2022

Optimal Domotic Systems Based on Archival Data Trend Analysis

Bettina Yvette Moore
Walden University

Walden University

College of Management and Human Potential

This is to certify that the doctoral dissertation by

Bettina Yvette Moore

has been found to be complete and satisfactory in all respects,
and that any and all revisions required by
the review committee have been made.

Review Committee
Dr. Nikunja Swain, Committee Chairperson, Management Faculty
Dr. Holly Rick, Committee Member, Management Faculty
Dr. David Gould, University Reviewer, Management Faculty

Chief Academic Officer and Provost
Sue Subocz, Ph.D.

Walden University
2022

Abstract

Optimal Domotic Systems Based on Archival Data Trend Analysis

by

Bettina Yvette Moore

ME, University of Colorado, 2001

BA, Lehigh University 1991

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Management

Walden University

August 2022

Abstract

Domotics is the integration of technology into building systems. Due to the rapid growth in the use of domotic systems in recent years, the industry is struggling to establish consistency and standardization. The purpose of this archival-based qualitative case study was to identify current trends and patterns in scholarly domotic research to create an instrument to evaluate domotic system and domotic interrelationships using bibliometric searches. The facilities management and modeling system provided the framework for the study. Archival research data were examined to identify trends and patterns in domotic research and provide visualization of domotic relationships through technology trajectory mapping and technology s-curve charts. Text-mining techniques were used to explore trends and patterns in recent scholarly domotic research. The technology s-curve was used to determine trends and patterns in domotic systems design. The results included a tool for the evaluation of domotic systems, which may provide domotic designers with a tool to evaluate the progress of domotic systems. The study also provided results on trends in domotic technologies, which may be used to improve building design development.

Optimal Domotic Systems Based on Archival Data Trend Analysis

by

Bettina Yvette Moore

ME, University of Colorado, 2001

BA, Lehigh University, 1991

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Management

Walden University

August 2022

Dedication

Dedicated to my amazing husband and my entire family who have supported me through this process. I dedicate this in memory of my beautiful son, Joseph Luther Moore. LLKJJ.

Acknowledgments

I would like to thank my committee chair, Dr. Nikunja Swain and my committee member Dr. Craig Barton for all of their support and guidance. I would also like to thank my research reviewer Dr. Dave Gould and my style and format reviewer Dr. Joe Gredler. I would like to acknowledge all the subject matter experts who reviewed my work and read over the many drafts. I offer a special thanks to my family and friends for their tireless support.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction to the Study

Domotic technology has been in a significant growth mode in recent years (Hong et al., 2020) and has serious commercial implications across multiple industries. Domotics is the integration of technology into buildings. Other commonly recognized terms include ambient technologies, smart homes, intelligent buildings, and home automation. Domotic technology has had a recent boost in growth from the improvements in artificial intelligence or AI (Jimenez et al., 2021), wireless technology, the proliferation of mobile devices, the rapid development of individual applications or apps on various platforms, as well as the lowered costs of domotic components (Mustafa et al., 2021).

Domotics uses include various applications such as security (Lee et al., 2019), privacy, building systems monitoring, energy consumption and emissions, building comfort and productivity, health management, communications, entertainment, and pet care. Domotic systems are becoming prevalent in homes, corporate buildings, and industrial complexes. These systems emerged from traditional organizations like ADT Corporation (formerly American District Telegraph), Vivint (formerly APX Alarm), Xfinity (formerly Comcast), American Telephone & Telegraph (AT&T), and Verizon (formerly Bell Atlantic Corporation). Most of these organizations formerly focused on either home and building security or telecommunications, but now have expanded to customized security, mobile communications, personal health monitoring, and building accessibility.

Emerging technologies based on natural language processing are beginning to dominate the domotic market. Newer speech-based interfaces such as Apple's Siri, Google Assistant, Microsoft's Cortana, and Amazon Alexa are making domotic systems accessible at a more affordable price (Sangal & Bathla, 2019). These devices are user friendly and provide quick responses to meet customised user needs.

However, with the abundance of domotic technologies, there is a significant issue of system compatibility and integration (Antic & Papp, 2021). Many other electronics-based industries have a standard that all organizations follow to ensure the compatibility of systems, yet there is no single standard for domotic systems. Domotic systems can operate over power lines (X10 protocol), Ethernet cables (computer based, wired), Wi-Fi (mobile devices), Near Field Communications protocols, Bluetooth, and radio frequency identification tags. Each system has advantages and disadvantages, and each presents different communication and integration problems.

The design of an optimal domotic system requires effective management of system integration issues. The Z-wave Alliance protocol, ZigBee Alliance (Drubin, 2021), and the EnOcean Alliance all ensure that products within their respective alliances are compatible with each other but not with the other alliances. Other emerging alliances such as the Allseen Alliance, the Open Connectivity Foundation (supported by Intel, Samsung, and Qualcomm), and Google are forming similar standard alliances. This leaves a multitude of products and protocols that are incompatible with each other (Dragomir et al., 2016), which limits the designer's ability to design an optimal system.

Weighing system needs against functions and system compatibilities can cause major system rebuilds, increased costs, and loss of service.

The optimal design of a domotic system can improve the quality of life in many ways. The use of domotic systems is increasing in the health care arena for improving accessibility needs, for monitoring older persons and children, and for increased patient independence (Curumsing et al., 2019). Domotics have experienced significant overall growth, but they were originally based on the field of security and surveillance (Albrechtslund & Ryberg, 2011). Building safety monitoring has been a part of domotic systems from the earliest designs. Domotic systems can monitor any changes in air quality, fire, flooding, carbon monoxide levels, changes in health conditions, and other hazards.

These systems can also alert authorities if there are any dangers, emergencies, security breaches, or dangerous weather circumstances (Calvopinna et al., 2019). Domotic systems can allow remote access and monitoring for after-school care, older care, persons with limited mobility, health issues, or repair personnel. These systems are essential to energy and emissions management, as internal building comfort and productivity management including lighting; temperature; heating, ventilation, and air conditioning (HVAC); and communications controls.

The objective of the current study was to evaluate the growth, trends, and diversity of domotic systems. The result of this study was an evaluative method that can be used to assess domotic systems, features, and uses. I explored the trends and emerging technologies around domotic technologies. Chapter 1 covers the evolution and types of domotic systems, the problem statement, the purpose of this study, the research questions for this study, the conceptual framework, and the nature of this study. This chapter also includes the definitions and assumptions used in this study, the scope and limitations of this study, and the significance of this study.

Background of the Study

Research has shown that there has been significant recent growth in domotic technologies (Hong et al., 2020). However, the introduction of new systems and products occurred without much coordination or regulation. This lack of coordination occurs more frequently with the rapid proliferation of wireless and mobile technologies, proprietary solutions, and independent domotic designers (van de Kaa et al., 2021). There has not been research on integrating an intelligent domotic system into the building design or designs that consider the building’s energy efficiency or the inhabitant’s safety, security, and health while considering sustainable practices and incorporating communication protocols between the varieties of building systems, all while minimizing costs (Gluszak et al., 2019). Designers could benefit from a decision process that assists in determining the needs of the complete system while considering the various compatibility issues and integration options. The current study may assist with refining the decision-making process while addressing compatibility issues and integration options that must occur in the design process.

Although many studies have been conducted in areas of domotics and in the evaluation of domotic systems (J. Wong & Li, 2006; J. K. W. Wong & Li, 2008; J. K. W. Wong & Li, 2010; J. Wong et al., 2008a; J. Wong et al., 2008b; J. K. W. Wong et al., 2005), they have not addressed the issue of evaluating an integrated domotic system as a whole. Researchers have evaluated HVAC control systems (J. K. W. Wong & Li, 2010), assessed building performance (J. K. W. Wong et al., 2008), and reviewed the latest building systems research (J. K. W. Wong et al., 2005). The current study was conducted to build on the methods and frameworks of these studies while filling the building system evaluation gap.

Intelligent buildings, smart homes, or buildings with some type of automation through technology are common terms used to describe domotic systems. The definition of domotics is a debated topic. In fact, J. K. W. Wong et al. (2005) stated that there are over 30 definitions for domotics, and the definition continues to evolve over time. The design of early domotic systems did not include the need for heavy integration with other products due to their initial reliance on solitary components that performed only one or two functions at a time (Miori et al., 2012; Pham et al., 2018). Present systems are much more complex and must satisfy a host of needs including some of the most common crucial components: energy savings, comfort, security, communications, health monitoring, and accessibility (Cofre et al., 2012). Currently, experts do not agree on a single standard for domotic systems (Han & Park, 2017).

The magnitude of the types of building systems can overwhelm building system designers. There are many types of systems, system applications, system hardware, and system add-ons. Each of these items can add to the compatibility issues, complexity, and costs associated with creating a domotic system (Gavrila et al., 2021). Startup costs can be high, and many paybacks come far after the design process is completed. This is especially true with smart meters where it can take 20 to 30 years before the initial investment costs are paid for (Poudel, 2016). High startup system costs can deter unsure designers who are not focused on the full life cycle costs or the long-term payout of the system (J. K. W. Wong & Li, 2010). The current study addressed current research trends and patterns in domotic technologies and provided visualizations of domotics by mapping the results of searches on scholarly domotic systems. Analyzing trends and patterns may decrease selection bias and promote the optimization of the selection process by focusing on compatibility and integration components of domotic systems. Identifying trends and patterns may improve the overall effectiveness of domotic design selections and reduce compatibility and integration

Problem Statement

Bonino et al. (2009) noted the lack of consensus in domotic technologies saying "most available systems have been developed nearly in isolation. … They are based on different technologies" (p. 971). The lack of common services will hinder the full development of domotic systems and will inhibit offerings to customers (Pham et al., 2018; Poudel, 2016). The varying technologies along with the rapid, unchecked growth of domotic systems has led to an influx of domotic systems and components that are often in conflict with each other. "Project design teams need to choose the optimum amalgamation of technologies and features from available building control system packages to form a configuration that meets or exceeds the expectations of developers and end users" (J. K. W. Wong & Li, 2010, p. 261). Although there is no current domotic protocol standard, there is strong competition between Zigbee and Z-Wave for industry dominance (van de Kaa et al., 2021).

The problem addressed in the current study was the rampant growth of domotic systems and the gap in data on the future of these isolated, conflicting, or incompatible domotic system components. This problem created a challenge for domotic designers to select an optimal domotic system and system components that meet the needs of the building inhabitants. This problem was especially significant for at-risk populations due to the rise of personal safety and health monitoring as well as the increase in accessibility options for people with limited mobility. I analyzed current scholarly research to discover and evaluate current trends, patterns, and interoperability of systems through text-mining techniques to provide a guide for optimal domotic design selection. The results provide a framework to guide domotic designers through the system options available.

Purpose of the Study

The purpose of this study was to analyze the current trends and patterns in scholarly domotic research to create an evaluation framework for planning domotic system technologies. With the ardent growth and new possibilities for domotic systems, there is a wealth of design opportunities but a dearth of evaluative criteria that can be used to select appropriate technologies. This study addressed trends and patterns in domotic research to provide visualization of domotic connections through trajectory mapping and technology s-curve techniques.

Grounded theory was first proposed as the design for this research. According to Creswell (2007), grounded theory is a process of developing a theory by coding data in stages to find connections. In grounded theory research, researchers set aside preconceived ideas of a subject and rely on the information that grows from the information collected (Yu et al., 2014). I sifted through current research to determine trends and establish clusters and connections. This made grounded theory an ideal qualitative method for this study. However, grounded theory is based on data from the field with specific emphasis on actions and social interactions of people (Creswell, 2007). Because grounded theory focuses on the interactions of people and the current study concentrated on the growth and connections of systems, grounded theory was dismissed as the design for this research.

Case study research is the study of one or more cases that are found within a bounded system (Creswell et al., 2007). I examined the case of the growth of domotic technologies within the bounded system of recent scholarly research. Only one case was studied: the growth of domotic technologies. This exploratory qualitative case study addressed descriptive themes in the area of the growth of domotics to create a holistic analysis of the themes. I attempted to find common themes and trends within the area of domotic technology growth.

I discovered information about domotic systems based on the information collected from bibliometrics and text mining. Text mining is often an ideal quantitative tool, but it can also be an appropriate qualitative tool, as demonstrated in the current study. In research from Pan et al., (2021), text mining allows the researcher to categorize and interpret information, in addition to counting and quantifying information. Identifying categories, trends, and patterns followed by analyzing and interpreting information was the basis of this study. The process for this study was consistent with qualitative research text-mining methods (see Yu et al., 2014).

Research Questions

I analyzed the current trends and patterns in scholarly domotic research to create an evaluative instrument. I explored what systems and features may be important to consider when designing an optimal domotic system. The main problems were the fast growth of domotic systems and the lack of consistency in the options available to designers. Through text frequency analysis, I determined the emerging trends in domotic system types. There are several domotic standards such as EnOcean Alliance, Zigbee, and Z-Wave that may seem to dominate marketing, but text mining of scholarly research provided an opportunity for careful analysis of the patterns and trends of the predominant domotic systems and components at the time of the study.

By analyzing the patterns of recent research on domotics, I identified and ranked trends in the research. I assessed the numbers of articles, the frequency of terms, and the critical components of systems over specific time spans to identify periods of growth or decline. I identified periods of growth or decline and began to group them into major categories. I determined the major domotic products and components to see where the field was going.

One major issue with domotic systems is that many are not compatible with each other. I analyzed the trends identified from journal articles and mapped the relationships between the major systems. Many of the new domotic products are stand-alone items that are incompatible with many of the older more established systems. I identified, grouped, and mapped out which products are likely to move forward as the technology grows.

I used text mining to analyze scholarly domotic research to gain further knowledge of the direction and relationships in domotic systems to answer the following research questions:

RQ1: What are the trends and patterns in current domotic research?

RQ2: What are the interrelationships between current domotic research products and components that a designer can use as an evaluation tool?

Conceptual Framework

Domotic systems rely on the collection and analysis of data. The data collection process and analysis are what makes domotic systems a valuable, compelling, and worthwhile subject of study. The selection, collection, coordination, and analysis of building data are essential in the functioning of building systems (Zach & Mahdavi, 2012). The effective management of building information data is key for controlling building functions (Qin, 2021). Lawrence et al. (2012) proposed the development of a system called the facilities management and modeling (FMM) system. The FMM system integrates the building system’s energy management data to create a better building management process. Optimization occurs through measuring, modeling, and managing building data. This data integration concept is a key aspect of an optimal intelligent control system. One of the major problems with domotic systems is the inability to integrate the multiple data chains into one comprehensive, practical system.

The FMM system served as an appropriate model for the current study because it allowed me to look at the building systems as a whole to see how they work and determine how they can work together more efficiently. The FMM is used to analyze energy use and considers the tradeoffs between building systems. I sought to create a similar model that analyzes the interrelationships between present domotic systems.

J. K. W. Wong and Li (2010) conducted numerous studies on the evaluation and selection of domotic systems over the past decade. Their models, however, focused on one type of system like the HVAC system or on the selection of a domotic system based on key selection criteria such as comfort or safety. J. K. W. Wong and Li presented important models for the current study because were part of a limited number of researchers who focused on domotic evaluation. The current study was intended to build on the concept of collecting and analyzing data to build a model to guide designers to create an optimal domotic system. This concept is explored in more detail in Chapter 2.

Nature of the Study

The rationale behind the selection of an archival-based case study was the significant amount of recent information on domotics. There have been significant increases in new information in both the amount of research produced as well as the areas comprising the technology. With so many system options available, designers need an easier way to evaluate the numerous choices available and to understand where the technology is moving toward. Many domotic options are available, but it is difficult to sort them out without understanding the growth trends.

Due to the rapid growth of domotics and the many challenges with the complexity and integration of systems, it is often difficult to develop a system that meets all of the needs of building inhabitants (Baresi & Guinea, 2012). The selection and assessment of the most important critical features may enable the design of an optimal domotic system that is based on trends of where the technology seems to be moving in the future. The objective of the current study was to determine which system will work best to meet the needs of the domotic designer based on the trends and patterns found in domotic research. One of the limitations of this study was it was bounded by the amount and availability of recent peer-reviewed articles in the area of domotics that provided the necessary information for the model development.

The first step of the data selection was conducting keyword searches in each of the databases within each of the organizational libraries to create a collection of unique domotic technology-related articles. These articles were analyzed through bibliometric investigations of the abstracts. Text analysis of the abstracts provided a set of key domotic topics for analysis. The information in the texts was analyzed for key topics as well as key uses of domotic technologies. These were ranked and graphed to determine growth rates of the various domotic technologies.

The data for this study comprised the bounded set of information compiled from current literature in domotics, ambient intelligence (AMI), and smart home technology that was coded and analyzed. Once the coding was complete, thematic analysis was conducted to determine the current trends and patterns in domotic research, and the results were mapped. The data were sorted, analyzed, and cleaned for the purpose of ensuring the appropriateness of the results. After the data were prepared, critical factors were listed and analyzed to determine the trends in the critical components and the major domotic systems that were addressed in scholarly research. The resulting data were analyzed and mapped to visualize the connections and patterns in the research using s-curves and trajectory analysis. This analysis may benefit system designers by showing the main patterns in current research as well as the trends of where the field is growing. I also identified areas of research that had received little attention, as is often the case with domotic technologies, and identified promising areas that may necessitate future research.

Definitions

Ambient intelligence (AmI): “AmI environment is sensitive to the needs of its inhabitants, and capable of anticipating their needs and behavior. It is aware of their personal requirements and preferences, and interacts with people in a user friendly way, even capable of expressing, recognizing and responding to emotion” (Sadri, 2011, p. 2).

Bibliometrics: “Bibliometrics is increasingly used to systematically measure scientific output in order to understand the genesis of a discipline or area of knowledge and to map its publication pattern. Similarly, to meta-analytic studies, bibliometrics needs hindsight to assess the trends observed in a particular subject area” (González Alonso et al., 2012, p. 945).

Building automation systems (BAS): “BAS are concerned with improving the interaction among integrated systems and the habitants/users of the buildings” (Figueiredo & Sá Da Costa, 2012, p. 85).

Building information mmanagment (BIM): For the purposes of this study, BIM refers to building information management as opposed to building information modeling (see Doan et al., 2019).

Internet of things (IoT): "IoT comprises an evolving array of technologies that extend the idea of instantaneous connectivity beyond computers, smartphones, and tablets to everyday objects" (Poudel, 2016, p. 997).

Smart buildings/intelligent buildings: "The intelligent building is conceived as a caring environment where computers adapt to human existence, rather than the other way around" (Albrechtslund & Ryberg, 2011, p. 35).

Smart homes/intelligent homes: "In the last decade, the term smart home has emerged as the keyword for such automated dwellings" (Kofler et al., 2012, p. 169).

Text mining: Text mining is a form of data mining, which is a tool used to analyze and extract meaningful information from data (Yu et al., 2014).

Ubiquitous computing: "Ubiquitous computing refers to the computing technology that disappears into the background, which becomes so seamlessly integrated into our environment that we do use it naturally without noticing it" (Portet et al., 2011, p. 168).

Assumptions

I used axiological assumptions to clarify and interpret the trend data. An important assumption in many of the supporting articles was that because the domotic industry is rapidly growing, it will continue to grow in the future. Although this is a reasonable assumption, there are factors that have inhibited the growth in the past, with one major inhibitor being the downturn of the building industry that began with the mortgage/housing collapse in 2008 (Chun-Hao & Jian-Min, 2012). The assumption of future growth of the domotic industry was important because it was the foundation of the current study. If there had been no future growth expected, there would have been no need to design a tool to assist in visualizing current trends or systems.

The selection of the focus areas of compatibility and interoperability of domotic systems for this study was due to the vast amount of research that indicated this was an issue (Miori et al., 2012; Poudel, 2016). In addition, much of the new research focused on the design of new components of domotic systems, but with not much emphasis on how these components would fit into current systems or where the industry might go in the future (Tang et al., 2017; van de Kaa et al., 2021). The intent of the design of each system component, it seems, is for each system to stand alone with little thought of how systems would fit into a complex system (Garroppo et al., 2012; Sun et al., 2021). Many of the contemporary systems do not integrate automatically into legacy systems, which were developed previously and often use old or obsolete software. A comprehensive study of the relationships between domotic systems may assist the design of domotic compatibility.

I also assumed that the growth of scholarly research would reflect growth in domotics. I assumed that as the amount of peer-reviewed research in the subject increases, the amount of interest in domotics increases. Bibliometric research is commonly used to determine trends, themes, and gaps and to identify where research the field is heading (Kim & Park, 2021).

Scope and Delimitations

The boundaries of this study were based on the recently published domotic journal articles. There were potentially new unreferenced advances, and there were potential commercial applications that could have been undocumented in peer-reviewed academic journals. The bounded population of this study was the recent peer-reviewed journal articles available at the time of the study. This study may be transferable to ongoing research. Domotics is a growing field, and there is a constant production of new journals with domotic studies, so this study could result in new knowledge areas and new research applications leading to new growth trajectories. This study could be especially important in determining the areas where there is little or no current research.

Limitations

One of the limitations of this study was the accessibility of the information located in the university libraries, the public library, and Google Scholar. The search was also limited to the terms found from the mining of the journal articles. Missing terms from this study would result in limits to the study. Overlooking any critical factors also constituted a potential limitation of this study. Additionally, if the data from the journal articles were lacking, the study would be limited.

Another limitation of the design methodology was that the frequency of a factor as it appeared in research implied the importance of the element as a critical factor. I addressed this limitation by normalizing the data. The basis of this study was current peer-reviewed research, and there was a chance that my analysis might not have captured all of the critical factors. However, data saturation was monitored to ensure the capture of most of the relevant aspects of domotic systems. There was a difference in scholarly articles and what is available through commercial outlets. The commercial literature on domotic systems is vast and could offer significantly different results.

There could have been a bias against the increased use of technology in home systems reflected in research. People may fear that domotics could lead to a *big brother* situation where someone is constantly monitoring building functions (Etzioni & Etzioni, 2017). By using only recent peer-reviewed documents from a variety of sources, I endeavored to overcome that bias. There was a large variety of researchers covering a variety of subjects, and there was no single dominant opinion documented. Reasonable measures to address limitations included the use of multiple campus libraries and databases, the open analysis of the text of the articles to determine most common terms, and the building of a data bank of possible terms based on the text analysis results. The use of multiple analysis techniques also limited bias, including critical factors, word frequency transforms, s-curves, and trajectory maps.

