesel et al. [20]. A full range of sensors for patient monitoring was reported by Cheng et al. who used intelligent mattress and pillows to monitor the heart rate, respiration and other data during sleep or an intelligent toilet to study urine levels [26]. Research outside our literature search highlighted the relevance of remote patient monitoring technologies for HaH care [51] and report on a shift from analog to digital [3]. At this point, we can only speculate as to why digital health and remote monitoring technologies are rarely implemented in HaH care models. Possible reasons include cost, lack of infrastructure in patients' homes and healthcare organizations, ethical concerns, or even a lack of knowledge about the tools and technologies available. Future research should explore these factors in depth to develop strategies for successful adoption of these technologies.

Only one paper [49] reported technological readiness as eligibility criteria. This omission raises concerns about whether all patients, particularly those with limited digital literacy or access to technology, can benefit equally from HaH care models. As recognized by Denecke et al. [11], the limited use of remote monitoring technologies and digital health tools points to a need for broader technological adoption and consideration of patient and caregiver capacities.

The patient's literacy level was only mentioned once explicitly [22] as eligibility criteria for admitting patients to HaH care. Bhattad and Pacifico already stated that health literacy affects patients and families before hospitalization, during their hospital stay, and after discharge [52]. To ensure effective communication, hospitals and healthcare providers should adopt a universal precaution approach, consistently applying health literacy-informed strategies. This helps patients and families understand health information, follow medical instructions, actively participate in their or their child's care, and navigate the healthcare system more effectively. However, there is an alarming lack of training for both patients and informal caregivers. Furthermore, healthcare staff themselves were not consistently reported as receiving adequate training for remote care delivery.

One important factor driving HaH care model adoption, especially during the COVID-19 pandemic, has been the high rate of admission avoidance. Several of the 34 studies in the review reported using the HaH model during the pandemic, highlighting its potential to alleviate the burden on healthcare systems by reducing in-hospital care demand.

Moreover, only one of the included studies [50] mentioned reimbursement models for financing HaH care. This omission could be explained by the clinical trial nature of the studies, which often focus on clinical outcomes rather than practical implementation issues such as payment structures. However, for broader adoption and scaling of HaH models, reimbursement mechanisms will need to be addressed. This clinical trial nature of the reported HaH care models also raises the question whether retrospective data analysis of HaH care allows to make reliable conclusions on the safety of HaH care. Yadav et al. support these concerns related to the safety of HaH care [41].

One additional dimension to be added to the taxonomy could be transport and other essential services associated with HaH care. Since related information was not well reported, we resisted on including such dimension. Beyond, we assume that there will be a broad range of services delivered at home resulting in many characteristics for the taxonomy which would complicate its application in practice and is in conflict with the taxonomy requirement of being concise.

We can recognize that HaH care models rather focus on providing acute medical care. Prevention [39] and continuous care for chronic conditions [28] was only found once in our validation dataset. This result is also reflected in the Cochrane review that focused on HaH

care models for admission avoidance and early discharge [6].

During the application of our taxonomy, we identified and incorporated several novel outcome measures, despite their singular occurrence in our dataset. These measures encompass a wide range of factors, including patient acceptability [30], reduction of workload for providers [20], falls incidents [22], kg CO_2 saved [30], travel time saved [30], health-related quality of life [38], prescription of drugs [39], family satisfaction. The inclusion of these diverse outcome measures reflects the multifaceted nature of healthcare evaluation and the evolving landscape of patient-centered care. While these measures appeared only once in our current dataset, their potential significance should not be underestimated. It is crucial to note that the relevance and validity of these newly added outcome measures require further investigation.

The "Outcome" dimension plays a crucial role in the comparative analysis of different care models. Its importance originates from its ability to provide quantifiable results, reflect patient experiences, and enable holistic assessment of care models. These outcome measures allow for a more comprehensive evaluation, considering not only clinical outcomes but also environmental, economic, and social impacts. Furthermore, robust outcome measures facilitate evidence-based decision-making, enabling healthcare administrators and policy makers to make informed choices when selecting or modifying care models. For this reason, we included all outcome metrics that were reported.