Significance of the Study

The potential contributions of this study toward the advancement of knowledge include the furthering of knowledge in the area of domotic systems. This is not a commonly known or referenced area of study, but it is one with significant growth potential. With the growth of the systems, more people may be interested in the implementation of these systems. With the results of this study, designers may be able to consider the current trends and interactions to design an optimal system. This could save time and money and ensure the inclusion of the critical factors desired by the designer.

This study may also fill the gap in current research by mapping interactions and addressing areas of incompatibility between systems.

Domotics contribute to positive social change by facilitating increased energy efficiency, lowering of overall costs of building operations, increasing safety, improving comfort, increasing occupant productivity, improving work conditions, improving resource use, improving building access for people with disabilities, improving health monitoring and alerts, and increasing the ease of occupant activities (Ghasemi et al., 2019; Nthubu, 2021; Saidi Sief et al., 2016). This study could advance practice by providing a view of current areas of research trends and interactions to optimize system design. The use of the results may save time by understanding the implications and complexities of a domotic design choice prior to design implementation. This may reduce the cost of the design help to determine the most important components of the design to select. Major contributions of domotic systems are that they can provide energy cost savings while decreasing the negative effect of buildings on the environment (F. Wang et al., 2021). Research from Salerno et al. (2021) stated that an energy management system combined with smart building components can lower cooling costs by 97% and building energy use by 49%. A 2015 report from the International Energy Agency (as cited in Tang et al., 2017) stated that artificial lights alone made up 15% of use in residential buildings. Improving or adding a single domotic control system could provide significant resource savings.

The potential positive social change also includes the advances to the health, safety, security, comfort, communications, accessibility, and the environment that these systems provide. Domotics can improve quality of life, mobility, and accessibility for those who are infirmed or have physical impairments (Saidi Sief et al., 2016). Domotics provide comfort and efficiency improvements (Seyedolhosseini et al., 2020) and can increase the value of the property for the property owners (Mir et al., 2021).

There is significant research on domotic systems that confirm that they are a vast, complex, and growing technological area (Pan et al., 2021). Although domotic systems are growing, so is the need to understand the connections between systems and system components (Phan & Kim, 2020). The current study was conducted to identify the trends and patterns in domotic technologies and present a map of domotic relationships.

Significance to Practice

This study may add to the practice of building information management, computer science, sensors, and smart homes/buildings, and may further the study of domotics as a field. There was little information addressing domotics as a field, and the field has grown to include smart buildings and the IoT. The current may contribute to expanding this field of study. This study may also assist in bringing attention to and contributing to the knowledge base of the field.

Significance to Theory

This study may advance theory in domotics by addressing the trends and the future areas of growth in domotics. The study may fill a gap regarding the missing connections between domotic technologies. There are many opportunities for growth, but the field could stagnate if there is no consensus in standards and compatibility, similar to Betamax losing to VHS in the videotape format competition.

Significance to Social Change

There are significant opportunities for domotics to create positive social change in the areas of older care and care of people with special needs. The older population is growing. The Dutch older population will grow by more than 25% over the next 30 years (Meulendijk et al., 2011). A survey conducted in Spain showed that a significant portion of the population age 65 and above was disabled (see Sadri, 2011). Sadri (2011) estimated that by 2050, there would be more older individuals worldwide than there are children from 0 to 14 years of age. The ratio of cost of providing older care compared to childcare is 5 to 3 (Sadri, 2011), indicating significant potential cost of care increases.

Domotic intelligence can provide the opportunity for improved mobility, increased independence, and superior safety and well-being (Ghasemi et al., 2019; Nthubu, 2021; Saidi Sief et al., 2016). Domotic systems can provide an alert based on behavior changes in case an inhabitant has been hurt or is in some type of distress. Fall detection in homes has become so important that designers have created embedded systems that can track real-time data based on balance and sway tracking that can detect exactly when a fall occurs or predict the fall before it happens (Paoli et al., 2012). This can provide essential response times, which can save lives (Nguyen-Truong & Fritz, 2018). Many falls happen late at night when building inhabitants are getting up to use the bathroom and when lighting is often limited (Ding & Wang, 2020). A pressure pad, sensor-based technology beside the bed, in the halls, and in the bathroom can trigger an alert in case of a fall (Jeong & Proctor, 2011).

Domotic systems like the Independent Lifestyle Assistant could provide the opportunity for individuals with impairments to reside longer in their own environments as well as decrease the reliance on outside caregivers (Resuli et al., 2020). These systems can also monitor concerns such as diet, activity, and exercise in diabetic patients to improve the health of patients while they are in their home (Fuchs et al., 2018). A major and increasing characteristic of domotic systems is to improve quality of life through improved accessibility and independence for individuals living with special needs. Nearly 500 million people in the world have some type of disability that limits their ability to function or their mobility (Cofre et al., 2012). These disabilities often limit the ability of individuals to function and can significantly decrease their quality of life. Domotic designers have the option of including touch screens (Cofre et al., 2012), vision controllers (Bonino et al., 2011), voice controllers (Portet et al., 2011), brain computer interface (Aloise et al., 2011), head motion trackers (Machado et al., 2013), activity or plan recognition (Ding & Wang, 2020), as well as motion-based controllers (Jalal et al., 2012) to help achieve a higher level of autonomy, accessibility, and mobility within the domotic building environment. Incorporating domotic systems into buildings often increases its worth and provides value for building inhabitants that can lead to improved inhabitant retention and contentment (J. K. W. Wong & Li, 2010).

Safety and security are addressed in domotic environments in part by allowing the inhabitants to monitor and evaluate their home remotely, in real time, and at any time of the day or night (Peng & Wang, 2020). Safety and security issues are also addressed by providing access to biometric options (Sangal & Bathla, 2019), motion and human detection sensors (Peng & Wang, 2020), smoke and gas alarms (Miori et al., 2012), and video-based surveillance (Elrawy et al., 2018). Domotic technology not only improves the quality of life for building inhabitants, but it can also provide a safe, healthy, and comfortable environment while controlling energy consumption and decreasing negative influences on the environment.

Summary and Transition

This qualitative case study included bibliometric text-mining searches of current research in intelligent domotic control systems. This data created a corpus of the most important components of an intelligent domotic control system through use of word frequency analysis. These components indicated the critical factors for creating the system design. The factors were graphed using trajectory maps and s-curve plots. I also analyzed current trends and patterns in domotic technologies. Chapter 2 contains details of the search strategy used for this study, as well as the conceptual framework used. This chapter also presents a literature review of current scholarly articles on domotics to provide background on the importance and issues associated with domotic systems.

Chapter 2: Literature Review

Recent literature showed that there has been substantial growth in domotic systems, and the growth is likely to continue (Baquero et al., 2012). With this growth, there are issues with compatibility of systems and integration problems (Miori et al., 2012). The introduction of new applications such as mobile and handheld devices changes the nature of domotic systems at a rapid pace (Mori et al., 2013). Information on what domotics means, the various types of domotic systems and carriers, the issues with compatibility and heterogeneity, bibliometrics and text mining, and the trend analysis were addressed in the literature review.

The problem addressed in this study was that there was no unifying framework for the design of a domotic system. Many changes and system progress have occurred in recent years, but there has not been a systematic plan for integrating and interconnecting the many aspects of domotics into a comprehensive system. The focus of early domotic systems was often on individual components that performed individual functions without much thought for a wholly integrated system (Miori et al., 2012). The segmentation of standards is often a major problem with domotic systems, and the abundance of proprietary solutions (Poudel, 2016) adds to the lack of compatibility.

The purpose of the current study was to determine trends and map the dependencies and interrelations of domotic systems presented in recent scholarly literature. With all the novel possibilities for domotics, there was a wealth of opportunities but a dearth of information that detailed the trends and interrelationships of domotic systems. I sought to identify trends and patterns and map out domotic interrelations.

Literature Search Strategy

Multiple libraries were accessed for the literature search in this study, including the University of Colorado-Colorado Springs (UCCS), Colorado State University-Pueblo (CSU-Pueblo), Walden University Library, and the Pikes Peak Library District. I also used the Google Scholar search engine. The initial search phrase used was *intelligent control systems*. This led to the prevalent term of *domotics* and *smart or intelligent buildings or home*. From the term domotics, several additional terms were found including: *ambient intelligence, automatic control systems*, *building information modeling*, *home automation, intelligent domotic environments*, *Internet of Things IoT*, and *ubiquitous computing*.

The sources of this research included scholarly scientific resources located in databases such as Scopus, ERIC, Academic OneFile, ACM Journals, JSTOR, Engineering Village, ScienceDirect, IEEE Xplore, and others to identify peer-reviewed domotic sources. Searches of multiple academic and public libraries provided data for the study. Most sources were from the last 5 years and were from peer-reviewed journals.

The literature search began with the concept of intelligent control systems for buildings. I scanned the Walden Online Library, CCCOnline, CSU-Pueblo Library, and the UCCS Library for each term. There was a small period in which the number of publications dropped and the search became difficult to find information, but publications began to increase again in 2009. Through these multiple searches, there was sufficient documentation to achieve saturation.

From these searches, I found the common term of domotics to encompass multiple aspects of building technology. I scanned the Walden Library for the common terms and located several books and articles. From these three libraries, similar terms articles were located and used including building automation, ambient intelligence, building management systems, and adaptive systems. I used these search terms across all libraries and Google Scholar. I used Mendeley as an electronic journal repository to search and keep track of my documentation to ensure that there were no duplicate entries and to document notes and highlighted text. I also used Scribbr to download, store, and capture necessary bibliographic information.

Conceptual Framework

J. K. W. Wong and Li's (2010) study provided an evaluation tool to assess the vast amounts of intelligent building tools available. These tools assessed the needs of domotic projects for optimal design. J. K. W. Wong and Li stated that there was a large number of control system tools available but a scarcity of tools available to best design the systems. From this problem, J. K. W. Wong and Li developed a selection evaluation model. Their research was very similar to my study due to the development of an evaluative tool. Current system requirements are complex and multifunctional, and it is imperative to balance the functions of the system with the expectations of users (J. K. W. Wong & Li, 2010). The current study provided a tool not only for control systems but also for various domotic control systems.

Much of recent research showed that the area of domotics is growing at an accelerated pace (Baquero et al., 2012; Bellavista et al., 2012; Bonino & Corno, 2010; Nguyen & Aiello, 2013; J. Wong & Li, 2006; J. K. W. Wong & Li, 2010). Domotic systems are now able to provide a wealth of services in the areas of health care (Aragues et al., 2012; Kim & Park, 2021; Nguyen & Aiello, 2013; Nguyen-Truong & Fritz, 2018; Nthubu, 2021), physical and data security (Han & Park, 2017), and accessibility for those who have disabilities (Saidi Sief et al., 2016). With this increase in services come issues with interconnectivity (Poudel, 2016), compatibility (Phan & Kim, 2020; van de Kaa et al., 2021), upgradeability (Gamez & Fuentes, 2013), which create difficulty in the selection of optimal systems.

Several researchers have tackled compatibility problems by creating middleware (Baquero et al., 2012; Bonino & Corno, 2010; Gamez & Fuentes, 2013; Miori et al., 2012; Zheng et al., 2017). However, a better way to design a system is to understand the requirements and interconnections of the system before implementation and to design the system to meet the necessary requirements from the start (Nthubu, 2021). One way to design an effective system is to map the relationships and networks of the most important aspects of the system. A bibliometric search can be conducted to cull the important aspects of a domotic system from documents. A bibliometric search provides an effective way to assess the quantity and quality of research in a particular subject. Bibliometrics provides a methodical way to measure scientific research in areas based on publications (Kim & Park, 2021). An assumption of bibliometrics is that the number of paper citations demonstrates the importance and influence that the topic has on the area of study. One major bibliometric measure is the impact factor, which is a measure of the average number of times an article is referenced in citations (Ugolini et al., 2011). Bibliometrics can show the influence of an article and how the topic of study has developed over time (Kim & Park, 2021). Bibliometrics allow researchers to take qualitative information and calculate qualitative measures. Bibliometrics can show trends over time as well as geographic and author distribution (Ugolini et al., 2011).

The approach that Kog and Loh (2012) took to define critical factors mirrored the approach used of the current study. I developed a set of critical evaluation factors through text searches of recent literature. J. K. W. Wong and Li (2010) presented an example of an evaluation method similar to that used in the current study, while F. Wang et al. (2021) presented a model of an analytic hierarchy process (AHP) evaluative framework similar to the methods of the current study. AHP is a method of evaluation used to solve complex multivariant problems using subjective weighted inputs (F. Wang et al., 2021).

The scope of intelligent domotic control systems has increased significantly in recent years. Digital controls have become more complex, sophisticated, integrated, and useful in areas where they were not used in prior applications (T. Wang & Cook, 2020) (T. Wang & Cook, 2020). Data collection has become increasingly important to control building systems (Doan et al., 2019). Buildings are now becoming more reliant on information systems to perform simple functions as well as more complex, higher level functions (Miori et al., 2012). The system selection, collection, coordination, and analysis of the data are vital in the functioning of the building (Majumdar et al., 2020). Building functions rely on the effective management of information, and data collections are essential to the management of building functions. Lawrence et al. (2012) proposed the development of a system called FMM that integrates the building system's energy management data to create a better building management process. This data integration concept is a key aspect of building an optimal intelligent control system.

The basis of the selection of the evaluation criteria framework was the selection and evaluation model for an intelligent HVAC control system (J. K. W. Wong & Li, 2010) where the designers developed a model to develop, test, and refine a conceptual selection evaluation model. The basis of the AHP model framework was the fuzzy AHP framework that Larimian et al. (2013) developed, which as a four-level hierarchical model that conducted pairwise comparisons for prioritization of factors. Jung and Joo (2011) developed a framework for BIM and stated that the process should be comprehensive enough to present all of the issues while being precise enough to present them in a systematic fashion. Jung and Joo (2011) went on to develop a table with six variables grouped in three hierarchical categories that encompassed the recent literature on BIM.

Data analysis is an important part of domotic systems. Text mining, a subset of data mining, is an application that supports the development of models to aid in the classification of information (Pan et al., 2021). Data mining is a way to recognize previously unknown, useful patterns in data. There are various stages in data mining including data cleaning, data integration, and data reduction. The selection of text mining for the current study was due to the ability of the method to glean patterns of information without outward bias or preconceived notions (see Yu et al., 2014). Text mining is ideal for qualitative data analysis. It is an iterative way of isolating common themes and categories while providing both consistency and replication. Bibliometrics is a form of text mining through gleaning information from journal bibliographies. Bibliometric studies represent an important component of scientific research and can be used to systematically evaluate scientific research products (Ugolini et al., 2011). I used bibliometric text searches.

The first step in text mining is to examine and log the data. The next step is to arrange, reduce, and organize the data to answer the research question. Based on the organized and reduced data, the researcher can determine themes, patterns, and connections. Step 3 is to identify themes and patterns, add or delete information, and determine whether there is any missing information that could provide exhaustive and complete information to aid in answering the research question. The final step is to revisit, verify, and test the data (Pan et al., 2021; Yu et al., 2014)

There are numerous decision support tools available to designers that can calculate the best decisions for building systems to improve the productivity and energy efficiency of buildings. Many decisions to implement domotic systems center on the desire to improve the productivity and efficiency of buildings. Energy requirements often form the basis of the selection of the domotic system. Decision support tools assist in the assessment of energy requirements (Strachan & Banfill, 2012).

The phases of an operations study include the definition of the problem, construction of the model, solution of the model, validation of the model, and implementation of the solution. During the definition stage, the designer must be able to indicate the alternatives, determine the objectives, and understand what limitations are inherent in the selected model (Taha, 2007). The problem in the current study was the lack of a systematic method to select a comprehensive domotic system for building designers. There are many domotic alternatives due to the numerous standards developed for various types of system needs. Different standards exist for various types of needs that are often not compatible with each other.

AHP is a common multicriteria decision-making tool used to model decisions under certainty that gives the user the ability to quantify subjective judgments (Taha, 2007). AHP is an ideal model for determining what domotic system to use because the knowledge of the designer forms the basis of the decision. One of the most important aspects of AHP is for the user to determine the relative weight of each alternative. The designer often determines the importance of the needs of the building inhabitants, and this is often a subjective decision to assign weights to the importance of each factor in the design. AHP makes pairwise comparisons for each decision alternative and determines a weight for each pairwise comparison (Taha, 2007). The fundamental scale for AHP ranges from 1 to 9 with 1 representing equal importance, 5 representing essential or strong importance of the factor (over the one being compared), and 9 representing extreme importance (Saaty, 1987). The first step in building a good AHP model is the development of the hierarchy with the main criteria, which decomposes into subcriteria, which leads into the alternatives (Saaty, 1987).

Another way to quantify subjective decisions is through the fuzzy AHP. I considered the use of the fuzzy AHP due to all of the benefits of using AHP, but it also has the ability to quantify weights that are not exact, but rather fall within a range of variables. This is useful when the weighing information is difficult to quantify or incomplete, or the decision maker does not have the necessary expertise to make a quantifiable decision as to the weight (Larimian et al., 2013). In the end, I chose the AHP rather than the fuzzy AHP because the expert in this case was the designer who had their own specific ideas about the importance of the weights of each of the criteria. The expert has all of the necessary knowledge vital to making an informed decision as to the weight of the criteria.

These framework studies related to the current study because they could help design a way to answer the research questions by using emerging information from reputable, current, academic sources. Most information technology (IT) projects fail due to misalignment of project objectives and the delivered IT solution. This is also true for domotic technology systems. The designer must have a clear understanding of the system constraints and the needs of the inhabitants prior to project implementation, or the system is not likely to be successful (Nthubu, 2021). The development of an evaluation method may assist designers in planning optimal domotic systems. J. K. W. Wong and Li (2010) also used the selection of critical success factors through bibliographic research. J. K. W. Wong and Li provided a framework for the design of the evaluation process of the current study through the bibliographic search for critical success factors and the use of AHP for evaluation. To further J. K. W. Wong and Li’s evaluation research foundation, I used bibliographic searches, text and frequency analysis, and trend and cluster analysis to determine the trends and relationships within domotic systems rather than limiting the study to only building and HVAC systems.

Literature Review

There are many descriptions of domotics, but the underlying definition speaks to the automation of building systems to enhance the comfort, function, efficiency, safety, or security of the building or inhabitants. Many experts use the terms domotics and smart or intelligent building or home automation interchangeably (Garroppo et al., 2012). Others think there is a difference in the meanings of the terms (Cofre et al., 2012).

Some experts use the terms green buildings, green construction, or sustainable buildings as a type of smart building (Nguyen & Aiello, 2013). Other researchers focus on the computational aspects of the building by using terms such as ubiquitous computing, AmI, IoT, or pervasive computing. Without a standardization of language, it is difficult to expect a standardization of systems. This is a major aspect of the problem with domotic systems.

A common definition of domotics comes from the combination of the Latin root domos meaning home, and automation. Many authors point out that domotic system should be adaptive, and context aware (Miori et al., 2012) while Garroppo et al. (2012) said that the model domotic system is one which is able to effectively control integrated systems automatically based on a variety of different input devices. This definition seems to be the prime example of an ideal domotic system rather than what is currently available for consumers. Systems are not currently fully integrated nor are the components currently heterogeneous. The definition, to Cofre et al. (2012), included systems that automate, control and monitor a home while being integrated into a central communications network located either internally or externally.

Bonino and Corno (2010) went even further to extend the domotic definition to include the intelligent domotic environment, which includes the domotic system, which integrates with a personal computing device to support the integration and automation with multiple devices. Bonino and Corno (2010) define a more comprehensive system called an intelligent domotic environment as one that has matured by incorporating aspects of AmI, pervasive computing, and smart environments.

Moreaux et al. (2012) gave a clarifying definition for a domotic system that states domotics is a set of preset understandable rules for humans who interact with the system. Using the example of the concept of rules from Moreaux et al is a good place to start, however, no simple set of rules can accurately describe the complexity of needs within a building's systems (Makonin et al., 2013). In fact, rules can often be contradictive when humans are involved. One individual's desire to be warm can be in direct conflict with energy saving rules set by the system designer. Often a simple definition gives the most meaning. A straightforward definition for domotics comes from Aloise et al. (2011) where the authors state domotics is "a set of methods and techniques for the automation of the home" (p. 219).

The definition of domotics is important because it gets to the root of the problem with domotic systems, which centers on issues of inconsistency. Many domotic system designs only address only one major aspect of building needs. Many commercial systems focus on security and alerts and the design of enterprise systems and subsystems pieced together in steps (Moreaux et al., 2012). The proliferation of wireless devices has freed domotic systems from their wire bound predecessors, thus allowing for new growth of systems that were not possible in the past (Kambourakis et al., 2020). The growth of sensor technology has made domotic systems cheaper and easier to implement (T. Wang & Cook, 2020). There are now multiple needs placed on domotic systems, which can assist in meeting the needs of the inhabitants. It has become a very simple task to create a domotic application. A lone individual may design an app to sell to a corporation, which may become a part of a domotic system. However, any two applications will most likely not work together within one system. There are many choices for consumers, but few systems that have the ability to work together as one. If domotic system designers had a method for evaluating the multitude of products, this method could alleviate compatibility issues down the road.

Issues with Domotic Systems

Limitations of systems in the past included their hard wiring, and their homegrown pieced together legacy systems (Miori et al., 2012). Legacy systems do not tend to be adaptable when there is a need for new components, and they often lack the flexibility of newer systems (Nguyen & Aiello, 2013). Present systems are often wireless, hidden, context aware, personalized, adaptive, anticipatory, and interoperable within their own systems (Perroud et al., 2011). The introduction of new system applications occurs at such a rapid pace designers cannot simply design for current possibilities; they also need to be able to add options that are adaptable for the future. It is ideal for designers to be able to add individual applications to upgrade a system one piece at a time, as desired or needed (Garroppo et al., 2012).

Corporations are developing new systems at a rapid pace. Corporate systems include: Vivint, ADT Pulse, Savant, SimpliSafe, Amazon Alexa, Google Assistant, Apple's Siri, and Siemens (Gokaraju et al., 2016). These systems work to meet the needs of users; however, they also lack flexibility for adding outside components onto the system. These systems are not designed to consider the new components that are coming onto the market. These systems do not tend to be context aware or able to learn or adapt to the needs of the users (Perroud et al., 2011).

An ideal system will allow the designer to personalize and adapt the system to meet the needs of the inhabitants, without significant cost increases or a total revamping of the system. An optimal design can improve the quality of life for users by increasing the building's efficiency, accessibility, mobility, safety, comfort, independence, fix itself, and send out health and severe weather alerts (Antic & Papp, 2021). The enhancement of the design of an ideal system begins with the early consideration of system capabilities, integration opportunities, personalization options, and component appropriateness.

There is currently no single standard used for domotic systems consequently a domotic system designer must select the components of a domotic system based on a nonstandard set of criteria (Aragues et al., 2012). This lack of a single standard leads to a significant issue of a lack of compatibility in intelligent domotic systems (Moreaux et al., 2012). Research shows that with the extensive growth of domotic systems there are significant problems with the incompatibility of systems Miori et al. (2012). There are also several examples of commonly used systems that are incompatible including X10, KNX, LonWorks, UPnP, HAVi, BACnet, and Jini (see Miori et al., 2012). Each system used different communication protocols like Ethernet, FireWire, Bluetooth, and ZigBee (Bernatin et al., 2021).

Bonino and Corno (2010) stated that there it is very evident that though there is a strong indication that there are problems with domotic compatibility, the advances in computational complexity will one day bring about a common solution. The initial design of many systems used one process in mind and then added subsystems to the system as needed (Sánchez et al., 2011). Many of these add-ons were not compatible with the original system thus causing communication problems and design issues (Moreaux et al., 2012).

With the increasing focus on energy management, domotic systems have become more widely adopted; however, high costs, installation issues, and compatibility problems have limited domotic use for everyday users (Carreira et al., 2014; Mir et al., 2021). Building control systems have been the victims of a lack of systematic approaches to the selection of a control system (J. K. W. Wong & Li, 2010). Without a comprehensive selection approach, the development of an optimal system is not an efficient process.

Another major difficulty with domotic systems is that in order to overcome compatibility issues, designers often have to develop specific custom-made layers and gateways in order to make the system work (Aragues et al., 2012; Lilis & Kayal, 2018). This high level of customization for each system can often inhibit design efforts.

Complexity can leave room for unnecessary errors. Many of the programs that control systems are highly susceptible to error and security breaches due to the need for the system to integrate multiple processes (Augusto & Hornos, 2013; Elrawy et al., 2018; Sangal & Bathla, 2019; Sharif & Tenbergen, 2020). Carreira et al. (2014) agreed that many domotic systems are not being used in buildings due to the high costs of the systems, installation problems, and the ability to integrate the systems into the building.

To achieve full functionality of domotic systems, designers must often coordinate numerous systems. For example, the DomoPredict system used five separate domotic systems including UPnP, Konnex, MyHome, X10, and BacNet to regulate their multimedia, AV, appliances, and system controllers (Miori et al., 2012). One of the most common ways to overcome coordination issues is to use one of the numerous middleware options available. Many of the major device networks like Z-wave, Zigbee, and uPnP still need some type of middleware provider in order to provide communications between each other to use new applications and standalone devices (Stavropoulos et al., 2013).

The problems with compatibility, standardization, and interoperability, present a significant issue for building designers. While there has been recent research by J. K. W. Wong and Li (2008, 2010) on the evaluation of specific building components, there has been scarce research specifically on the design of optimal domotic building systems as a whole.

Building system designers need to have a way to compile building needs, user needs, and the types of systems available. Therefore, there is a need for the identification of critical factors for optimal systems to balance system needs with options and their costs. Currently no single domotic system will be able to provide required interoperability to standardize the field (Miori et al., 2012).

Domotics and Energy

A major aspect of a domotic system is the energy management system. Buildings in the United States consume 40% of the energy supply with over 70% of electricity going toward heating, cooling, and lighting (Gershenfeld et al., 2010). Domotic energy solutions can provide reduced energy consumption as well as reduced CO2 emissions by nearly 72% (Saba et al., 2017). Nearly 30% of potential energy savings in buildings could come from improving commercial building energy efficiency and 27% from residential energy efficiency improvement (Kerner et al., 2013). This presents significant saving potential through an effective energy management system (Mir et al., 2021; Salerno et al., 2021). Domotics regularly addresses the energy management aspect of automation by determining the best times, amounts of energy, comfort levels, and tradeoffs for energy systems while seeking to decrease the negative impact on the environment (Z. Wang et al., 2012).

Domotic technology also provides substantial data related support for environmental policymaking decisions. The reduction of energy waste, an increase in the use of energy management systems, the reduction of harmful emissions, and the harvesting energy systems all work together to improve building efficiency and create a positive effect on the communities in which the buildings operate (Kerner et al., 2013; Saba et al., 2017). There have also been significant advances made in electronics, which have improved power use, decreased the size of devices, and reduced computing costs that have made domotics in general, and energy management specifically more feasible and easily accessible (Bouchabou et al., 2021). In addition, many countries now require adherence to energy standards that make domotic systems ideal for regulation compliance (Vinagre Díaz et al., 2013).

In addition to energy management systems, there are also opportunities through domotics in the energy demand-response (Salerno et al., 2021) and energy harvesting arenas (Dinulovic et al., 2021). EnOcean, a Siemens spin-off company, is a domotic network that uses battery free modules that collect energy (Dai & Sugano, 2019). The energy harvesting concept derived from the concept that there is an ample supply of ambient energy, which will sufficiently power radios and sensors therefore, no additional power supplies need to be included in the system (Aragues et al., 2012; Bogue, 2012).

Domotics Growth

Vivint is a home automation provider that offers domotic services for a monthly fee. The system has three main components including home security, energy management, and home automation. Vivint is a touchscreen-based system, and it has 1.7 million customers and is compatible with Google Nest, and Amazon devices. Customers can connect to the Vivint system by using their iPad or other mobile device to access system, record video, control lighting, or unlock or lock doors remotely. A major advantage to the Vivint system is that it is a black box system, and it comes ready to use (Gokaraju et al., 2016). The design of all of the components work together under a single system and meets the needs of specific target populations, like parents who want to check in on their children afterschool. A distinct disadvantage of the pre-designed system is that it sells for a monthly charge and has $599 base startup costs. The system is not tailored to the inhabitants, but rather is non personalized, prepackaged, and leased out to meet the needs of a target group based on a set of lifestyle packages (Vivint Smart Home, n.d.).

Similarly, ADT is a home security company that has delved into home automation systems. Their home automation system controls lighting, thermostat control, door look control, security alerts, alerts for emergency conditions, child arrival alerts, and custom set up including entertainment systems for specific events. This system uses z-wave technology and includes live monitoring. This system sells with tiered, monthly package rates (Gokaraju et al., 2016). Similar to Vivint, this system uses preset system packages with select from the menu customization (ADT, 2021).

These commercial systems have closed, and fixed applications to meet a specific, fixed set of needs (Garroppo et al., 2012). A well-designed system could provide opportunities for more responsive systems that operate in an intelligent environment rather than in a static environment. This approach provides more responsiveness, adaptability, and flexibility for the users. One way to have domotic systems become truly adaptable, responsive, and flexible is to consider the possibility of creating truly modular systems where all components are standardized and interchangeable. This is preferable over components that are specialized to accomplish only certain tasks (Antic & Papp, 2021).

The rapid growth of domotic technology has brought new challenges for the effective design and integration of optimal domotic systems. Major domotic systems include components of energy savings, comfort, security, communications, health monitoring, and accessibility.

The expansive growth of wireless technologies has increased the development of domotic systems by alleviating many of the physical problems and costs associated with previous wired technologies (Kambourakis et al., 2020). However, wireless solutions do not eliminate all of the problems with implementing wired solutions. Wired systems have to fit a building's current or envisioned configuration, and wireless solutions often have reliability issues, and are prone to interference from other devices (Kerner et al., 2013). There seems to be no clear solution to eliminate the compatibility issue.

Older technologies like X-10 rely on existing power lines (Baquero et al., 2012) and do not have the physical barriers of wired technologies, but rather have problems with interference. However, none of these issues has hindered the growth of domotic systems. Alternative solutions address many of the interference issues. Some solutions offer a way for home/building network to communicate over both electrical wires and radio waves, creating a dual mesh network (Kerner et al., 2013). If the message is not getting through on one platform, the system will try the other platform. Instead of routing the message, the device will broadcast the message out to all devices until one picks up the message (Kerner et al., 2013). Other common solutions are through the design of middleware bridges (Lilis & Kayal, 2018; Stavropoulos et al., 2013). Additionally, miniaturization, and the improved communication and connectivity of components, along with lowering of production costs have increased opportunities for the development of new domotic devices (Perroud et al., 2011).

Current research in domotics shows that domotic technology is in a growth phase (Baquero et al., 2012; Hong et al., 2020). The smart home market is expected to grow globally from 76.6 billion dollars in 2018 to 151.4 billion dollars in 2024 (Hong et al., 2020). However, rapid growth is not without challenges. Many domotic systems are completed in steps, and these steps are not necessarily forward compatible or compatible across systems (Bonino & Corno, 2010; Miori et al., 2012; Moreaux et al., 2012). This poses a problem to designers due to the potential high costs of developing a complete system all at one time; so many domotic systems are developed and implemented in stages (Bonino & Corno, 2010).

Customization in Domotics

Building systems are now becoming more inhabitant centered and must respond to the needs of the users (Jeong & Proctor, 2011). Systems today must demonstrate computational intelligence and be able to adjust to the needs of users without being intrusive (Makonin et al., 2013). Another issue is that many individuals already own or use some type of communication device, namely mobile devices (Garroppo et al., 2012) which often are not compatible with domotic systems. Domotic building systems must be able to be responsive to the current users. The domotic system manages and monitors their buildings operations thus, it is important for the system to be responsive. Users should not need to have to purchase a different mobile device just to be able to manage a building application. While it is essential that building systems are responsive, many of the design choices must be made very early in the construction process (Phan & Kim, 2020). Often, not a great deal of thought goes into these choices about how these choices will affect the domotic processes within the structure in the future. This often limits the amount of modification possibilities to the system later (Sampaio et al., 2012). In order to be effective, current domotic systems have to be responsive, adaptable, and dynamic.

The complexities of domotic systems have increased as systems now handle more than one activity. Domotic systems are now able to provide energy savings, comfort, security, communications, and accessibility for building occupants, where in the past they might have only had one process (Stolojescu-Crisan et al., 2021). The simple domotic systems of the past are no longer sufficient to handle the ubiquitous computational needs of the present building inhabitants (Bonino & Corno, 2010). Current systems need to operate in real time and from a distance without the interruption of services. There is not an easy solution to solve the integration problem of these highly complex and interrelated systems (Bellavista et al., 2012). However, there are now multitudes of design opportunities for domotic designers.

Data is an increasingly important aspect of domotic systems. Systems are more and more data driven and the better data fed into the system, the better the system response. The quality of the information fed into the system determines the system decisions. Systems can now be service based, self-adjusting, and interaction based (Warriach et al., 2013).

Evolution of Domotics

One of the most significant problems in domotic system design is that many original systems are legacy systems and when new components are needed, the system's communication processes are incompatible (Hong et al., 2020; Moreaux et al., 2012).

This often leads to the design of a gateway system to serve as the crossover element to ensure communication between systems (Lilis & Kayal, 2018; Stavropoulos et al., 2013). In order to plan a system that functions at full capacity and meets the needs of the designer, many systems must employ multiple varieties of technologies. For instance, systems may simultaneously use Wi-Fi, Bluetooth, and ZigBee in conjunction with each other (Garroppo et al., 2012). There are several domotic systems developed as standards including KNX, LonWorks, EnOcean, and X10, but the major problem with these is that there is no one standard and no consensus in which system to use as the clear standard, which is evident by the vast number of standards (Sánchez et al., 2011).

The lack of interoperability is a major problem with domotic systems. One way to overcome this problem would be to agree on a common standard or better yet, to create interoperability within systems that allow systems to communicate easily with each other (Drubin, 2021). Some attempts toward this cross operability are emerging, but the field is still in it’s an infancy stage (Hong et al., 2020; Phan & Kim, 2020). The more common model is demonstrated with the myriad of growth of middleware solutions (Moreaux et al., 2012; Zheng et al., 2017). Because there is no single accepted standard that will work with all systems, the design of middleware bridges the systems. Middleware communicates between the various types of devices, systems, and families of standards (Miori et al., 2012). There are often multitudes of new applications and individual devices that have existed independently for some time or that have recently reached the market that needs unification into a common platform. Standards and alliances help with interoperability, but do not include every individual device available on the market

(Drubin, 2021). Middleware helps alleviate the issues that come from the lack of interoperability (Stavropoulos et al., 2013).

Many of the common standards use the same industrial, scientific, and medical (ISM) band (Haase, 2013). When there are multiple users or devices on a band at the same time, there can be significant signal interference (Kerner et al., 2013; Strba & Krajčovič, 2012). This is especially true of two of the most common standards Wi-Fi and Zigbee, which both operate at the unlicensed 2.4 GHz band which have 16 narrow (2 MHz wide), non-overlapping channels. This narrow banding allows up to 16 different networks to work without interference in the same area (Garroppo et al., 2012).

BAS have been widely available since the 1970s, but widely adopted. This was due to their complexity, cost, and the lack of standardization (Baquero et al., 2012). The introduction of the X-10 domotic communication protocol in the 1970s and was popular due to its use of currently existing power lines, thus making its use easy for designers. The design of X10, however, was as a transmitter only and was not as a signal receiver (Baquero et al., 2012). According to *Smart Building Systems for Architects, Owners, and Builders* by (Sinopoli, 2010), the concept of building domotics began in the early 1980s when smart buildings were termed as a combination of telecommunications and building management. Early domotic systems had physical connections integrated into their design. The systems were independent and were closely related to each other, causing changes in one part of the system to affect other parts of the system (Miori et al., 2012).

Wireless technologies have made a great impact on the design of domotic systems. The integrated concept of smart buildings has been around since the 1990s, and it represents the concept of adding sensors and actuators throughout the building, evoking the futuristic vision of robotic homes (Bonino & Corno, 2010). Wireless technologies opened new possibilities to expand domotic systems. Wi-Fi enabled designers to use domotic systems in places where hardwiring is a physical challenge. Wi-Fi signals can travel through brick, marble, and concrete (Miori et al., 2012). This is advantageous if getting wires through these mediums are a challenge. The problem with initial wireless systems was that the design was for specific groups of activities. ZigBee and Z-wave were both for health monitoring activities while HAVI and UPnP focused on audio and video applications (Miori et al., 2012).

With the evolution of domotic technology, there are many different ways to describe building controls. The terms domotics, building automation, and smart buildings are the terms that have appeared most often. The term ubiquitous computing grew from AmI (Sampaio et al., 2012). Home automation, domotics, and smart homes grew from BAS prevalent in commercial buildings (Carreira et al., 2014). AmI systems grew from home automation and BAS (Baquero et al., 2012).

Current domotic systems have grown into context aware, interactive systems (Carreira et al., 2014). Researchers have said that domotics are, “socializing elements, integrators, and facilitators in our daily lives,” (González Alonso et al., 2012, p. 889). The difference between simple domotic systems and AmI lies in the nature of the interactions. The term ambient intelligence represents the mechanisms that control the performance of the environment. AmI systems are more human-centric and interactive than their passive counterparts (Martinez-Martin et al., 2021). Current systems cannot operate effectively without a significant amount of consideration for the needs of the human inhabitants. These systems often have similar defining elements including, context awareness, the ability to integrate, the ability to be personalized, easily adaptability, flexibility, and anticipation of needs (Martinez-Martin et al., 2021).

One very important, reoccurring theme is that domotic technology should be unobtrusive. This is a key element in the growth of the technology. With the advent of wireless technologies, domotic system design now includes areas once excluded, and systems can become hidden and relatively invisible. The goal of domotic technology should be to become seamless, unnoticed, and natural. This ability to hide allows domotic systems to be effective, domotic systems should be nonintrusive (Perroud et al., 2011).

Energy control systems are an important aspect of domotic technologies (Mir et al., 2021; Salerno et al., 2021). Many building expenses come from energy use and the most effective way to control costs lie in effective energy control systems. Building management system design controls and monitors energy use with numerous sensors and actuators mainly through wireless sensor networks (van de Kaa et al., 2021).

The EnOcean sensor network is so energy conscious that the system will harvest energy produced, which reduces the total life cycle costs as well as maintenance costs (Haase, 2013). EnOcean is the most energy efficient wireless radio protocol. It uses short messaging and very high data rates (Strba & Krajčovič, 2012). EnOcean harvests energy by exploiting the energy excitation and potential and allows the systems to operate without using batteries-based power (Aragues et al., 2012). It is bidirectional and offers interoperability with numerous devices (Kambourakis et al., 2020).

Building lighting systems can account for up to 5-15% of energy consumed and energy and buildings make up 70% of US electricity usage (Zarindast et al., 2021). An effective domotic system can decrease energy consumption significantly through efficient equipment and responsive controls. Trend analysis from Zarindast et al. (2021) showed that energy, comfort, and smart lighting are all gaining interest and popularity, with energy saving being the most popular research topic followed by user comfort.

Other activities that can decrease lighting loads include daylight harvesting, occupancy sensing, load shedding, and room scheduling management (Nguyen & Aiello, 2013). An ideal lighting system will be able to recognize and adapt to the needs, preferences, activities, and behavioral changes of the users (Nguyen & Aiello, 2013). There are numerous opportunities to improve lighting management. Over 70% of a buildings energy use comes from electricity and 70% of energy use in America comes from electricity. Smart lighting has great potential to improve building user’s comfort and lower building energy use (Zarindast et al., 2021).

Technical Aspects of Domotic Systems

While there are numerous domotic communication standards, most protocols like ZigBee, build on the IEEE 802.15.4 wireless standard (Nedelcu et al., 2009). This standard is WPAN, or the Wireless Personal Area Network. ZigBee is a low rate, short range wireless communication standard that has a high bandwidth radio technology (Hu et al., 2013). WPAN has low complexity, low cost, low power consumption, and low data rate transmissions (Baquero et al., 2012).

The IEEE 802.11 family of standards includes common standards 802.11a, b, g, and n. Each new generation offers significant improvements over the previous generation. The common commercial trademark for 802.11 a/b/g/n standards is Wi-Fi. The 802.11ac, introduced in 2012, supports multiuser, multiple input multiple output, (MIMO) devices. MIMO allows for a more efficient use of network capacity due to the versatility that it affords (Alsabbagh et al., 2013). The 802.11 ac standard is currently under development and capitalizes the wider available bandwidth available with the 5 GHz frequency (Aragues et al., 2012). The expectation is that mobile devices that support the 802.11ac are expected to grow significantly with annual estimates of over 400 million devices by 2016 (Alsabbagh et al., 2013).

The IEEE 802.11 operates over the 2.4GHz Industrial, Scientific, and Medical (ISM) band. It has the ability to operate over several channels including 11, 13, or 14. The channels are 22MHz wide and have some overlap. As a result, usage is limited to three or fewer networks simultaneously in one area in order to reduce interference (Garroppo et al., 2012).

IEEE 802.3 standard, better known as Ethernet, is a communication transmission medium that uses twisted pair wire or fiber optics, and typically has a Cat 5 connector. Ethernet is an essential communication tool for wire-based products and is commonly associated with Local Area Networks (LANs). This standard supports both wired as well as wireless technologies by acting as a bridge for wireless devices. Ethernet can provide power and high-quality data transmission through the wired connections (Anders, 2010).

Similar to Wi-Fi, Bluetooth serves as a wireless alternative to cable-based communications (Aragues et al., 2012; Jebroni et al., 2020). Bluetooth is a communication standard, which employs a low power, close proximity technology (Aragues et al., 2012). Bluetooth has undergone several versions of revisions including BT2.1+EDR, BT3.0+HS, and BT4.0 also known as BTLE, used on high end mobile devices due to the low power consumption (Aragues et al., 2012).

ZigBee is a low cost, radio frequency standard, based on IEEE 802.15.4 (Okada et al., 2021). Zigbee, is often used in healthcare, building automation, energy management, and industrial applications. It uses low power and relatively low-cost applications (Haase, 2013). Implementation of a Wireless Personal Area Network (WPAN) by Zigbee uses mesh technologies and creates an environment conducive to working with other wireless technologies (Nedelcu et al., 2009).

The Building Automation and Controls Network (BACnet) protocol is a system commonly used for facility energy management for demand and response that can be used for the Smart Grid (Gaitan & Ungurean, 2021; Holmberg, 2011). BACnet is a standard communication protocol designated by American Society of Heating, Refrigerating, and Air Conditioning Engineers (Gomez-Otero, et al., 2012). BACNet is an ISO global standard, as well as a standard in the United States, Europe, and over 30 countries. It is a building automation open protocol and used for scheduling as well as alarm systems (Baquero et al., 2012). BACnet can assist with interoperability of building system manufacturers if the manufacturer agrees to the BACnet interoperability building blocks (Anders, 2010).

The Digital Living Network Alliance (DLNA), formed in 2003, creates standards for digital devices. Over 245 corporations establish the DLNA, which published their guidelines for entertainment devices in 2004. The DLNA has more interoperability features than options like AirPlay and allows direct access to entertainment media directly rather than through a digital media server (Sangani, 2012). The DLNA is a poor fit for homes because it does not adequately support user management over the technology to allow the development of applications that are portable or applications that for use over multiple devices (Dixon et al., 2012).

The establishment of EnOcean Alliance developed a specification for interoperable sensor profiles for wireless devices (Anders, 2010; Kambourakis et al., 2020). This sensor-based network operates in frequencies of 315MHz in North America. EnOcean uses a battery free unit that harvests energy through wireless sensor networks (Haase, 2013). EnOcean is highly desirable because it uses self-powered monitoring and control systems. It is one of the most efficient wireless protocols due to its short transmissions and high data rate (Strba & Krajčovič, 2012). EnOcean has a BACnet working group that is building protocols that will work with multiple manufacturers (Anders, 2010).

Insteon is a power line-based technology, and is an affordable domotic technology (Stavropoulos et al., 2013). It works on 904MHz and has a signal range of 45m, by line of sight. Insteon's main use is for building automation, alarms, and access. It is an optimal system for short messages, but currently has no encryption option (Haase, 2013).

KNX is a communication system based on the international standard ISO/IEC 14543-3. It operates at the 868.3MHz frequency and can be a twisted pair cable or connected through existing power lines. KNX allows components to communicate even if they are not in radio frequency range or if the signal is blocked (Haase, 2013). It is an open system, and used to control lights, shades and shutters, blinds, and HVAC systems (Baquero et al., 2012). KNX, along with LonWorks, is a leading home automation provider (Sánchez et al., 2011).