For future work, we suggest focusing on the specification of outcome measures that are specific to HaH care models. For example, patient preferences, comfort and satisfaction with HaH care models are critical to assessing its feasibility and acceptability. The development or adaptation of standardized patient-reported outcome measures specific to HaH care models is necessary to effectively capture these perspectives.

In addition, many HaH care models rely heavily on informal carers, shifting the burden of care from trained professionals to untrained individuals. Their satisfaction and experiences with the care process (e.g. support received and burden of care) are equally important to assess. Including measures reported by informal carers alongside patient-reported outcomes provides a more holistic assessment of HaH care models.

As HaH aligns with several of the United Nations Sustainable Development Goals (SDGs) (https://www.un.org/sustainabledevelopment/), outcome measures should also address environmental impacts, social inequalities, and responsible consumption and production. These dimensions are essential to ensure that HaH care not only delivers quality health care, but also contributes to broader global sustainability goals.

Practical applications of the HaH taxonomy

We envision that the taxonomy can be used when evaluating existing HaH care approaches, but it could also support designing new HaH care approaches. We present some application examples in the following.

To support the design of HaH care approaches, the taxonomy provides a structured framework that outlines the essential components of HaH care models. This framework can be used to specify the key elements of a new HaH care model. Each characteristic within the taxonomy can be addressed with concrete solutions or left blank, depending on the specific needs regarding the care model. For example, the taxonomy's list of potential technologies can help identify the technological requirements necessary for successful implementation. By structuring the planning process around the taxonomy, organizations can ensure a thorough, consistent and evidence-based approach to HaH implementation, improving both feasibility and scalability. In addition, the clusters identified can help organizations focus on specific elements of the care model that are most relevant to particular use cases, enabling more tailored and effective interventions. The taxonomy could be used to design archetypes of care models for resource-constrained settings focusing on foundational components of HaH care. Conversely, in high-resource settings, the taxonomy could be applied to develop a specialized care model considering advanced technologies for monitoring and specialists to accommodate diverse patient populations.

The taxonomy provides a systematic and comprehensive framework to support the evaluation of existing HaH care models by defining clear, standardized components and metrics for assessment. It enables evaluators to assess whether components are missing or could be added. In particular the list of quality metrics can help in defining individual criteria to judge the quality of a HaH care model.

When the same metrics are measured across care models benchmarks can be developed and care model implementations can be compared in respect to the outcome. The taxonomy could also help in analyzing gaps of a HaH care model – as it was shown by our analysis and the revealed gap of technical solutions involved for monitoring and other tasks. By providing a framework for gap analysis, the taxonomy helps identify areas where HaH care models may be deviating from best practice or failing to achieve desired outcomes.

The taxonomy could also inform the development of reporting guidelines for HaH care models. The Template for Intervention Description and Replication (TIDieR, [53]) is a reporting guidelines which aims to ensure

complete reporting of intervention details. Based on this guideline, a specific adaptation for HaH interventions could comprise the following elements:

- Brief name
- Why: Rationale and goal of the HaH intervention
- What: Materials and equipment used in HaH care, including technology
- Who provided: Detailed roles and responsibilities of the persons involved in HaH care including their training
- How: Describe the care delivery approach including interactions through technologies
- Workflow: Key processes such as patient selection, initial point of contact
- Target population: Eligibility criteria for patients including medical, function, social considerations
- Outcomes: Quality indicators used to assess outcomes including patient-reported outcomes, cost-related outcomes, safety

Future research could use this suggestion for specifying an adaption of Template for Intervention Description and Replication for HaH care models.

Limitations

Unfortunately, many studies failed to provide adequate descriptions of HaH services, further complicating the ability to assess and replicate these models. Although web sources and external databases could provide additional context, we intentionally limited our analysis to the included papers. Importantly, only one study applied a structured reporting guideline, the Template for Intervention Description and Replication (TIDieR, [53]). The absence of a detailed reporting in the studies undermines the transparency and replicability of HaH interventions.