One of the advantages of LonWorks is that it uses dual carrier frequency technology to deliver improved reliability and reduce interference (Morales et al., 2012). It can monitor, control, and regulate building activities like HVAC systems. It provides a standardized integrated building system. The most common Lon Works medium is a twisted pair, but it can also use power lines, radio frequency, and fiber optics (Baquero et al., 2012). LonWorks is a proprietary platform that operates over ISO/IEC 14908-1 (Aragues et al., 2012).

The Universal Plug and Play (UPnP) is a commonly used standard that often used in home communication networks. It is one of the most widely used standards to control LANs and multimedia services, and generic applications (Bellavista et al., 2012). UpnP is a device neutral technology that allows devices to work independently (Warriach et al., 2013). UPnP was proposed by Microsoft and presented in 1999 and is the basis for DLNA (González Alonso et al., 2012).

Z-wave is a closed system based on a mesh network that seems to have some recent security issues (Hong et al., 2020; Moreaux et al., 2012). The mesh network is important because it allows multiple ways for information to get to the desired endpoint (Kerner et al., 2013). It focuses on wireless remote control for home automation and operates in the 868 MHz frequency with a range of up to 30 meters (Haase, 2013). It uses a source routing algorithm to find the fastest route on the mesh system. Once the command enters the system, an algorithm finds the best way to decide how to send messages (Kerner et al., 2013). Z-Wave is an alliance protocol that sets standards for use by manufacturers. It controls home entertainment devices, motors, garage doors, blinds, home security HVAC, and environmental sensors (Stavropoulos et al., 2013).

In a 2020 study (see Hong et al., 2020), researchers analyzed threats to homes that used Z-Wave using simulated security attack scenarios. The researchers found 46 threats based on the model to Z-Wave devices. The results of real-world scenarios showed that there were potentially significant vulnerabilities to Z-Wave devices (Hong et al., 2020).

Summary and Conclusions

This literary review for this study was conducted using text searches of recent articles concerning domotic systems. The search uncovered the top trends for domotic systems by analyzing the current trends and patterns in current research. I used technology s-curves, cluster analysis, frequency analysis, and trajectory maps to show trends, patterns, and interconnections of the results for this study.

There are many aspects of positive social change evident in this study. My research may allow designers to plan optimal systems that will improve health, comfort, accessibility, quality of life, efficiency, security, privacy, as well as decrease the negative environmental impact for the designer. Designers may be able to see the current trends and patterns in current research to determine the benefits of each system and their interconnections. This may enable an optimal design the best system early in the design process and to improve the adaptability of the system components. This study provides a tool to support improved decision making for system designers. Some of the benefits of implementing a domotic building system may include improved building performance and reliability, improved inhabitant comfort and productivity, higher operational efficiency of systems, better safety, and better energy efficiency. The organization of the rest of this study is as follows: Chapter 3 includes the methodology of the study. The study was comprised of text analysis of scholarly journal articles using NVivo software. Frequency analysis of the data provided the basis for the identification of trends and patterns in the data. Trajectory maps and technology s-curves were used to show the trends and patterns in domotic technology.

Chapter 3: Research Method

Many research methods were considered and explored for this study before determining that a qualitative exploratory case study would be the most appropriate approach to determine the trends within domotic technology. Case studies are often used to answer “how” or “why” questions, and exploratory studies generally answer questions that ask “what.” This study was designed to identify the trends and patterns in scholarly domotic research and to create an evaluative framework for domotic technologies. Qualitative methodology was appropriate to answer the research questions posed in this study. This chapter addresses the methods that were considered but not selected for this study, and I discuss the methods used for this study including bibliometrics, text mining, NVivo, decision tools, and case study research. The two research questions were the following:

RQ1: What are the trends and patterns in current domotic research?

RQ2: What are the interrelationships between current domotic research products and components that a designer can use as an evaluation tool?

Research Design and Rationale

The purpose of this study was to answer the research questions. Answering these questions may help to determine what relevant features to consider when designing an optimal domotic system. I used text mining and frequency analysis to investigate scholarly domotic research papers to gain knowledge of the trends and relationships between domotic systems. The objectives of the research were to explore current scholarly domotic research to determine the trends, patterns, and interrelationships between domotic systems and to create a domotic technology framework.

Mixed-methods research was considered as a research method for this study because it offers the advantages of qualitative and quantitative research methods. Mixed-methods researchers collect and analyze qualitative and quantitative data because both methods are necessary to answer the research questions posed in the study (Creswell & Clark, 2017). Mixed methods are often used when no single method of research will answer the research questions.

Mixed methods first considered for this study due to the complex nature of the research questions (Creswell & Clark, 2017). This study was designed to identify and analyze trends in current domotic research. Initially it seemed that this study would need qualitative methods to determine the elements that contributed to the domotic growth as well as quantitative methods to analyze and measure the trend data. Mixed-methods research was not used for this study because the research questions could be answered in a qualitative study. A single case study was conducted to measure the trends in domotic research through text analysis, and these trends were mapped using technology s-curves and trajectory maps. I used qualitative methods by analyzing the frequency of terms and content within scholarly domotic journal articles through text mining and mapping the results based on frequency analysis.

One of the most common quantitative methods, a designed experiment, was also considered for this study. However, this study was exploratory in nature and was not suited for a designed experiment. Due to the nature of this study, I determined that a quantitative design would not serve the purpose of this study. Several common qualitative designs including narrative, phenomenology, grounded theory, and case study were considered for this study. Ethnography was also considered for this study but was rejected early based on the research questions posed.

Narrative research focuses on the stories and experiences of individuals (Creswell et al., 2007). The primary method of data capture for narrative research is through3 interviews, letters, and other written documents that may tell the story of the selected individual. This study was not designed to focus on an individual but rather on determining the trends in current domotic scholarly research.

Phenomenological research is similar to narrative research except that the focus of phenomenological research is on the lived experiences of several individuals instead of the single individual studied in narrative research. The focus of phenomenological research is a phenomenon or an object of human experience. The focus is to analyze the data to describe the essence of the experience (Creswell, 2007). Phenomenological methods might have been appropriate for this study if it was about the effects of domotic technology on a group of people, but because this study focused on the trends and patterns of domotics, this design was not selected.

Grounded theory was a strong contender for the design of this study. Creswell (2007) stated that grounded theory provides a framework for taking a body of information in which the researcher has achieved a degree of saturation and placing the body of information into categories through coding. Once the information is coded, themes can be determined and connected to build a proposition. Grounded theory has multiple steps including open coding, saturation of category, and division into subcategories, and presents the categories on a continuum (Creswell, 2007).

Ethnographic research focuses on observing the shared patterns such as language, beliefs, and values of a cultural group. This is generally a field-based method in which the researcher spends an extensive amount of time observing and collecting data within the cultural setting (Creswell, 2007). After reviewing this method, I determined that ethnographic research was not appropriate for this study because the research questions posed were not focused on cultural characteristics.

Case study research focuses on the in-depth understanding of contemporary phenomenon in context (Farquhar, 2012). Case study research is qualitative research that enables the in-depth exploration of a bounded subject using a variety of data sources. This method of multiple data source exploration allows a variety of new aspects of the subject to be examined (Baxter & Jack, 2015). To perform effective and reasonable case study research, the researcher must first determine the unit of analysis for the case and the case must be bounded. Cases may be bounded by time and place, time and activity, or definition and context (Baxter & Jack, 2015).

Case study research often includes a variety of data sources that enhances credibility but can be overwhelming for researchers. To keep case study research at a reasonable and manageable level, researchers must ensure case information is well organized, focused, and clearly bounded. The large amount of data collected for the current study required significant data organization. To organize and manage the case data, I used NVivo. One reason that this method was selected for this study, was that the behavior of the subject involved in the case study would not be manipulated (see Baxter & Jack, 2015).

Bibliometrics was important to this study due to the richness of information collected from journal bibliographies through text mining, frequency analysis, and citation analysis. Bibliometrics has been used in quantitative analysis to evaluate trends in academic literature (Kim & Park, 2021). Text mining, a subset of data mining, provides a quantitative way to analyze qualitative data to provide meaningful patterns and statistics. Frequency analysis is used to identify potential themes and groupings to enable grouping and coding for data analysis (Pan et al., 2021). Word frequency analysis is a major component of the NVivo software analysis tool.

Text mining helped me analyze the frequency of terms used in domotic research to determine the major areas of study. One major problem that domotic designers face is that there is not a compilation of comprehensive information on the new options and possible combinations of system components. There is not a good way for a domotic designer to ascertain what systems and system component combinations will combine to create an optimal system that meets the needs of the inhabitants. An exploration of journal articles through text mining analysis may help domotic designers determine what patterns and combinations of options could lead to an optimal design for a domotic system. This search could lead to trend and pattern discoveries to evaluate an optimal design solution.

With text-mining search, timelines can become evident through careful analysis of the number and quality of articles published over a specified time frame. This could indicate whether scholarly domotic research has increased or decreased over a given time. The identification of trends over time can answer questions about the progression of trends in domotic research.

Domotic systems vary widely across platforms, equipment, and communication protocols. This creates a significant number of problems when designing a system to meet the needs of the inhabitants. Compatibility issues can cause system implementation delays as well as increase design costs (Phan & Kim, 2020). Lack of integration of systems can cause the needs of the building inhabitants to be unmet.

The purpose of this study was to identify and analyze the recent trends in published domotic research to identify what domotic technologies are currently the subject of academic research. J. K. W. Wong and Li (2008, 2010) completed several studies on building system analysis and the development of critical factors, while Kim and Park (2021) demonstrated how a bibliometric study of academic journals can be used to conduct trend analysis.

Research included a review of intelligent building systems (J. K. W. Wong et al., 2005); the construction, application, and validation of a selection evaluation model (J. K. W. Wong and Li, 2010); the application of AHP in the selection of intelligent buildings (J. K. W. Wong and Li, 2008); and the development of key intelligent indicators for intelligent buildings (J. K. W. Wong and Li, 2008). These researchers built a foundation of the study and analysis of building systems and paved the way for further research. I built on J. K. W. Wong and Li’s foundation to determine the research trends in current domotic research.

Bibliometric research was selected for this study based on the research question that addressed trends in current research related to domotics. Bibliometric research is a growing area used to measure scientific output and to plot patterns and trends in publications (Guilera et al., 2012; Kim & Park, 2021). Many new and unproven commercial domotic systems and components are growing daily. By focusing on current bibliometric research areas, I sought to identify tested and established domotic trends.

Many of the studies included surveys for data collection (Bonino & Corno, 2010; Sánchez et al., 2011). This data collection method was not selected for the current study due to the potential subjectivity and bias that may occur in survey data. The focus of this study was to discover the trends and patterns in current research, so survey methodology was not as useful as studying case information to answer the research questions.

Another common qualitative data collection method is conducting interviews. Interviews have to be meticulously designed and implemented by a well-versed interviewer to correctly interpret the data (Yu et al., 2014). These data must be documented, coded, and analyzed to obtain meaningful results. This method was not considered appropriate for the current study because interviews would not have produced the data needed to answer the research questions. The ideas and perceptions of interview participants can sometimes obscure the results of a study. One of the advantages of using case study research from archival dat, is that the documents are fixed and cannot be changed. This decreases the risk of misintrepretation because there is a permanent record of the case information. The trends in the current study were based on documents that could be generalized and replicated by others with access to the same documents.

The selection of NVivo was based on the software's ability to conduct frequency analysis on the bibliometric information. NVivo is a powerful analysis tool used in the bibliometric research. I selected this tool due to the classification, sorting, and frequency analysis tools provided by the program. Frequency analysis could provide useful information on the current state of domotic research through analysis of the quantity, information clusters, and trends in current domotic research. From the frequency analysis, critical factors could be found, and these could be visualized through technology s-curves and trajectory maps. This would show where the trends in scholarly domotic research were flourishing or failing. Text mining is a research tool that involves the collection and analysis of data. The emphasis of text mining is the algorithm-based counting of words, but it also incorporates the aspect of interpreting the context of the words that are collected (Yu et al., 2014).

Role of the Researcher

My role as the researcher in this study was to collect unbiased information and analyze the information to determine trends in current domotic research. I sought to ensure the integrity, accuracy, privacy, and security of the data obtained. There were no supervisory relationships in this study. Archival literature was the main source of data for this study; therefore, there were no participants.

A systematic data collection process was used to manage bias. Peer-reviewed articles were collected from science- and engineering-related journals from several journal collections including the Walden Library, University of Colorado at Colorado Springs Library, Colorado State University-Pueblo Library, CCCOnline Library, and the

Pikes Peak Library District to achieve saturation of documents. Keywords included domotics, ambient intelligence, smart/intelligent buildings/homes, ubiquitous computing, and IoT. NVivo was used for frequency analysis to identify the most relevant issues and concerns in domotic research. The verification of the critical factors determined the criteria for mapping.

The use of multiple catalogs, multiple databases, and multiple types of organizations enhanced validity through triangulation. The various methods of mapping the data also increased validity through triangulation. Finally, a strong audit trail supported the rigor and trustworthiness of this study.

Methodology

This bibliometric study comprised a thorough search of journal articles. I used recent peer-reviewed articles from several institutions including Walden University, University of Colorado at Colorado Springs, Colorado State University-Pueblo, Google Scholar, CCOnline Library, and the Pikes Peak Library District. I gathered and analyzed the data through an exhaustive search of the identified institutions. This exhaustive search strategy allowed for saturation of the journals on the subject of domotics. A keyword search was used to identify the critical factors related to domotic technology. The search was expanded as needed and included the top journals related to building technology from the United States until saturation was achieved. Data consisting of the articles and the text searches and frequency results were documented, and a secure archive of the data will be saved for 5 years.

A bibliometric, frequency analysis sampling strategy is a relevant research method for archival research. Scientific publications are a recognized form of academic research. Bibliometric research is a common method to determine trends over time, and to assess the relative position of a topic within a scientific field (Kim & Park, 2021; Ugolini et al., 2011). Using archival data was the best way to answer my research questions. The selection of the data was based on whether the articles filled the requirements of the domotics based keyword search, if the articles came from an acceptable database, if the articles came from peer reviewed journal articles, and if the articles meet the limits of the research questions. The bibliometric searches continued with at least four libraries until saturation was reached. If by chance saturation was not reached with articles that meet the criteria from the last five years, the search would move backward, by year until saturation was reached. There was an anticipated sample size of a minimum of 2000 acceptable articles, which is the number of articles retrieved for the initial literature review of this study.

The first phase of my study used selected articles from all listed catalogs, databases, and institutions by using domotic keywords. These terms created a corpus of unique articles that were used for the study. The first analysis was a bibliometric study of the keywords of the carefully chosen articles to determine the critical factors of the study. In the next phase I analyzed the abstracts within each of the articles for more trends and patterns.

Participant Selection Logic

This study consisted of a bibliometric study comprised of a thorough search of journal articles. I used recent, peer reviewed, articles from several institutions including Walden University, University of Colorado at Colorado Springs, Colorado State University-Pueblo, Google Scholar, CCOnline Library, and the Pikes Peak Library District. I gathered articles to use for the bibliometric study and I analyzed the corpus data through an exhaustive search of the identified institutions. This exhaustive search strategy allowed for saturation of the journals on the subject of domotics. I used a keyword search to find the critical factors related to domotic technology. The search was expanded as needed and included the top journals related to building technology from the United States until saturation was achieved. Data consisting of the articles and the text searches and frequency results was documented and a secure archive will be archived and saved.

A bibliometric, frequency analysis sampling strategy is a relevant research method for archival research. Scientific publications are a recognized form of academic research. Bibliometric research is a common method to determine trends over time, and to assess the relative position of a topic within a scientific field (Kim & Park, 2021; Ugolini et al., 2011). Using archival data was the best way to answer the essential aspect of the research question presented for this study. The selection of the data was based on whether the articles filled the requirements of the domotics based keyword search, if the articles came from an acceptable database, if the articles came from peer reviewed journal articles, and if the articles meet the limits of the research questions. The bibliometric searches continued with the libraries until saturation was reached.

Instrumentation

NVivo was used to identify, collect, and store archived data from peer reviewed articles. Documentation of data will be archived and stored on a separate drive after the study is concluded. The source of the journal articles included prominent science and engineering databases such as IEEE Explore, JSTOR, Springer, and Science Direct. The databases are sufficiently large enough to collect sufficient data results. IEEE Explore has access to over 3,578,700 items, JSTOR has over 4,500,000 articles, 8,148,089 documents, and Science Direct has over 11,000,000 journals and book chapters.

Academic science, engineering, and technology journals was used for this study due to their reputation for quality research publications and their relevance to the subject matter. In addition, only peer reviewed journal articles were used for this study. Peer reviewed articles are written and vetted by subject matter experts, thus demonstrating that they represent the best source of data available to accurately answer the research questions.

By collecting peer reviewed journal articles from the past 10 years to achieve saturation, I sufficiently collected data to determine trends in current domotic research. Creswell (2007) stated that saturation occurs when new information does not provide any additional information for the category. The articles collected from the library searches may show some bias toward the degrees offered at any individual institution. This potential bias was addressed by collecting peer reviewed articles from multiple libraries and different types of institutions.

Procedures for Recruitment, Participation, and Data Collection

Data were collected from peer reviewed, science, engineering, and technology journal articles from the past 20 years by using at least four library databases. I collected the data and used NVivo to assemble, store, and analyze the data corpus. This data collection was collected and analyzed and saturation was achieved. The collected articles were analyzed with NVivo software, and the articles and analysis will be archived on a separate drive to safeguard and preserve the results after the study. The data was cataloged and coded to analyze it for correctness and appropriateness for my study. Data were noted and discarded if the articles did not meet the scope of the study. The resulting analysis of the articles were listed and mapped in order to determine trends, interconnections, and associations of domotic technologies.

Data Analysis Plan

Each journal collected from the bibliometric text search was reviewed and analyzed for the appropriateness of my study. The journals were sent through coding and frequency analysis software to determine the most common factors listed in the articles. The factors were narrowed down to the critical factors in order to determine common themes and categories. Any data selected by the text search, but that does not meet the needs of the study was cataloged and omitted for the purpose of this study. Trajectory maps and s-curves were designed from the trends in the critical factors over time. Mapping of the critical factors showed trends and associations between critical domotic components. Coding was carried out primarily in NVivo and the articles were reviewed and verified to ensure that they meet the requirements of the research questions. Articles that did not fit the research questions for this study were noted and discarded. The final data corpus was reviewed and checked for acceptability for the study. The final critical factors were analyzed and mapped to determine the trends in domotic research.

Issues of Trustworthiness

Credibility

To establish credibility, the researcher will seek recurring evidence. This study employed rigorous data collection strategies in order to determine answers to the research questions. The main means to establish credibility for this study was through saturation and triangulation methods. Triangulation was achieved using multiple catalogs, multiple databases, and multiple types of institutions. Triangulation was also achieved through the mapping of different types of information. Saturation was the point at which no new information was found for the study. This study queried multiple databases, from multiple institutions using multiple search keywords until an acceptable level of relevant peer reviewed articles was found that provided the basis of the text frequency analysis.

“Triangulation is a validity procedure where researchers search for convergence among multiple and different sources of information to form themes or categories in a study” (Creswell & Miller, 2010, p. 126). Multiple and different sources of information were used for this study. Multiple databases, from multiple institutions were queried in order to obtain saturation for this subject matter. This form of triangulation helped to establish credibility for this study.

Transferability

Transferability was achieved mainly through the variation in selection of the articles in this study. This was achieved by the number of libraries used, the types and quantity of databases used, the coding by NVivo, and trend analysis, which provided a high level of consistency. Building system designers could replicate the results of this study to help develop their own optimal domotic designs. Replication of the results from this study are possible by using NVivo and could show the same results regardless of the researcher if the same coding rules were applied consistently. Replication of the data is possible; however, the inductive analysis of each researcher could yield varying results even with the same data that I used. I reviewed and analyzed my NVivo selections to ensure reliability of data. Exceptions that did not apply to this study were noted and eliminated from the data analysis. The journal articles used were published and did not have any confidential concerns. I collected and stored this data on password protected devices and backed up the information on an external drive. The journal data is open to the public and did not need post study destruction.

Dependability

Dependability was achieved through triangulation and audit trails. This study created a significant amount of data, which was tracked and cataloged during the course of the study. This audit trail was documented in order to not only show the results of the study, but to also document the iterative process of retrieving and analyzing the data. Triangulation is a process of searching for convergence from multiple and varying sources in order to find themes or categories in a study (Sweetman et al., 2010).

Triangulation for this study was achieved through multiple libraries multiple key word searches, multiple databases, and multiple methods of reviewing the data.

Audit trails were created through the careful data collection process and documentation of the research process. The journal searches were logged along with the resulting articles listed in the searches which included: the actual articles in PDF format (if available), the frequency analysis queries, the results of the queries, the critical factors found, the mapping of the results, the final trajectory maps, and the s-curves. All of these were collected and archived on a separate data storage device in order to preserve the accuracy of the data and the process of this study.

Confirmability

The confirmability of this study was achieved primarily through reflexivity. Reflexivity is where the researcher discloses the beliefs and biases that may affect the study in order to suspend the biases for the purpose of the study (Creswell & Miller, 2010). Reflexivity is often done through journaling and careful reflection of personal biases and opinions. In this study, reflexivity was obtained through neutral cataloging of relevant topics, themes, and information as they ensued in the literature review. The first search string for this study was intelligent control systems. Once this search was executed, it led to a string of related terms including the most common topic which turned out to be domotic systems. A listing of all relevant terms and topics was cataloged as the search ensued which became the basis of this study. Documentation of this process has allowed the study to grow based on was found in the research rather than from the biases of the researcher.

Ethical Procedures

I ensured that this study followed ethical procedures. The first step of this process was to obtain approval from the Institutional Review Board. This study had no human subjects. The ethical concerns related to the selection of the documents was also minimal. All of the journals were open to access and were obtained through the permission of the host institutions. Data collection concerns were minimal because the documents are available for research. The data were documented, archived, and stored on a separate, protected drive to ensure consistency, data protection, and a back-up copy. There are no known conflicts of interest or incentives used for this study. I used the raw data collected from searches and I will cause no harm to subjects or cause any known ethical concerns.