From this limited availability of information on the HaH care approaches, we cannot conclude that the reviewed care approaches do not have the characteristics included in our taxonomy. They might be simply not reported. For this reason, we also did not excluded characteristics with only one reference from the taxonomy structure. A survey could be conducted involving the authors of the papers included in our validation process to let them provide the information along our taxonomy structure. This would give a more complete picture. Due to this limitation of reporting, we cannot definitely conclude that the landscape of current HaH approaches does not have any other characteristics or that there are other clusters of HaH care models. Ideally, future descriptions of HaH care models will follow the characteristics of the proposed taxonomy. This would allow to comprehensively describe and compare the landscape of HaH care models.

The taxonomy validation step was carried out by only one person, which raises the limitation that some reported information may have been overlooked. This introduces the possibility of subjectivity, as the individual's interpretations and decisions may have been influenced by personal biases or assumptions. To address this limitation, as a next step, a Delphi study will be conducted, engaging a panel of experts in iterative rounds of structured feedback to refine and validate the taxonomy's dimensions and characteristics. The Delphi panel will be started in January 2025. We expect three rounds to find consensus and results available after six months. In parallel, researchers and practitioners presenting HaH care models in scientific publications will be invited to apply the taxonomy to present their care models and report on their experiences. Feedback from these applications would provide valuable insights into the clarity, applicability and comprehensiveness of the taxonomy, allowing for iterative improvements. Combining the Delphi methodology with practical applications in real-world contexts will help ensure that the taxonomy evolves into a robust and widely accepted framework. An update of the taxonomy can therefore be expected in the second semester of 2025.

While clustering was used to identify archetypes of HaH care models, some rarely reported characteristics, such as insurance-driven models or environmental metrics, were excluded from the clustering process to ensure meaningful clustering. However, these characteristics were retained in the taxonomy to maintain its generalisability and applicability to a wider range of contexts. The aforementioned validation step will be instrumental in assessing the relevance of these characteristics and determining whether they should be retained or excluded in future iterations of the taxonomy.

During the application of the taxonomy to the care models, additional characteristics were added when they were recognized in the description of the care models. Before this was done, it was carefully checked whether the characteristic could be included in already existing ones. This process may have added characteristics of individual models. To ensure that the taxonomy does not include redundant characteristics, the next step would be an expert validation where redundancies and characteristics that are not of overall interest can be excluded. The ending conditions were not verified by a person not involved in the taxonomy development process. In particular, the ending condition of being explanatory still has

to be approved by persons that apply the taxonomy to describe their HaH care model.

Conclusions

In this paper, we introduced a comprehensive taxonomy for HaH care models, which was validated through its application to 34 HaH care models reported in the literature. The challenges encountered in collecting information on different characteristics of the taxonomy underscore the urgent need for more comprehensive and standardized reporting in scientific papers on HaH interventions. This gap in reporting currently hinders the ability to fully understand, compare and replicate successful models. We propose the extension of structured reporting guidelines such as Template for Intervention Description and Replication to ensure that HaH interventions are described in a transparent, replicable and comprehensive manner. Our findings also suggest that future descriptions of HaH care models should incorporate information technology readiness and health literacy of patients, staff and caregiver training protocols as well as practical considerations, including reimbursement models. By including these elements, researchers and practitioners can enhance the practical relevance and applicability of HaH models in different healthcare settings.

The taxonomy developed in this study provides a valuable framework for health care providers, policy makers and researchers to systematically evaluate and implement HaH care models. It provides a structured approach to understanding the key components and variations in HaH interventions, facilitating evidence-based decision making and care model development. In conclusion, this research makes a significant contribution to the growing field of HaH care by providing a robust taxonomy and highlighting critical areas for improvement in reporting and implementation. As health systems around the world continue to explore alternatives to traditional inpatient care, this work lays the foundation for more effective, patient-centered, and economically viable HaH models.

Supplementary Information

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Supplementary Material 1.

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Authors' contributions
I did the research described in the manuscript on my own.

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Data availability
The data extraction table is provided as Appendix 2.

Declarations

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Not applicable.

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