Summary

This study was comprised of a bibliometric, text mining study design of recent, peer reviewed journal articles on domotics. Data was collected from multiple sources and analyzed in NVivo. The analysis focued on common keywords surrounding domotic technologies. The articles were collected to determine the corpus of data until saturation was achieved. The corpus was inductively analyzed and cleaned until a set of critical domotic factors were established. The critical factors were diagramed through technology s-curves and trajectory maps. The data was analyzed through frequency analysis and charts showed interconnections and associations between the critical factors that were found. This final set of data was graphed through technology s-curves and trajectory maps in order to determine the trends and patterns of domotic research.

Table 1

Research Question Analysis Methods

Research question	Type of analysis
What are the trends and patterns in current domotic research?	Categorization of data, citation analysis, data clustering, frequency analysis, forecasting, s-curve
What are the interrelationships between current domotic research areas?	Data clustering, network diagram, tree mapping

Chapter 4: Results

Research Setting

The field of domotics is multidisciplinary and covers a multitude of uncoordinated topics, areas of focus, and products. The purpose of this study was to develop knowledge about the trends and patterns in current domotic scholarly research. The intention was to gather information about trends in the field of domotics. The focus for this study centered on assessing whether domotic research is in a growth stage, whether the research area is beginning to wane, whether the field is moving toward specific focus areas, what the emerging topics are, whether the field is becoming more consistent, and what areas have received the most scholarly research. The research questions for this study were the following:

RQ1: What are the trends and patterns in current domotic research?

RQ2: What are the interrelationships between current domotic research products and components that a designer can use as an evaluation tool?

This chapter includes the purpose of the study, the potential impact of the study, and how the study was conducted. I also describe the data collection process, coding process, and issues that came up with the data. Next, I discuss the trustworthiness of the data, including credibility, transferability, and consistency. The results are then described with the inclusion of corresponding tables and figures. The final section provides a summary of the results.

Data Collection

I conducted a qualitative bibliographic data-mining study by analyzing data collected from peer-reviewed journal articles on domotic technology. Journal article data often needed authorized access and, in most cases, needed to be accessed in person. For this study, it was necessary to make numerous site visits to libraries on two campuses and one city library including the University of Colorado-Colorado Springs (UCCS) Kraemer Library , the Colorado State University-Pueblo (CSU-P) Library, and the Pikes Peak Library District East Library. Searches were also conducted from online data sources including Google Scholar webpages, the Colorado Community College Online (CCCO) Library, and the Walden University Library webpages. It was necessary to first obtain access privileges from the campus library databases to begin the data collection process by obtaining authorized library credentials.

Each library contained several journal database sources. For example, the CSU-P library had subject searches by categories including multisubject, arts and humanities, business and management, multicultural studies, education, English, government and law, health sciences, history, mathematics, newspapers, primary sources, reference sources, science and technology, and social science. I determined that because of the multidisciplinary nature of domotics that crosses over many disciplines, the multisubject categories should be used for this study.

Under the CSU-Pueblo multisubject heading, there were various journal databases: Academic Search Premier (EBSCOhost), Article first (FirstSearch), Congressional Publications (ProQuest), CQ Researcher, Credo Reference, CSUP Journals

A to Z (Journal Finder), Digital Dissertations, eBook Collection (EBSCOhost), eBook Library (EBL), EndNote Web, Ethnic NewsWatch (ProQuest), FINDarticles.com, Gale Virtual Reference Library, IngentaConnect, JSTOR, LexisNexis, MasterFILE Premier (EBSCOhost), OAlster, OmniFile Full Text Select (EBSCOhost), ScienceDirect Journals, TOPICSearch (EBSCOhost), and WorldCat (FirstSearch). Several of these databases were not relevant to this study and were not searched for results. For example, the Digital Dissertations database was not relevant to this study because only peer-reviewed articles were used. Test searches were conducted on all remaining relevant journal categories to identify relevant data.

Once test searches were complete, samples of the data were collected and analyzed to prepare for consolidation. Given the multiple selections of libraries and the vast selections of databases, there was little uniformity among the data files. To resolve this, I investigated numerous free electronic data capture systems. The first free program was a Mozilla Firefox web capture add-on called Screengrab by Oleksander. This tool is useful in capturing the complete page information as an image from searches conducted on pages with longer results to preserve them for future viewing. Screengrab can also be used to capture images from the full-page search without having to scroll down and conducting additional snips from the page. This also allowed small portions of the page to be captured, similar to the Microsoft OneNote tool. Screengrab was not optimal for the current data analysis because all of the resulting information would be stored as a static image and data could not easily be extracted from the pages. Similarly screen capture tools that only captured images of the data were also investigated and rejected.

This led to the exploration of free web scraping or web data extraction tools. One tool that stood out for ease of use and having the options necessary for this study was import.io. This tool allows data capture of live online information in a format conducive for data analysis. Web data can be extracted and collected into csv or Excel formats for future analysis. Import.io has a simple and easy-to-learn free interface that can be conducted after saving the executable file to a computer. The tool has several data collection formats including a crawler that continuously collects real-time data and an authentication extractor that can be used on password-protected websites. The extractor was selected for testing on the library databases.

The first extraction application program interface (API) was created and used on the CSU-P Academic Search Premier journal database using the search term *domotics*. The API was set up to capture journal information including article title, author names, journal information, keywords, abstract, and digital object identifier (DOI). Using the API extractor tool, I trained rows and columns to remember selected search information to return accurate results. The more training that was conducted, the better the results returned by the API. The first run of the API returned correct and useable data for the first page of data results. A new API had to be created for each type of journal database and for each library due to the variability of the journal information on each database.

However, the API only returned data on the first page of returned results if it would publish at all. The authenticated API was also tested with the same results. This API was problematic because the search term yielded multiple pages of results and there were multiple search terms. After further study, I determined that data extractors such as import.io had limited processing capacity and the APIs that exceed the processing time limits on each page were limited due to costs incurred from this type of search. Pages with significant amounts of JavaScript also caused APIs not to publish. The API was rebuilt to disable Java with no changes in the results. In checking with technical support, I confirmed that pagination would continue to be an issue with this type of data extractor. Similar programs such as Kimonolabs.com and Parsehub.com produced similar results. I determined that these types of data extractors were not capable of producing the results needed for this study given that they also could not handle the security levels that exist with library databases.

The lack of appropriate data extraction tools created a need to find a way to compile and aggregate the data. After consulting with a technical expert, I determined that the easiest way would be to collect the data and save the files as HTML files. Similar files such as the EBSCOhost-based files could be collected and converted to an Excel file using Python, and then using Microsoft Power Query. Overall, 162 data files were collected and combined with an average of 100 journal entries per file, the maximum number of journal entries that could be saved through the journal database save options.

The literature review portion of this study indicated that there were several key terms that encompassed the theme of domotic technology. Domotics was not the sole term used to describe the main concept of smart or intelligent homes or buildings that was the focus of this study, but it was the best limiter for the topic. In addition to domotics, three key terms came up as the most significant to cover the majority of smart building concepts: *domotics*, *ambient intelligence*, and *ubiquitous computing*. The searches were also limited by the peer-reviewed filter to ensure the scholarly documents desired for this study. By using these three terms, I selected over 5,000 titles total and 3,000 usable journal titles from the library and online data sources.

These files were compiled and converted into a single Excel file named Citations. This file, however, was not perfect due to the variation in the data stored in the journal article databases. An Excel document named Masterfile with over 6,000 pages of information was saved as an original backup file that could be referenced in case of any discrepancies in the data or questions about any of the records. At any point this file could be used to recreate any of the downloaded Excel file information. The Masterfile was saved on OneDrive, thumb drive, and an external hard drive.

At this point the data needed to be thoroughly vetted, cleaned, and normalized. The article titles were used as the first point of reference for the data entry. The first iteration of data cleaning began with eliminating unnecessary data columns, rearranging data columns for ease of use, and eliminating duplicate data. For instance, some journals captured the article title using words such as, *the*, *or*, and *an* for the first word while others eliminated these words in the title results. These duplicates were not found by the computer during the first sort, and some had to be eliminated manually. This process brought the entries down to just over 3,000 entries.

The second and much more time intensive iteration of cleaning was looking for titles that did not belong in the domotics category. Although the peer-reviewed designation was a limiter on the searches, the final titles often included editorials, obituaries, and conference proceedings. These were manually eliminated from the study.

Also, articles that were not listed in English were eliminated from the study due to the problems that would occur when the data mining was completed. Non-English articles were eliminated if the abstracts were not in English. This process brought the journal entries down to about 2,600 entries.

The third and most time-consuming iteration of the cleaning process consisted of reviewing the remaining titles and abstracts and verifying that they were appropriate for the study. Many files did not capture the abstracts for the articles, so these had to be refenced and manually added to the data file. Some titles focused on technologies used in domotic systems, but the description did not state that the article related to a home or building technology. This was especially true for titles related to ubiquitous computing and energy. As a result, the number of applicable titles was decreased to 1,645 records for the frequency analysis. Domotics turned out to be the best search option to return optimal, clean data.

Data Analysis

After the data were collected, the entire data set was reviewed, analyzed, and graphed. The data were broken down into several separate Excel worksheets to conduct the analysis. The complete file was graphed and analyzed from 2001 through 2021 using the data through the end of 2021, which was the last complete year of data. The data were converted into a pivot chart for ease of analysis and the raw data were formatted for analysis in NVivo.

Data for trend analysis were first created in Excel, and then each file was analyzed for journal rankings to determine the implied importance of the information in the articles. Bibliometrics is an important area of academic study because it allows quantitative analysis of academic literature (Kim & Park, 2021). One important aspect of bibliometric research is the ability to rank the influence of an article based on measures of relative importance. For example, one of the most common measures of bibliometric research is the article citation impact factor, which is the assumption that the more important an article is to the field, the more often it is cited. The implication is that the influence of an article on the field is determined by substantial important citations by other authors and therefore it becomes important to the field (Samiee & Chabowski, 2012).

Although article citation analysis is a well-used measure for academic importance at the article level, I relied on measures for the academic importance at the journal level. Journal-level rankings were better measures for this study because journal rankings provided an overall picture comparison of scholarly quality focused within the field of study. One of the most important and widely used journal measure of importance is the Thompson Reuters journal impact factor (JIF). This calculation is based on a 2-year period and involves dividing the number of times articles were cited by the number of articles that are citable in the journal in that timeframe. The higher JIF shows that the journal is more often cited and therefore indicates a higher quality journal. Impact factor ranks can be found by logging on to the Thompson Reuters Journal Citation Reports on the Institute of Scientific Information Web of Science.

Although the JIF is a popular measure, it has some limitations. These limitations include the lack of focus on prestige in favor of measures of popularity that can be manipulated by adding less significant articles like letters to the editor and editorials (Yin et al., 2022). As a result of the limitations of the JIF, other journal measures have been developed including the h-index, SCImago rank, Article Influence, and Eigenfactors.

Using multiple journal prestige measures increases the reliability and validity of the results of the study because each measure is calculated by different measures. Each measure has advantages and disadvantages. The h-index is a measure of productivity and measures the number of articles (denoted by h) in a specific journal that has received at least h citations. The h-index measures the scientific impact of journal within a specific field. The higher the h-index, the more often cited the publication. Only highly cited articles contribute to the h-index. This index is versatile and may be used for scientists, journals, and countries (Yin et al., 2022). H-index journal scores are located on scimago.com.

The SCImago journal ranking is a measure that takes into account the number of citations in a journal and the importance of the journals from where the articles are cited. The SCImago journal ranking uses an algorithm similar to the Google page ranking algorithm. This ranking uses the number of citations as well as the importance of the journals from where the articles are cited. These rankings are located on scimago.com.

The Eigenfactor rank is meant to show the importance of a journal in the scientific field. This measure considers citations from highly ranked journals as having more importance. The Eigenfactor score is a measure of journal importance based on the number of citations, with highly ranked journal citations scoring higher. These scores are a measure of the importance of a citation and use the importance of the citing journal divided by the number of citations in that journal and use the total publications over a 5-year timeframe. Eigenfactor scores also use an iterative algorithm similar to Google page rankings (Yin et al., 2022). These scores are scaled such that the sum of all of the journals equals 100. The Eigenfactor score divided by the number of articles in the journal will give the Article of Influence score. The average of this score is equal to 1.00. If the Article of Influence score is greater than 1.00, this indicates that the journal has a higher-than-average influence on the field. Eigenfactor ranks and Article of Influence scores are found on eigenfactor.org.

Based on the varied advantages and disadvantages of the journal ranking models, several models were used and compared to determine academic quality of the dataset. The usefulness of these rankings is in constant debate and the continued refinement of the measures reflects the growth and dynamic nature of bibliometric research (Yaoyang & Boeing, 2013). In the end, the journal ranking methods proved to be too inconsistent and too unreliable to be of use for this study and this measure was abandoned for the purpose of this study.

The next step in the analysis was to conduct the text mining. The titles, subjects, keywords, and the abstracts for every journal article in the masterfile were located and included in the analysis. The top 100 terms two characters or longer were used for the analysis for each title file and abstract file. The text mining also used stemmed words, and eliminated stop words such as: *if, the,* and *with* as well as repeated informational words like abstract and copyright. Top terms were found and compared to the overall data set containing all 21 years. Similar words were grouped together and analyzed as a set and individually.

In bibliometric studies, word frequency analysis is commonly used as a tool to determine trends and patterns. The changes in word frequency often give an indication of what is going on in the field of research. Research from Jarić et al. (2012) stated that "The most common words should indicate the research priorities within the studied period, while the change in their frequency should reveal main tends within the respective scientific field" (p. 70).

NVivo was used to analyze the text frequency of the journal titles, and abstracts by year from 2001 through 2021 and all together to determine if there were any trends or patterns. The first test run determined that the text was not yet clean enough for clear analysis. Occasionally the titles and abstracts were from foreign countries, resulting in differences in the spelling of common words, like *behavior* and *behaviour*. These differences had to be normalized and this was generally resolved through the grouping similar words together. Also, the hyphenation of terms such as the word *based* as in *cloud-based* and *model-based* was found to be inconsistent. The grouping of terms also decreased the inconsistencies with the hyphenated terms. Once the titles and abstract text was cleaned, the files were independently run through NVivo for word frequency analysis and coding and compared universally through matrix queries. The resulting word frequency lists were coded, compared, charted, and analyzed.

The themes that emerged included: a definite upward trend in the amounts of scholarly domotic research, and the variety of research topics from 2001 through 2021, and an upward trend in research that is consistent with the technology s-curve forecast model. This trend also aligns with Christensen et al. (2018) research of disruptive innovation in academic journals where he also collected academic research output as a source to forecast trends.

Evidence of Trustworthiness

Credibility

The evidence of trustworthiness included the use of multiple data sources. There were numerous journal databases available within a library. For example, the Kraemer Library at UCCS has over 150 electronic databases with over 95,000 full-text journals available. To increase the pool of potential qualified journal articles for this study, multiple libraries with multiple databases were used. Articles from UCCS Library, Colorado State University-Pueblo Library, CCCOnline Library, Walden University Library, The Pikes Peak Library District East Library, and Google Scholar were queried for qualified articles. While the use of multiple libraries produced significant overlap in articles, it also allowed for a comprehensive corpus of data. Multiple databases within the libraries were queried and the results were compiled into a comprehensive dataset until saturation was achieved.

This dataset was then manually evaluated to ensure qualified articles were included and unqualified articles were excluded. This manual evaluation process was iterative, and the final data was thoroughly vetted to ensure trustworthiness. Every article's title and abstract was mined for appropriateness as well as reviewed by the researcher to validate the suitability for inclusion in this study. For example, while the library journal search criteria specified that only peer reviewed articles should be included in the query, there were multiple instances of results that included obituaries, editorials, magazine articles, and conference proceedings. These types of articles had to be eliminated from the study through careful visual review of the data results.

Once the final data was evaluated for appropriateness of inclusion in the study, the files received a final vetting when the files went through the NVivo software for word frequency analysis. The frequency analysis allowed visualization of the most frequently used words within each file and words that were incompatible with the study requirements were eliminated and the results re-analyzed. The data files were run through NVivo at a minimum of two times to ensure consistency and accuracy of the results. The search word length requirements were tested with 2, 3, 4, 5, 6 and 7 letters to determine if the results were significantly different based on the length of the words returned. Based on the test results, and the average most common word length of five letters; however, the length parameter of two letters was selected for this study to capture some vital abbreviations like IA for artificial intelligence and the variety of uses of IoT for Internet of Things.

Transferability

Transferability was established using multiple libraries, with multiple databases within those libraries, the various types of journals queried, and the use of NVivo, a qualitative data analysis software package. This study was designed to use readily available data that could be easily accessed by gaining proper library permissions. This study can be easily replicated with the same, or an amended set of parameters. The data collection process could be replicated by searching new or similar library databases and the uses of the scholarly limiters will yield similar data output.

Dependability

Dependability was achieved through triangulation of data and through detailed audit trails. This study tracked and cataloged the data collection processes and stored multiple copies of the data at various stages throughout the process. The various iterations of data cleaning and analysis were documented and stored. Triangulation was achieved through the convergence of multiple data sources for the final data set to achieve saturation of samples. Multiple libraries, multiple journal databases, and multiple keyword searches were used to ensure saturation of the appropriate articles for this study.

Confirmability

Confirmability in this study was achieved through reflexivity. Reflexivity was achieved through neutral cataloging of the data sets without allowing personal bias to enter into the analysis. This was an exploratory study where the goal was to have the data lead the study to determine the outcomes. The data was analyzed through the NVivo software program which produced unbiased data, free of personal influences.

Ethical Procedures

This study has no human subjects and has been cleared through the Institutional Review Board (IRB) # 05-28-15-0042950. Ethical concerns for this study should be minimal due to the use of secondary archival data. The data was collected from library databases, and the searches were documented, archived and backed-up for future reference. The data collection process in this study uses non-human documents and should not cause any harm or present any known ethical concerns.

Study Results

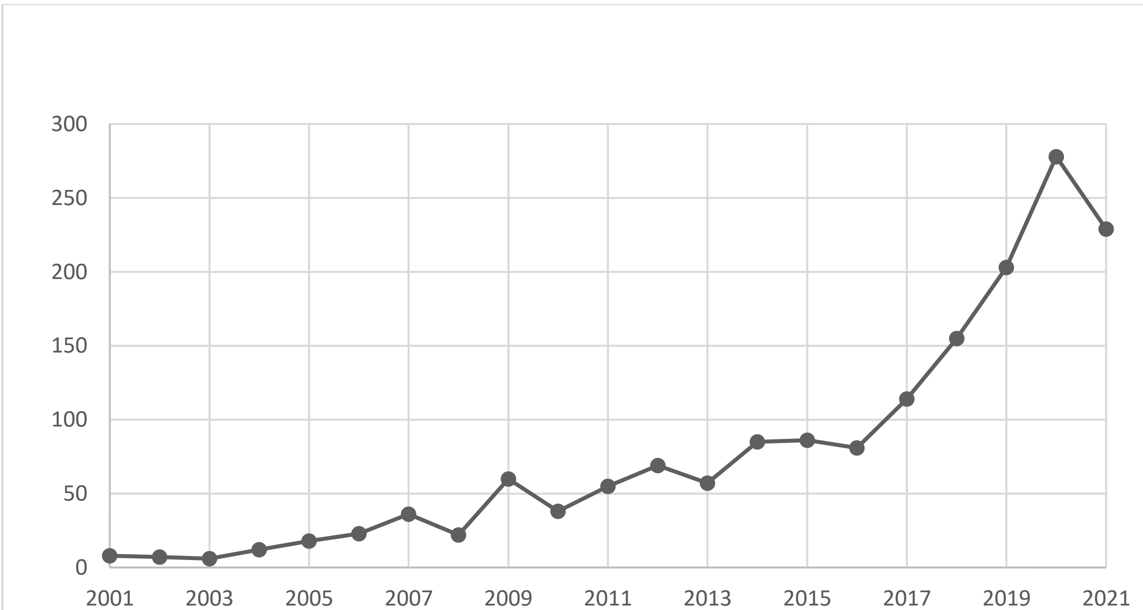
The goals of this study were to determine trends and patterns in domotic research and to determine the interrelationships between current domotic research products and components. This study used bibliographic text mining techniques to categorize data compiled from library searches of peer reviewed articles relating to domotic technologies. The results of this study did show that there is a positive upward trend in academic output related to domotic technologies in 2021 during the final year of the study. This could indicate that the technology is entering into winter season in the cycle of growth as modeled by s-curve analysis (Boretos, 2012). The results show upward trends in the quantity of articles as well as the breadth of research in domotics. The interrelationships between the research output and the variety of products and components are complex and varied as would be expected in a multi-faceted and multi-disciplinary technology such as domotics.

Trends and Patterns in Domotic Research Articles

The first step in determining trends and patterns in domotic research was to compile a list of scholarly domotic research articles. The first analysis was on production of articles over time. The data collection process found approximately 2,600 peer reviewed articles based on domotic technology (only). After a thorough data cleaning process, and elimination of duplicates, the records were pared down to 1,642 qualified articles ranging from 2001 through 2021. Graphing these articled by year shows that there was a distinct upward trend in domotic articles. Except for significant dips in 2008 showed a 39% decrease and 2010 showed a 37% decrease.

Figure 1

Bar Graph Showing the Growth of Domotic Research From 2001 to 2021



Overall Word Frequency Trends

The first frequency analysis was to determine overall trends in domotic research. Separate files were created for each year with data including the Article Title, Author Name(s), Journal Title, ISSN, ISBN, Publication Date, Volume, Issue, First Page, Page Count, Accession Number, DOI, Publisher, Document Type, Subject Codes, Keywords, Abstract and PLink. This data was reviewed for consistency, cleaned and prepared for import into NVivo. The first import into NVivo analyzed all years and all categories of words (titles, subjects, abstracts, and keywords) through frequency analysis.

The first comprehensive frequency analysis was reviewed for words that should not be used for the analysis. For instance, the word abstract appeared frequently within the frequency analysis and therefore was added to the list of stop words so they would not negatively affect the frequency analysis.

The top 20 stemmed words from all years with a weighted percentage above .5 include activity, automation, community, computing, controls, data, devices, energy, environment, Internet, IOT, managing, models, networking, sensors, services, systems, technology, users and using. These words were used as a starting point to determine patterns in the annual data files.

Table 2

Word Frequency for Top 40 Most Frequent Words 2001–2021

Word	Length	Count	Weighted (%)	Similar words
users’	6	4437	1.80	user, user’, users, users’, users’
using	5	4008	1.62	use, used, useful, usefully, usefulness, uses, using
systems’	8	3740	1.51	system, systemic, systemizes, systems, systems’
energy	6	2718	1.10	energies, energy
network	7	2376	0.96	network, networked, networking, networks, networks’
automation	10	2169	0.88	automate, automated, automates, automating, automation, automations
computing	9	2095	0.85	comput, computation, computational, computationally, computations, compute, computed, computer, computers, computes, computing
sensors’	8	2037	0.82	sensor, sensores, sensorics, sensorized, sensors, sensors’
technology	10	2027	0.82	technologic, technological, technologically, technologies, technologies’, technologies’, technology
data	4	1792	0.73	data
services	8	1685	0.68	service, services
activity	8	1678	0.68	activate, activated, activating, activation, activations, activator, active, actively, actives, activism, activities, activities’, ‘activities, activity

Word	Length	Count	Weighted (%)	Similar words
devices’	8	1635	0.66	device, devices, devices’, devices’
models	6	1553	0.63	model, ‘model, modeled, modeler, modeling, modelled, modelling, models, models’, models’
controls	8	1425	0.58	control, controle, controllability, controllable, controlled, controller, controllers, controlling, controls
managing	8	1376	0.56	manage, manageability, manageable, managed, management, management’, ‘management, manager, managers, manages, managing
internet	8	1340	0.54	internet, ‘internet, internets
community	9	1307	0.53	communicate, communicated, communicates, communicating, communication, communicational, communications, communicators, communities, community
environments	12	1287	0.52	environment, environment’, environments, environments’
iots	4	1284	0.52	iot, iots
appliances	10	1241	0.50	appliance, appliances, appliances’
applications	12	1195	0.48	applicability, applicable, application, applications, applications’, applicative
electric	8	1183	0.48	electric, electrical, electrically, electricity
wireless	8	1162	0.47	wireless, wirelessly
security	8	1146	0.46	secure, secured, securely, securer, securing, securities, security
design	6	1089	0.44	design, designed, designer, designers, designing, designs
power**s**	6	1081	0.44	power, power’, powered, powerful, powering, powers
things’	7	1027	0.42	thing, things, things’
developments	12	991	0.40	develop, develope, developed, developer, developers, developing, development, ‘development, developments, develops
timing	6	983	0.40	time, timed, timely, times, timing, timings
electronics	11	969	0.39	electron, electronic, electronics
intelligent	11	916	0.37	intelligence, intelligent, intelligently, intelligible
recognition	11	914	0.37	recognition, recognitions
results	7	904	0.37	result, resulted, resulting, results
algorithm	9	886	0.36	algorithm, algorithmic, algorithms, algorithms’
provide	7	870	0.35	provide, provided, provider, providers, provides, providing
approach	8	861	0.35	approach, approachable, approached, approaches, approaching

Word	Length	Count	Weighted (%)	Similar words
informs	7	846	0.34	inform, informal, information, informational, informative, informed, informing, informs
performed	9	811	0.33	perform, performance, performances, performative, performed, performers, performing, performs
humans	6	767	0.31	human, humane, humanities, humanized, humans, humans’

Title Word Frequency Trends

The next factor examined was the overall word frequency analysis of the titles, and abstracts. Then the word frequency analysis was repeated for each of the title and the abstract files by year. The top 10 most frequent words from each year were found and compared over the 21-year period. Then each of the top 20 keywords from each year were compiled into one list and each year’s information was added to a single table. The results showed that the keywords were consistent over the years with an increase in breadth of subjects as the count of articles increased.

Table 3

Word Frequency for Top 10 Most Frequent Words in 2010 Titles

Word	Length	Count	Weighted percentage (%)	Similar words
Activity	8	89	4.54	activities, activity, analysis, application, architecture, assistance, association, behaviour, bridge, building, computation, computing, construction, control, cooperation, design, development, energy, evacuation, function, gathering, healthcare, house, intelligence, intervention, mechanism, model, modeling, modelling, organization, process, production, project, regulation, representation,

Word	Length	Count	Weighted percentage (%)	Similar words
				research, selection, services, short, supply, support, supporting, technology, training, using
content	7	64	2.85	application, approach, architecture, commercial, communication, content, design, error, intelligence, interface, introduction, learning, living, memory, messages, model, motion, overview, prediction, project, protocol, prototype, recognition, regulation, reminder, representation, scheme, solution, special, specification, study, technology, understanding, universal, world
cognitively	11	53	1.68	brain, cognitively, content, design, devices, intelligence, learning, living, memory, model, movement, ontology, organization, perspective, power, process, recognition, reminder, representation, scheme, study, system, understanding, universal, world
process	7	44	1.53	activity, affect, alternative, association, computation, computing, consequence, construction, control, developing, development, evolution, identification, integration, learning, mechanism, memory, process, processes, product, proliferation, recognition, regulation, selection, study, supply, understanding
communication	13	42	1.40	agent, analysis, application, broadcasting, communication, content, gathering, house, identification, intelligence, introduction, motion, network, organization, prediction, production, project, radio, recognition, reminder, representation, solution, special, study, title, understanding
organization	12	40	1.29	activity, association, brain, chain, computer, controller, cooperative, house, independent, inhabitant, integrated, intelligence, machine, management, model, organization, scheme, society, system
intelligent	11	36	4.62	brain, intelligence, intelligent, power, smart, understanding
support	7	34	1.80	accessory, activity, assistance, based, bridge, contribute, control, support,

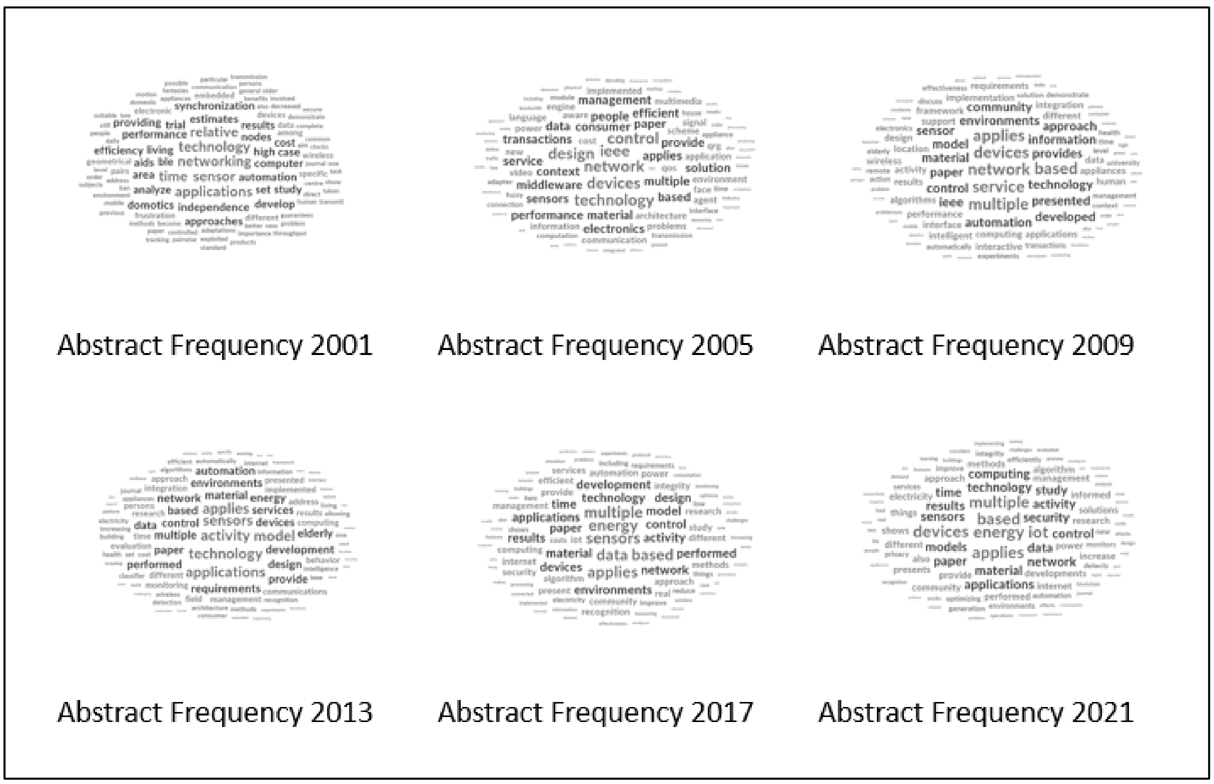
Word	Length	Count	Weighted percentage (%)	Similar words
				supported, supporting, tolerant, validation
power	5	33	0.76	brain, control, design, intelligence, memory, methodology, power, solution, supply, system, understanding
based	5	29	1.82	based, control, homes, infrastructure, support, supported

NVivo uses several factors to show text frequency results. Results included the most frequent word count and excluded stop words such as: a, and, are, as at, be, but, by, for, if, in, into, is, it, no, not, of, on, or, such, that, the, their, then, there, these, they, this, to, was, will, and with. The queries conducted for this study used the option to combine similar words into a group by using the word similarity slider setting adjustment. The query was set to display only words from the specified file, and to return the top 100 most frequent words with common stop words like abstract, copyright, and abridged excluded from the final analysis.

The final query option was set to return words with five letters or more to see if this search would return more meaningful words in the query results. The next portion of the query result lists the length of each of the frequent words during the middle years, and the weighted percentage of the words. The weighted percentage gives the frequency of the word relative to the total words. The final column lists the similar words and shows other words that were included in the similar word search slider adjustment. The results are shown in the word cloud compilation in the table below. Based on the results one of the most common words each year was a derivative of the word “activity”. Intelligent was consistent in all years as well but was removed as a stop word to because it was a common search word for the data selection. Derivatives of the words “building” and “automatic” were also set as stop words. Other words such as “communication”, “content”, “environment”, “support”, and “system” also had a consistently high word frequency in the title files. Below is the table of the top results for abstracts for 2001, 2005, 2009, 2013, 2017 and 2021.

Figure 2

Compilation of Abstract Word Frequency Word Clouds From 2001 to 2021



Analysis showed that word frequency of domotic research titles remained steady over the 5-year span. The themes that emerged reflect the mechanical and automatic nature of the systems, and an emphasis on specific control over the systems and building environments. The titles reflect the importance of communication within domotic environments. The use of the terms smart or intelligent reflects the more ubiquitous and self-reliant nature of the domotic systems.

Certain keywords were analyzed more closely. For instance, the word “based” was often hyphenated and used in combination with other words, and so the actual meaning of the term differed depending on the use. By using the word group option on the NVivo query, it was shown that the term *based* was associated with control, homes, infrastructure, and support.

Table 4 includes the various grouping of the word “based”. The word is consistently grouped with the same words across the years. Titles using the word *based* have information preceding the word as in “sensor-based” or “rule-based”. The word also has information after it which changes the meaning of the word such as “based on” Arduino or “based” home monitoring system. Without the preceding of following information, the word based gives no specific meaning as to trends in domotic systems. However, the grouping of the terms related to “based” remained consistent over time.

Table 4

Word Grouping for ‘“Based” From Title Files 2010–2014

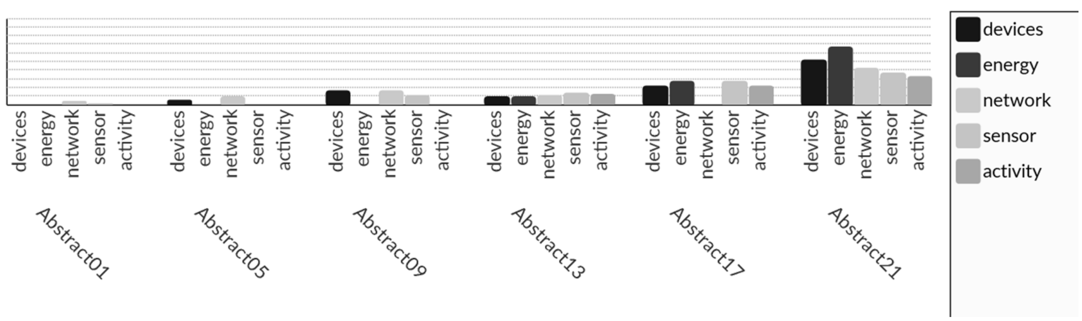
	2010	2011	2012	2013	2014
Based	control, homes, infrastructure, support, supported	control, floor, homes	control, floor, homes, infrastructure, location, support	control, ground, homes, location, means, support	build, control, homes, infrastructure, location, support
Count	29	29	54	41	59
%	1.82	1.80	1.79	1.28	1.54

Abstract Word Frequency Trends

The next analysis was on the word frequency of the abstracts. The abstracts had more words to conduct the analysis so the thought was that the data would yield different results than that of the title data, so the analysis was conducted separately. The frequencies of the abstracts are different from the frequencies in the titles. The abstracts contained significantly more data than the title files and are more descriptive. For the most part, the frequencies of the most popular words increase annually over the last five years. This indicates that research over the timeframe of the study is moving in the same direction but with an increase in frequency of use.

Figure 3

Word Frequency From Abstracts 2015–2021



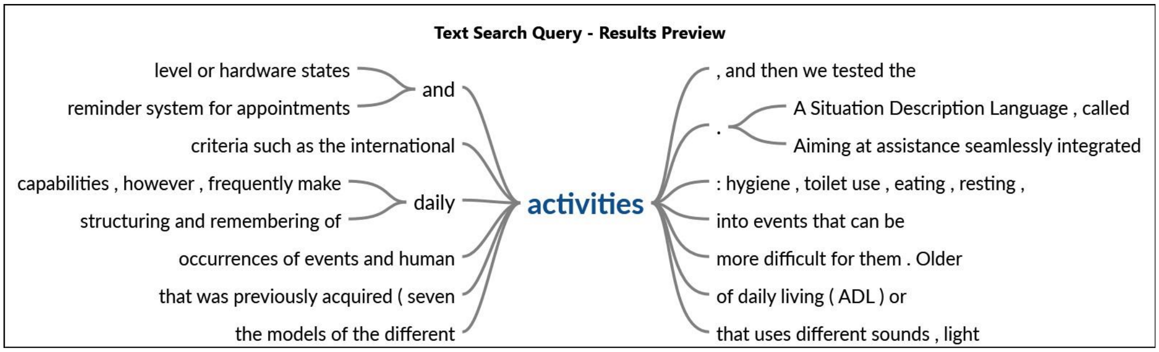
In reviewing the phrases associated with the word, “activity”, there were many changes from 2001 to 2021. Not only was there significant increase in the frequency of the word, but there was a greater variety of terms associated with the word. In 2010, the terms most often associated with the word “activity” centered on the theme of assisted living. The words “human”, “daily”, and “real-world” appeared before the high frequency word. The terms “daily”, “living”, and “assist” often appeared after the term. The word “activity” in 2010 had numerous references to “daily living”, “real world activities”, and “human activities”.

In 2020, terms associated with the word recognition begin to emerge from association with the word “activity”. “Modeling”, “context”, and “sensors” were also common words appearing with the word “activity”. The 2020 abstracts have themes surrounding detection and modeling of domotic systems

In both 2010 and 2020, the terms associated with the highest frequency word “activity” center around activities and how humans’ function in buildings. In 2010 the themes focused more on describing the human activities within domotic systems, while the themes in 2010 were more focused on the detection and modeling of activities of domotic systems. All words associated with the word “activity” were focused on systems that enhance autonomous living within buildings.

Figure 4

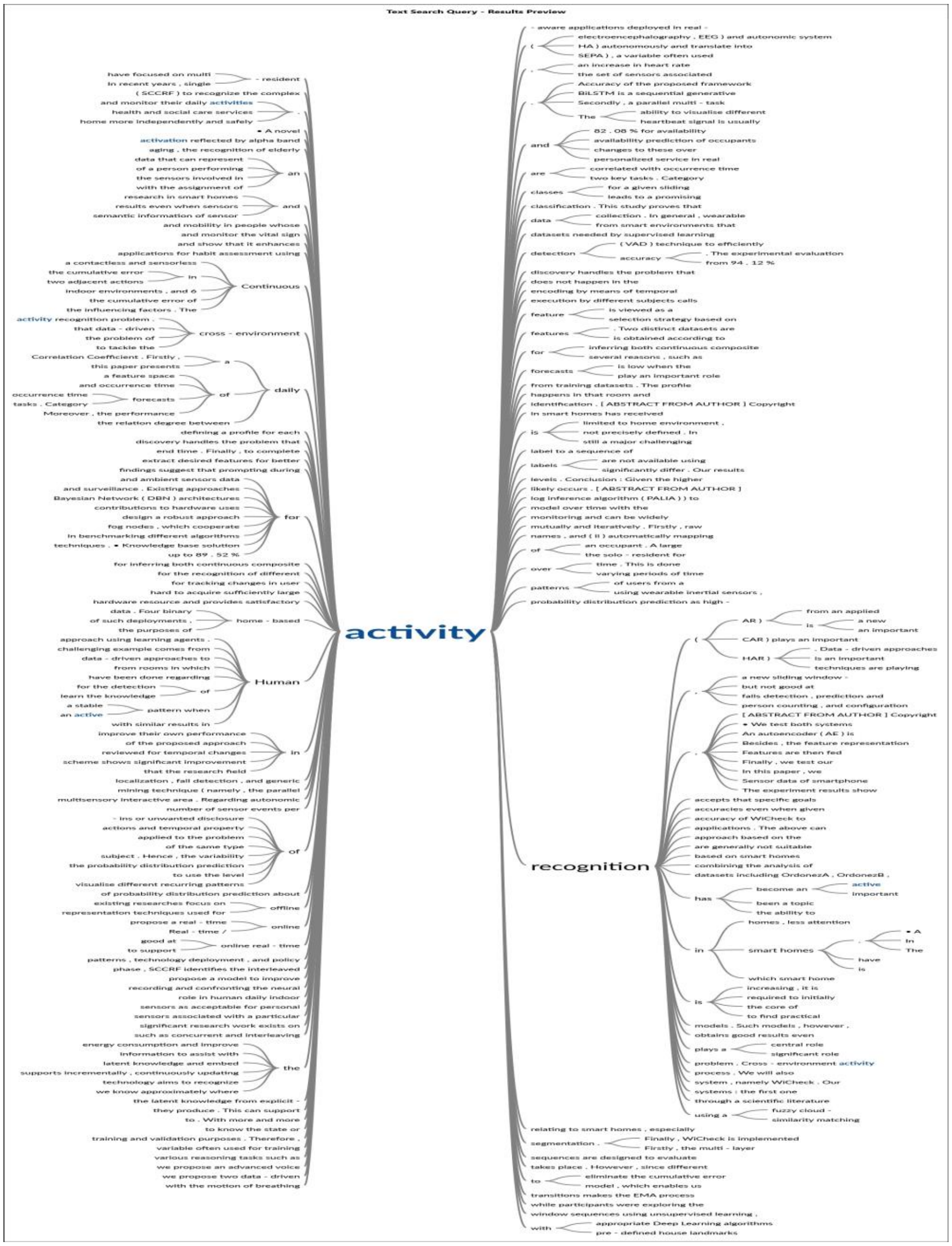
Word Tree Comparison of "Activity" in 2010



Both the number of connections and the breadth of connections to the word base of activity increased significantly from 2010 to 2020. This emphasizes the increase in complexity as well as the increase in the amount of research over the time of the study.

Figure 5

Word Tree Comparison of "Activity" in 2020



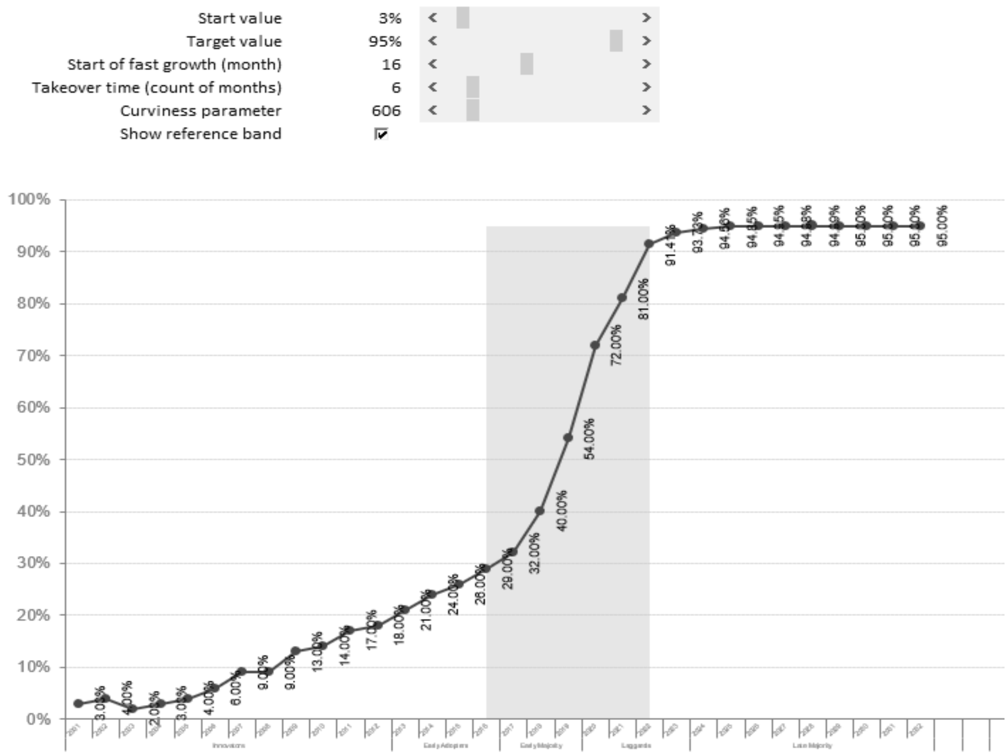
Technology S-Curve

Businesses often strive to forecast impending advances in technology. One useful tool in tracking technology trajectories is the technology s-curve, or the s-curve of innovation. The s-curve is a very useful tool in determining market trends as well as understanding the perceptions of the innovations over time (Weinstein, 2008). The s-curve is used to show relationships between the technological innovation's performance and effort over time and for product life cycle analysis. New technologies tend to have a long lag between inception and adoption and users are often overoptimistic of technology in the short term. In the long-term, technologies often take a significant amount of time to mature (Weinstein, 2008).

There are typically several phases to a technology s-curve. For example there is Boretos' (2012) phases of winter (survival), spring (growth), summer (large gains), fall (decline) and winter (survival). Based on the data collected in this study, research in domotic technology has progressed beyond the early exploration phase and is now exiting the growth phase, as indicated by the sharp upward trajectory, and beginning the flattened maturity phase. Once the technology is at a high level of maturity, the technology will begin to level off and new technologies may begin to compete with the prevailing, mature technology.

Figure 6

Technology S-Curve Forecast Using Article Counts 2001–2021

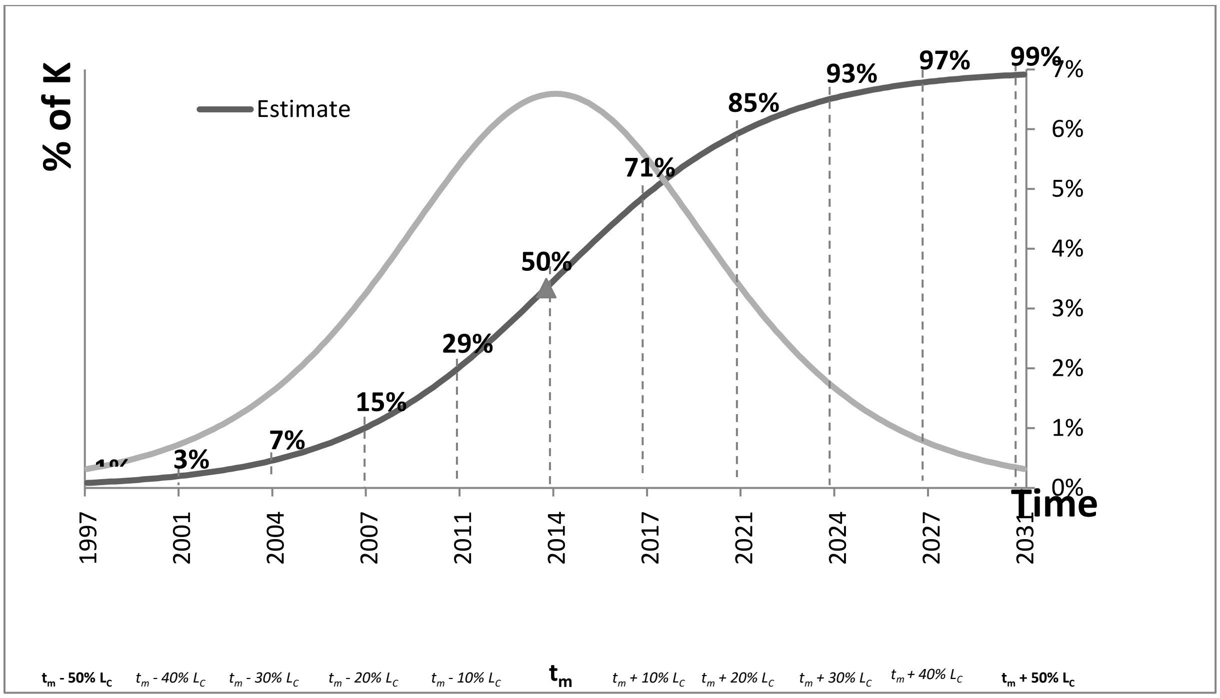


For this study, data from the 2001 through 2021 was placed into a technology s-curve forecasting tool created by Boretos located at www.forcastingnet.com. To gain greater insights into the data, three-year averages were used to plot the curve. A target of 95% saturation was also used for the purpose of this study.

The s-curve uses a sigmoid function or a logistic function having an s-shape. It is defined by the equation: f(t) = $\frac{1}{1+e^{-t}}$. The collected data shows that the research in domotics is currently in a growth phase and should enter a maturity stage around 2024 and finally hit saturation around 2027. The carrying capacity K, is the steepness of the curve, and the life cycle L_C was determined to be 33.3 years. T_M is the midpoint, in this case the year 2014, the last year of our actual data point.

Figure 7

Technology S-Curve Versus Bell Curve 1997–2031



The technology s-curve forecast shows that by 2031 domotic research will have passed the saturation point and should be in the flattened maturity phase. Results of this study show that the collected data on domotic research can be used to forecast the technology s-curve for the future trend of domotic research. The growth of domotic research should continue to increase over the next few years and should finally enter into a stable and mature phase around 2027. Domotic products and components reviewed in the scholarly articles should also reflect the growth of the research. The bell curve shows incremental adoption versus the s-curve that shows cumulative adoption

Summary

The results of this study showed that there was a positive trend in academic output related to domotic technologies from 2010 to 2021. The output was increasing at a steady growth rate that suggests that domotic research is in the rapid adoption or growth phase. The word frequency analysis showed that many of the words in the titles and abstracts were common over the years at differing frequencies. Although the words were common among various years, the terms associated with the words were often slightly different. The terms surrounding the key word activity in the abstracts gave a different focus in 2010 than in 2021. “Activity” in 2010 was more closely related to “human assistance” in “daily activities”. In 2014 “activity” was more likely to be associated with “recognition” and “modeling” terms. This suggests a transition from the concept of daily assistance to more modeling of systems and sensors that recognize specific activity.

Finally, the information collected for this study was mapped into the technology s-curve forecasting tool and it was determined that the current data fits well within a technology s-curve forecast. The forecasting tool showed that domotic research is currently in the growth phase and should begin the maturity phase around 2024 and saturation around 2031. The results of this study show that the s-curve forecasting tool was a beneficial tool in determining the trends and patterns in domotic research. The findings confirm that domotic research is on the rise and this trajectory should continue over the next decade.

Finally, Chapter 5 will review the purpose of the study and summarize key findings. The chapter will discuss how the study will add to the body of knowledge in domotics. The study will conclude with analysis and interpretation of findings as well as recommendations for future research.

Chapter 5: Discussion, Conclusions, and Recommendations

The purpose of this qualitative case study was to determine the trends and patterns in domotic research using bibliometrics and text mining. This study was designed to be a tool for designers to narrow the focus when wading through the vast amounts of information found on domotic technologies. Findings showed that there was a positive trend in the quantity of domotic research. The number of domotic articles published between 2014 and 2021 steadily increased from 85 to 278. The text frequency analysis showed that all years had similar words that occurred most frequently. The terms were grouped by similarity and the groupings showed comparable growth over the past 5 years. The frequencies of the top words in the titles and the abstracts showed similar patterns of growth. The difference came with the terms that appeared before and after the keyword. Those leading and trailing terms constituted the differences. The technology s-curve forecast showed that the current state of domotic technology research is showing an upward trend and the data fit well within the s-curve estimating forecast. The forecast showed that domotic research is in a growth stage and will most likely enter the maturity phase around 2024, followed by full saturation.

Interpretation of Findings

The findings of this study confirmed that the trend of quantity of domotic research is moving in a positive upward trajectory. The number of scholarly domotic articles had increased at a steady pace from 2001 to 2014, with 2021 representing the first significant decrease. If domotic research follows the trend of most technologies, the results should follow the sigmoid shape of the technology s-curve.

One assumption of this study was that the research was changing significantly over time. This was not shown to be true. Due to the broad variety of focus areas in domotic technologies, no one product or component emerged as a frequent pattern. Although domotic research is increasing and the quality of domotic research is increasing, there was no indication that there were any major new movements in the research. The trends in the text analysis of the titles as well as the abstracts were similar in nature and did not vary much over the years. This indicated that the growth in domotic research has been stable around similar topics, but the amount of research in those topics has been growing at a steady pace.

Although there is still the broad issue of incompatibility within specific domotic technologies, the research in domotics seems to be focusing on similar aspects of the technology. There were many of the same types of issues and products that had been researched over the last 5 years. This indicated that there was some convergence in the research among the rapid growth. Products may not be heading toward compatibility; however, based on the mining of the research titles and abstracts, the research topics in the field of domotics may be heading toward a consensus.

This research added to the body of knowledge through exploration of the descriptive language surrounding domotic research and the trends in the scholarly research. This study provided an opportunity to fill gaps in domotic research by showing where the research was focused. The s-curve forecast used in the study showed that although domotic research is increasing, it has not yet reached its peak. This study showed that there may be more research articles coming over the next decade before a decline begins.

The technology s-curve is a tool that can be used to estimate the rate of adoption of a technological innovation. The s-curve was used for this study to assist designers to make informed decisions about selecting domotic technologies. This can be done by using the patterns found from the current domotic research forecast. The s-curve forecasting tool was selected for this study to help designers to make informed decisions about domotic technologies by using the patterns in current domotic research to forecast the future of the technology. Because domotic technologies comprise a vast number of products and concepts, it was important to first gather and then extract all of the articles that addressed domotic technologies. These articles were scrutinized to select the articles that fit the requirements of the study. The final articles were documented, compiled, and grouped to determine the recent trends for domotic research. These trends were then graphed by using an s-curve forecasting tool. The results can be used by designers and homeowners to determine whether domotic technology is a viable option for their projects. If the technology were in a state of decline, the best option might be to opt out of using the domotics in lieu of a more viable technology. The s-curve forecast showed that the technology appears to be in a state of growth.

The domotic technology research began with slow growth and low performance or effort. The s-curve then showed that there were improvements in the technology output during the period of significant growth and that the technology would have a period of flattening and maturity. The vertical axis of the s-curve is used to show performance or effort. I used performance as the output of the scholarly research. The output performance had increased steadily over the past 5 years. These data reflected the standard s-curve based on prior historical performance that started small and was limited in the early years (2001–2015). The research output then began to increase steadily from 2001 to the sharp rise beginning in 2016. Time is generally the common measure for the x axis. The s-curve can be used to determine when the technology has passed the point of increase and has moved into the maturity phase. This could allow designers to begin to identify opportunities for domotic research or when to look for new technologies to focus on before the field begins to flatten.

Limitations of the Study

This study was limited to the availability of the articles that contained domotic research in the selected libraries. Multiple libraries with multiple databases were selected to increase the number of articles for the study, but any article not listed in these databases was not included in the study. The study was also limited by my interpretation of the suitability of the articles. Although keyword searches produced satisfactory output of articles that met the requirements of the search, some of the results of the search were not closely tied to the requirements of the study. The acceptable results had to be extracted from the data set to meet the needs of the study, and therefore some judgments of acceptability had to be made.

This study was also limited by the decision to use scholarly research. This decision was made to improve the trustworthiness of the data collected because scholarly research has to conform to ethical and scientific guidelines. Domotic products are being mass marketed, and there is a plethora of commercial products that could have been selected to study. Commercial product research may have yielded different results from the scholarly results compiled for this study.

Another major limitation of the study was the reliance on databases. By using multiple databases to achieve saturation, the variability in format also increased. It was difficult to extract the data from some electronic data sources. With a text-mining study, consistency in data format is essential. Homogenous data are essential for data queries. Because the data were collected from multiple sources, it became necessary to expend much time and energy to make the data viable for queries. If the collected data had misspellings, multiple spellings, unusual digital formatting, or typos, the results of the query would have been inaccurate. When downloaded files had dissimilar formats, they had to be reformatted to accurately query the data. Using a single data source could have decreased some of the data collection limitations in this study.

Recommendations

Due to the limited amount of scholarly research on domotics, I focused on all domotic technologies. This provided an overall view of the field of domotics. Future research could address specific areas of the technology in wider categories. Many articles focused on older care and monitoring, energy and consumption, building comfort, or security and monitoring. Each of these categories could be examined for trends in a similar fashion as was used in this study. Based on the current study findings, there could be significant growth in domotic research in the future, which could yield a more comprehensive body of data to study. Future studies could be conducted on domotic products that are available in the marketplace to determine whether the academic research on domotics mirrors what is occurring in the marketplace.

Electronic library data sources presented a difficulty for this study. Future research in the area could focus on finding better means of electronic data collection from library databases to increase the accuracy and the amount of data that could be captured for this type of study. It could be important to have uniform and accurate data at the beginning of the study to decrease the amount of time spent cleaning the data results.

Implications

Domotics play an important role in improving the quality of life for individuals who need monitoring, who have limited mobility, and who need assistance with daily activities. Domotics also play a large role in improving energy management for buildings, decreasing negative impacts on the environment, and improving building comfort. I analyzed the progress of research in domotic technologies to make it easier for designers to decide whether domotic technologies could be a viable design consideration for their projects. The results of this study showed that domotic technology research is increasing, improving in quality, and moving in an upward growth trajectory. This indicates that it is a good time for designers to plan for the use of the technologies in their current and future designs. The research trajectory has not leveled out and is not in a mature phase, so the field presents many opportunities for use. Because this study relied on scholarly research, the resulting articles had an implied trustworthiness, and designers can be confident that the information is dependable and credible.

Compatibility of domotic technologies still remains an issue (van de Kaa et al., 2021). The journal articles indicate that there is still no single domotic system standard. Research from Phan and Kim (2020) states that the domotics field is troubled with fragmentation issues due to the array of technical protocols available. Zigbee is one common domotic technology, but it has been shown to be vulnerable to low-rate denial of service attacks (Okada et al., 2021). The Zigbee Alliance is starting to gain support, but still has a long way to go before it becomes a standard protocol (Drubin, 2021).

New products are constantly being introduced into the market, and the low cost of market giants such as Amazon's Alexa Microsoft's Cortana and Apple's Siri are increasing access to domotics for casual users (Jimenez et al., 2021). This means that domotic systems do not need an expert designer and there is no longer a need to build an entire system using the same protocols. Consumers can purchase a single domotic element or combine several without incurring major costs. This ease of access, combined with significant product offerings, is adding to the compatibility problem (Sanguinetti et al., 2018). Based on recent journal publications, here does not seem to be a compatibility solution in the near future.

Domotic technologies allow for buildings to use AmI and become what are called smart buildings. Smart buildings save money by using data collected from sensors and by analyzing the data collected to make optimal decisions. The decisions may be related to energy or comfort, or they can provide lifesaving assistance. Energy management systems not only save money, but they also provide a positive impact on the environment by decreasing emissions and reducing the number of resources expended for the building.

Domotics for health monitoring and prediction present improved quality of life for the users. Research in domotic technologies provides for the transfer of knowledge that can inform designers about the state of the technology.

Domotic technologies often improve integration of building systems and increase the ability to get things done in a timely manner. By exploring research on domotic technologies, I relied on optimal examples of the state of art within the field. Designers may feel confident that the trends in domotic research will yield an authentic examination of what is happening in the field. This study may be used as a guide for designers to pursue designs using domotic technologies.

Conclusions

Domotic technologies are an important (T. Wang & Cook, 2020) and growing (Stolojescu-Crisan et al., 2021) field of research that can have significant positive influence on society (Martinez-Martin et al., 2021). This study addressed the rapid growth of the field (Jimenez et al., 2021) and endeavored to explain some of the implications of the growth (van de Kaa et al., 2021) through the qualitative analysis of the current research in the domotic field by using a bibliometric text mining of scholarly articles. Domotic technologies will have a substantial positive impact on future building design (Salerno et al., 2021). The growth of the field demonstrates strong interest in the possibilities of the technologies on future buildings (Sanguinetti et al., 2018). The well-being of numerous populations can be improved with the use of domotic technologies (Nthubu, 2021). Major societal issues like older care (Ghasemi et al., 2019), health assessments (Kim & Park, 2021), predictive care and monitoring (Peng & Wang, 2020), safety and security (Sharif & Tenbergen, 2020), energy management (Salerno et al., 2021), building comfort and efficiency (Saba et al., 2017), and mobility assistance (Saidi Sief et al., 2016) can be addressed through domotic technologies.

Research in this field provides the opportunity to consider multiple areas of focus and allows designers access to credible and well-documented investigations into these state-of-the-art and growing domotic technologies. It is important to evaluate the credible sources of information available before making decisions based on the profusion of the novel products that are currently being marketed in domotic technologies. Designers should analyze the current state of domotics and examine the trends in the technologies to ensure that their product selection has longevity and consistency. Scholarly research can provide information on the state of the field, and this study addressed domotic research to provide an authentic background into the trends and patterns in domotics. The results of this study may provide an opportunity for designers to have a tool to help make decisions related to domotic technologies.

I have shown that research in domotic technology is in a state of growth (Stolojescu-Crisan et al., 2021). Findings also showed that the quality of domotics is improving as the field is becoming more diverse. As the research in domotics grows, the options for designers also grow (Phan & Kim, 2020). Designers have many technological options and it is important to be conscientious about the information used to make decisions (Bouchabou et al., 2021). Scholarly publications are ideal references for analysis into the trends and patterns of the domotic field. Domotics will be an important aspect of most buildings inhabited in the future (Hong et al., 2020), and the research from this study provides a tool that may be used to facilitate a thoughtful and intentional design using domotic technologies.

References

ADT. (n.d.). Retrieved December 14, 2021, from https://www.adt.com/products

Albrechtslund, A., & Ryberg, T. (2011). Participatory surveillance in the intelligent building. *Design Issues*, *27*(3), 35–46. https://doi.org/10.1162/desi_a_00089

Aloise, F., Schettini, F., Aricò, P., Salinari, S., Guger, C., Rinsma, J., Aiello, M., Mattia, D., & Cincotti, F. (2011). Asynchronous P300-Based brain-computer interface to control a virtual environment: Initial tests on end users. *Clinical EEG and Neuroscience*, *42*(4), 219–224. https://journals.sagepub.com/doi/10.1177/155005941104200406

Alsabbagh, E., Yu, H., & Gallagher, K. (2013). 802.11ac design considerations for mobile devices. *Microwave Journal*, *56*(2), 80–88. https://www.microwavejournal.com/articles/19094-11ac-design-considerations-for-mobile-devices

Anders, A. (2010). Bridging the wired and wireless gap. *HPAC Engineering*, *82*(11), 48–51. http://hpac.com/building-controls/bridging-wired-and-wireless-gap

Antic, M., & Papp, I. (2021). Smart home integration with external IoT device platforms and services. *IEEE Consumer Electronics Magazine*, *10*(6), 69–75. https://ieeexplore.ieee.org/document/9277669

Aragues, A., Martinez, I., Valle, P., Munoz, P., Escayola, J., & Trigo, J. (2012). Trends in entertainment, home automation and e-health: Toward cross-domain integration. *IEEE Communications Magazine*, *50*(6), 160–167. https://doi.org/10.1109/mcom.2012.6211501

Augusto, J. C., & Hornos, M. J. (2013). Software simulation and verification to increase the reliability of intelligent environments. *Advances in Engineering Software*, *58*, 18–34. https://doi.org/10.1016/j.advengsoft.2012.12.004

Baquero, R., Rodríguez, J., Mendoza, S., Decouchant, D., & Papis, A. P. M. (2012). FunBlocks: A modular framework for AmI system development. *Sensors*, *12*(8), 10259–10291. https://doi.org/10.3390/s120810259

Baresi, L., & Guinea, S. (2012). Architectural styles for adaptive systems: A tutorial. *2012 IEEE Sixth International Conference on Self-Adaptive and Self-Organizing Systems*, *2012*, 237-238. https://doi.org/10.1109/saso.2012.38

Baxter, P., & Jack, S. (2015). Qualitative case study methodology: Study design and implementation for novice researchers. *Qualitative Report*, *13*(4), 544-559. https://doi.org/10.46743/2160-3715/2008.1573

Bellavista, P., Gallo, P., Giannelli, C., Toniolo, G., & Zoccola, A. (2012). Discovering and accessing peer-to-peer services in UPnP-based federated domotic islands. *IEEE Transactions on Consumer Electronics*, *58*(3), 810–818. https://doi.org/10.1109/tce.2012.6311322

Bernatin, T., Nisha, S. A., Revathy, & Chitra, P. (2021). Implementation of communication aid using Zigbee technology. *2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS)*, *2021*, 29-32, https://doi.org/10.1109/iciccs51141.2021.9432357

Bogue, R. (2012). Solar-powered sensors: A review of products and applications. *Sensor Review*, *32*(2), 95–100. https://doi.org/10.1108/02602281211209374

Bonino, D., Castellina, E., Corno, F., & de Russis, L. (2011). DOGeye: Controlling your home with eye interaction. *Interacting with Computers*, *23*(5), 484–498. https://doi.org/10.1016/j.intcom.2011.06.002

Bonino, D., Castellina, E., Corno, F., & Liu, M. (2009). Technology independent interoperation of domotic devices through rules. *2009 IEEE 13th International Symposium on Consumer Electronics*, *2009*, 29-32. https://doi.org/10.1109/isce.2009.5157026

Bonino, D., & Corno, F. (2010). Rule-based intelligence for domotic environments. *Automation in Construction*, *19*(2), 183–196. https://doi.org/10.1016/j.autcon.2009.10.008

Boretos, G. P. (2012). *S-curves and their applications in marketing, business, and the economy*. Marketing Research Association Alert. https://www.forecastingnet.com/Alert_0212_34-39.pdf

Bouchabou, D., Nguyen, S. M., Lohr, C., LeDuc, B., & Kanellos, I. (2021). A survey of human activity recognition in smart homes based on IoT sensors algorithms: Taxonomies, challenges, and opportunities with deep learning. *Sensors*, *21*(18), 6037. https://doi.org/10.3390/s21186037

Calvopinna, A., Tapia, F., & Tello-Oquendo, L. (2019). Weather monitoring architecture for smart home using Alexa, Raspberry Pi, and DarkSky API. *2019 8th International Conference on Software Process Improvement (CIMPS), 2019,* 1-5. https://doi.org/10.1109/cimps49236.2019.9082423

Carreira, P., Resendes, S., & Santos, A. C. (2014). Towards automatic conflict detection in home and building automation systems. *Pervasive and Mobile Computing*, *12*, 37–57. https://doi.org/10.1016/j.pmcj.2013.06.001

Christensen, C. M., McDonald, R., Altman, E. J., & Palmer, J. E. (2018). Disruptive innovation: An intellectual history and directions for future research. *Journal of Management Studies*, *55*(7), 1043–1078. https://doi.org/10.1111/joms.12349

Chun-Hao, C., & Jian-Min, Y. (2012). A bibliometric study of financial risk literature: A historic approach. *Applied Economics*, *44*(22), 2827–2839. https://doi.org/10.1080/00036846.2011.566208

Cofre, J. P., Moraga, G., Rusu, C., Mercado, I., Inostroza, R., & Jimenez, C. (2012). Developing a touchscreen-based domotic tool for users with motor disabilities. *2012 Ninth International Conference on Information Technology - New Generations*, *2012*, 696-701. https://doi.org/10.1109/itng.2012.139

Creswell, J. W. (2007). *Qualitative inquiry & research design: Choosing among five approaches.* Sage.

Creswell, J. W., & Clark, V. L. P. (2017). *Designing and conducting mixed methods research*. Sage.

Creswell, J. W., Hanson, W. E., Clark Plano, V. L., & Morales, A. (2007). Qualitative research designs. *The Counseling Psychologist*, *35*(2), 236–264. https://doi.org/10.1177/0011000006287390

Creswell, J. W., & Miller, D. L. (2010). Determining validity in qualitative inquiry. *Theory Into Practice*, *39*(3), 37-41. https://doi.org/10.1207/s15430421tip3903_2

Curumsing, M. K., Fernando, N., Abdelrazek, M., Vasa, R., Mouzakis, K., & Grundy, J.

(2019). Emotion-oriented requirements engineering: A case study in developing a smart home system for the elderly. *Journal of Systems and Software*, *147*, 215–229. https://doi.org/10.1016/j.jss.2018.06.077

Dai, J., & Sugano, M. (2019). Low-cost sensor network for collecting real-time data for agriculture by combining energy harvesting and LPWA technology. *2019 IEEE Global Humanitarian Technology Conference (GHTC)*. *2019*, 1-4. https://doi.org/10.1109/ghtc46095.2019.9033114

Ding, J., & Wang, Y. (2020). A WiFi-based smart home fall detection system using recurrent neural network. *IEEE Transactions on Consumer Electronics*, *66*(4), 308–317. https://doi.org/10.1109/tce.2020.3021398

Dinulovic, D., Shousha, M., Al-Batol, M., Zafar, T., Bickel, J., Ngo, H. D., & Haug, M. (2021). Dual-rotor electromagnetic-based energy harvesting system for smart home applications. *IEEE Transactions on Magnetics*, *57*(2), 1–5. https://doi.org/10.1109/tmag.2020.3014065

Dixon, C., Mahajan, R., Agarwal, S., Brush, A. J., Lee, B., Saroiu, S., & Bahl, P. (2012). An operating system for the home. *9th USENIX symposium on networked systems design and implementation*, *2012*,. 337-352. https://www.usenix.org/system/files/conference/nsdi12/nsdi12-final149.pdf

Doan, D. T., Ghaffarianhoseini, A., Naismith, N., Zhang, T., Rehman, A. U., Tookey, J., & Ghaffarianhoseini, A. (2019). What is BIM? A need for a unique BIM definition. *MATEC Web of Conferences*, *266*(2019), 05005. https://doi.org/10.1051/matecconf/201926605005

Dragomir, D., Gheorghe, L., Costea, S., & Radovici, A. (2016). *A Survey on secure communication protocols for IoT systems*. IEEE. *2016*, 47-62. https://doi.org/10.1109/siot.2016.012

Drubin, C. (2021). loT leaders join the Zigbee alliance's IP working group. *Microwave Journal*, *64*(1), 45–46. https://www.automation.com/en-us/articles/november-2020/iot-leaders-join-zigbee-alliance-ip-group

Elrawy, M. F., Awad, A. I., & Hamed, H. F. A. (2018). Intrusion detection systems for IoT-based smart environments: A survey. *Journal of Cloud Computing*, *7*(1), 21. https://doi.org/10.1186/s13677-018-0123-6

Etzioni, A., & Etzioni, O. (2017). Incorporating ethics into artificial intelligence. *Journal of Ethics*, *21*(4), 403–418. https://doi.org/10.1007/s10892-017-9252-2

Farquhar, J. D. (2012). *Case study research for business*. Sage.

Figueiredo, J., & Sá Da Costa, J. (2012). A SCADA system for energy management in intelligent buildings. *Energy and Buildings*, *49*, 85–98. https://doi.org/10.1016/j.enbuild.2012.01.041

Fuchs, K. L., Haldimann, M., Vuckovac, D., & Ilic, A. (2018). Automation of Data collection techniques for recording food intake: A review of publicly available and well-adopted diet apps. *2018 International Conference on Information and Communication Technology Convergence (ICTC)*, *2018*, 58-65. https://doi.org/10.1109/ictc.2018.8539468

Gaitan, N. C., & Ungurean, I. (2021). BACnet application layer over Bluetooth-Implementation and validation. *Sensors*, *21*(2), 538.

https://doi.org/10.3390/s21020538

Gamez, N., & Fuentes, L. (2013). Architectural evolution of FamiWare using cardinality-based feature models. *Information and Software Technology*, *55*(3), 563–580. https://doi.org/10.1016/j.infsof.2012.06.012

Garroppo, R. G., Gazzarrini, L., Giordano, S., & Tavanti, L. (2012). Experimental evaluation of a SIP-based home gateway with multiple wireless interfaces for domotics systems. *Journal of Computer Networks and Communications*, *1*(15), 190639. https://doi.org/10.1155/2012/190639

Gavrila, C., Popescu, V., Fadda, M., Anedda, M., & Murroni, M. (2021). On the suitability of HbbTV for unified smart home experience. *IEEE Transactions on Broadcasting*, *67*(1), 253–262. https://doi.org/10.1109/tbc.2020.2977539

Gershenfeld, N., Samouhos, S., & Nordman, B. (2010). Intelligent infrastructure for energy efficiency. *Science*, *327*(5969), 1086–1088. https://doi.org/10.1126/science.1174082

Ghasemi, F., Rezaee, A., & Rahmani, A. M. (2019). Structural and behavioral reference model for IoT-based elderly health-care systems in smart home. *International Journal of Communication Systems*, *32*(12), e4002. https://doi.org/10.1002/dac.4002

Gluszak, M., Gawlik, R., & Zieba, M. (2019). Smart and green buildings features in the decision-making hierarchy of office space entrants: An analytic hierarchy process study. *Administrative Sciences*, *9*(3), 52. https://doi.org/10.3390/admsci9030052

Gomez-Otero, C., Martinez, R., & Caffarel, J. (2012). ClimApp: A novel approach of an intelligent HVAC control system. *7th Iberian Conference on Information Systems and Technologies (CISTI), 2012*, 1-6. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6263228

González Alonso, I., Álvarez Fres, O., Alonso Fernández, A., del Torno, P. G., Maestre, J., & Almudena García Fuente, M. (2012). Towards a new open communication standard between homes and service robots, the DHCompliant case. *Robotics and Autonomous Systems*, *60*(6), 889–900. https://doi.org/10.1016/j.robot.2012.01.006

Gokaraju, B., Yessick, D., Steel, J., Doss, D. A., & Turlapaty, A. C. (2016). Integration of intrusion detection and web service alarm for home automation system using 'ARM' microprocessor. *SoutheastCon 2016*, 1-2, https://doi.org/10.1109/secon.2016.7506717

Guilera, G., Barrios, M., & Gomez-Benito, J. (2012). Meta-analysis in psychology: A bibliometric study. *Scientometrics*, *94*(3), 943-954. https://doi.org/10.1007/s11192-012-0761-2

Haase, J. (2013). Wireless network standards for building automation. *Embedded Systems for Smart Appliances and Energy Management*, *3*, 53-65. https://doi.org/10.1007/978-1-4419-8795-2

Han, J., & Park, T. (2017). Security-enhanced push button configuration for home smart control. *Sensors*, *17*(6), 1334. https://doi.org/10.3390/s17061334

Holmberg, D. (2011). Demand response and standards: New role for buildings in the smart grid. *BACnet Today and the Smart Grid*, *53*(11), B23-B28. http://www.nist.gov/customcf/get_pdf.cfm?pub_id=909018

Hong, A., Nam, C., & Kim, S. (2020). What will be the possible barriers to consumers' adoption of smart home services?. *Telecommunications Policy*, *44*(2), 101867. https://doi.org/10.1016/j.telpol.2019.101867

Hu, L., Dung, O. M., Liu, Q., Han, T., & Sun, Y. (2013). Integration of wireless body area networks (WBANs) and WAN, WiMAX and LTE. *KSII Transactions on Internet and Information Systems*, *7*(5), 980–997. https://doi.org/10.3837/tiis.2013.05.003

Jalal, A., Uddin, M., & Kim, T. S. (2012). Depth video-based human activity recognition system using translation and scaling invariant features for life logging at smart home. *IEEE Transactions on Consumer Electronics*, *58*(3), 863–871. https://doi.org/10.1109/tce.2012.6311329

Jarić, I., Cvijanović, G., Knežević-Jarić, J., & Lenhardt, M. (2012). Trends in fisheries science from 2000 to 2009: A bibliometric study. *Reviews in Fisheries Science*, *20*(2), 70–79. https://doi.org/10.1080/10641262.2012.659775

Jebroni, Z., Afonso, J., & Tidhaf, B. (2020). Smart home energy management system based on a hybrid wireless network architecture. *EAI Endorsed Transactions on Energy Web*, *7*(25), 161437. https://doi.org/10.4108/eai.13-7-2018.161437

Jeong, K. A., & Proctor, R. W. (2011). Inhabitant-centered interaction technology for future homes. *Ergonomics in Design: The Quarterly of Human Factors Applications*, *19*(3), 9–14. https://doi.org/10.1177/1064804611416593

Jimenez, C., Saavedra, E., del Campo, G., & Santamaria, A. (2021). Alexa-based voice assistant for smart home applications. *IEEE Potentials*, *40*(4), 31–38.

https://doi.org/10.1109/mpot.2020.3002526

Jung, Y., & Joo, M. (2011). Building information modelling (BIM) framework for practical implementation. *Automation in Construction*, *20*(2), 126–133. https://doi.org/10.1016/j.autcon.2010.09.010

Kambourakis, G., Kolias, C., Geneiatakis, D., Karopoulos, G., Makrakis, G. M., & Kounelis, I. (2020). A State-of-the-art review on the security of mainstream IoT wireless PAN protocol stacks. *Symmetry*, *12*(4), 579. https://doi.org/10.3390/sym12040579

Kerner, A., Simunic, D., & Prasad, R. (2013). Ambient intelligence as one of the key ICT factors for energy efficiency in buildings. *Journal of Green Engineering*, *3*, 219–243. http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.459.4382

Kim, A. R., & Park, H. Y. (2021). Theme trends and knowledge-relationship in lifestyle research: A bibliometric analysis. *International Journal of Environmental Research and Public Health*, *18*(14), 7503. https://doi.org/10.3390/ijerph18147503

Kofler, M. J., Reinisch, C., & Kastner, W. (2012). A semantic representation of energy-related information in future smart homes. *Energy and Buildings*, *47*, 169–179. https://doi.org/10.1016/j.enbuild.2011.11.044

Kog, Y. C., & Loh, P. K. (2012). Critical success factors for different components of construction projects. *Journal of Construction Engineering and Management*, *138*(4), 520–528. https://doi.org/10.1061/(asce)co.1943-7862.0000464

Larimian, T., Zarabadi, Z. S. S., & Sadeghi, A. (2013). Developing a fuzzy AHP model to evaluate environmental sustainability from the perspective of secured by design scheme—A case study. *Sustainable Cities and Society*, *7*, 25–36. https://doi.org/10.1016/j.scs.2012.10.001

Lawrence, T. M., Watson, R. T., Boudreau, M., Johnsen, K., Perry, J., & Ding, L. (2012). A new paradigm for the design and management of building systems. *Energy and Buildings*, *51*, 56–63. https://doi.org/10.1016/j.enbuild.2012.04.016

Lee, S. S., Shi, H., Tan, K., Liu, Y., Lee, S., & Cui, Y. (2019). S2Net: Preserving privacy in smart home routers. *IEEE Transactions on Dependable and Secure Computing*, *18*(3), 1409-1424. https://doi.org/10.1109/tdsc.2019.2924624

Lilis, G., & Kayal, M. (2018). A secure and distributed message-oriented middleware for smart building applications. *Automation in Construction*, *86*, 163–175. https://doi.org/10.1016/j.autcon.2017.10.030

Machado, M. L., Guincestre, J. Y., Aimé, M., Drouet, M. H., Giry, C., LeDoze, F., Lamy Au Rousseau, G., Denise, P., & Besnard, S. (2013). Head pilot: A new webcam-based head tracking system tested in permanently disabled patients. *IRBM*, *34*(2), 124–130. https://doi.org/10.1016/j.irbm.2013.02.001

Majumdar, C., Lopez-Benitez, M., & Merchant, S. N. (2020). Real smart home data-assisted statistical traffic modeling for the Internet of things. *IEEE Internet of Things Journal*, *7*(6), 4761–4776. https://doi.org/10.1109/jiot.2020.2969318

Makonin, S., Bartram, L., & Popowich, F. (2013). A smarter smart home: Case studies of ambient intelligence. *IEEE Pervasive Computing*, *12*(1), 58–66. https://doi.org/10.1109/mprv.2012.58

Martinez-Martin, N., Luo, Z., Kaushal, A., Adeli, E., Haque, A., Kelly, S. S., Wieten, S., Cho, M. K., Magnus, D., Fei-Fei, L., Schulman, K., & Milstein, A. (2021). Ethical issues in using ambient intelligence in health-care settings. *Lancet Digital Health*, *3*(2), e115–e123. https://doi.org/10.1016/s2589-7500(20)30275-2

Meulendijk, M., van de Wijngaert, L., Brinkkemper, S., & Leenstra, H. (2011). AmI in good care? Developing design principles for ambient intelligent domotics for elderly. *Informatics for Health and Social Care*, *36*(2), 75–88. https://doi.org/10.3109/17538157.2010.542528

Miori, V., Russo, D., & Concordia, C. (2012). Meeting people's needs in a fully interoperable domotic environment. *Sensors*, *12*(6), 6802–6824. https://doi.org/10.3390/s120606802

Mir, U., Abbasi, U., Mir, T., Kanwal, S., & Alamri, S. (2021). Energy management in smart buildings and homes: Current approaches, a hypothetical solution, and open issues and challenges. *IEEE Access*, *9*, 94132–94148. https://doi.org/10.1109/access.2021.3092304

Morales, R., Badesa, F. J., García-Aracil, N., Perez-Vidal, C., & Sabater, J. M. (2012). Distributed smart device for monitoring, control and management of electric loads in domotic environments. *Sensors*, *12*(5), 5212–5224. https://doi.org/10.3390/s120505212

Moreaux, P., Sartor, F., & Vernier, F. (2012). An effective approach for home services management. *2012 20th Euromicro International Conference on Parallel, Distributed and Network-Based Processing, 2012*, 47-51.

https://doi.org/10.1109/pdp.2012.45

Mori R., A., Mazzeo, M., Mercurio, G., & Verbicaro, R. (2013). Holistic health: Predicting our data future (from inter-operability among systems to co-operability among people). *International Journal of Medical Informatics*, *82*(4), e14–e28. https://doi.org/10.1016/j.ijmedinf.2012.09.003

Mustafa, B., Iqbal, M. W., Saeed, M., Shafqat, A. R., Sajjad, H., & Naqvi, M. R. (2021). IOT based low-cost smart home automation system. *2021 3rd International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*. *2021*, 1-6. https://doi.org/10.1109/hora52670.2021.9461276

Nedelcu, A. V., Sandu, F., Machedon-Pisu, M., Alexandru, M., & Ogrutan, P. (2009). Wireless-based remote monitoring and control of intelligent buildings. *2009 IEEE International Workshop on Robotic and Sensors Environments*, *2021*, 1-6. https://doi.org/10.1109/rose.2009.5355999

Nguyen, T. A., & Aiello, M. (2013). Energy intelligent buildings based on user activity: A survey. *Energy and Buildings*, *56*, 244–257. https://doi.org/10.1016/j.enbuild.2012.09.005

Nguyen-Truong, C. K. Y., & Fritz, R. L. (2018). Health-assistive smart homes for aging in place: Leading the way for integration of the Asian immigrant minority voice. *Asian/Pacific Island Nursing Journal*, *3*(4), 154–159. https://doi.org/10.31372/20180304.1087

Nthubu, B. (2021). An overview of sensors, design and healthcare challenges in smart homes: Future design questions. *In Healthcare*, *9*(10), 1329. https://doi.org/10.3390/healthcare9101329

Okada, S., Miyamoto, D., Sekiya, Y., & Nakamura, H. (2021). New LDoS attack in Zigbee network and its possible countermeasures. *2021 IEEE International Conference on Smart Computing (SMARTCOMP)*, *2021*, 246-251. https://doi.org/10.1109/smartcomp52413.2021.00055

Pan, X., Zhong, B., Wang, X., & Xiang, R. (2021). Text mining-based patent analysis of BIM application in construction. *Journal of Civil Engineering and Management*, *27*(5), 303–315. https://doi.org/10.3846/jcem.2021.14907

Paoli, R., Fernández-Luque, F. J., Doménech, G., Martínez, F., Zapata, J., & Ruiz, R. (2012). A system for ubiquitous fall monitoring at home via a wireless sensor network and a wearable mote. *Expert Systems with Applications*, *39*(5), 5566–5575. https://doi.org/10.1016/j.eswa.2011.11.061

Peng, P., & Wang, A. (2020). SmartMon: Misbehavior detection via monitoring smart home automations. *2020 IEEE/ACM Symposium on Edge Computing (SEC)*, *2020*, 327-333. https://doi.org/10.1109/sec50012.2020.00047

Perroud, D., Angelini, L., Mugellini, E., & Khaled, O. A. (2011). Context-aware multimodal feedback in a smart environment. *AMBIENT 2011: The First International Conference on Ambient Computing, Applications, Services and Technologies*, *2011*, 1-6. http://www.thinkmind.org/index.php?view=article&articleid=ambient_2011_1_10_60033

Pham, C., Lim, Y., & Tan, Y. (2018). A Platform for integrating Alexa voice service into ECHONET-based smart homes. *2018 IEEE International Conference on Consumer Electronics-Taiwan (ICCE-TW), 2018, 1-5*. https://doi.org/10.1109/icce-china.2018.8448893

Phan, L. A., & Kim, T. (2020). Breaking down the compatibility problem in smart homes: A dynamically updatable gateway platform. *Sensors*, *20*(10), 2783. https://doi.org/10.3390/s20102783

Portet, F., Vacher, M., Golanski, C., Roux, C., & Meillon, B. (2011). Design and evaluation of a smart home voice interface for the elderly: Acceptability and objection aspects. *Personal and Ubiquitous Computing*, *17*(1), 127–144. https://doi.org/10.1007/s00779-011-0470-5

Poudel, S. (2016). Internet of things: Underlying technologies, interoperability, and threats to privacy and security. *Berkeley Technology Law Journal, 31*(2), 997–1022. https://www.jstor.org/stable/26377779

Qin, Y. (2021). BIM combined intelligent computer system in precast concrete structure design with data mining integration. *2021 Third International Conference on Inventive Research in Computing Applications (ICIRCA), 2021*, 1683-1686. https://doi.org/10.1109/icirca51532.2021.9544614

Resuli, N., Skubic, M., & Kovaleski, S. (2020). Learning room structure and activity patterns using RF sensing for in-home monitoring of older adults. *2020 IEEE International Conference on Bioinformatics and Biomedicine (BIBM), 2020,* 2054-2061. https://doi.org/10.1109/bibm49941.2020.9313335

Saaty, R. (1987). The analytic hierarchy process—what it is and how it is used. *Mathematical Modelling*, *9*(3–5), 161–176. https://doi.org/10.1016/0270-0255(87)90473-8

Saba, D., Degha, H. E., Berbaoui, B., Laallam, F. Z., & Maouedj, R. (2017). Contribution to the modeling and simulation of multiagent systems for energy saving in the habitat. *2017 International Conference on Mathematics and Information Technology (ICMIT)*, *2017*, 204-208. https://doi.org/10.1109/mathit.2017.8259718

Sadri, F. (2011). Ambient intelligence. *ACM Computing Surveys*, *43*(4), 1–66. https://doi.org/10.1145/1978802.1978815

Saidi Sief, A., Pruski, A., Bennia, A., & Handouzi, W. (2016). Swinging doors accessibility assessment for a wheelchair user. *Technology and Disability*, *28*(1/2), 53–66. https://doi.org/10.3233/tad-160444

Salerno, I., Anjos, M. F., McKinnon, K., & Gómez-Herrera, J. A. (2021). Adaptable energy management system for smart buildings. *Journal of Building Engineering*, *44*, 102748. https://doi.org/10.1016/j.jobe.2021.102748

Samiee, S., & Chabowski, B. R. (2012). Knowledge structure in international marketing: A multi-method bibliometric analysis. *Journal of the Academy of Marketing Science*, *40*(2), 364-386. https://doi.org/10.1007/s11747-011-0296-8

Sampaio, D., Paulo Reis, L., & Rodrigues, R. (2012). A survey on ambient intelligence projects. *7th Iberian Conference on Information Systems and Technologies (CISTI)*, *2012*, 1-6.

https://ieeexplore.ieee.org/document/6263229?arnumber=6263229

Sánchez, P., Jiménez, M., Rosique, F., ÁLvarez, B., & Iborra, A. (2011). A framework for developing home automation systems: From requirements to code. *Journal of Systems and Software*, *84*(6), 1008–1021. https://doi.org/10.1016/j.jss.2011.01.052

Sangal, S., & Bathla, R. (2019). Implementation of restrictions in smart home devices for safety of children. *2019 4th International Conference on Information Systems and Computer Networks (ISCON), 2019,* 139-143. https://doi.org/10.1109/iscon47742.2019.9036218

Sangani, K. (2012). Smart home tech. *Engineering & Technology*, *7*(6), 46. https://doi.org/10.1049/et.2012.0604

Sanguinetti, A., Karlin, B., & Ford, R. (2018). Understanding the path to smart home adoption: Segmenting and describing consumers across the innovation-decision process. *Energy Research & Social Science*, *46*, 274–283. https://doi.org/10.1016/j.erss.2018.08.002

Seyedolhosseini, A., Masoumi, N., Modarressi, M., & Karimian, N. (2020). Daylight adaptive smart indoor lighting control method using artificial neural networks. *Journal of Building Engineering*, *29*, 101141. https://doi.org/10.1016/j.jobe.2019.101141

Sharif, K., & Tenbergen, B. (2020). Smart home voice assistants: A literature survey of user privacy and security vulnerabilities. *Complex Systems Informatics and Modeling Quarterly*, *24*, 15–30. https://doi.org/10.7250/csimq.2020-24.02

Sinopoli, J. (2010). *Smart building systems for architects, owners, and builders.* Burlington, MA: Elsevier.

Stavropoulos, T. G., Gottis, K., Vrakas, D., & Vlahavas, I. (2013). aWESoME: A web service middleware for ambient intelligence. *Expert Systems with Applications*, *40*(11), 4380–4392. https://doi.org/10.1016/j.eswa.2013.01.061

Stolojescu-Crisan, C., Crisan, C., & Butunoi, B. P. (2021). An IoT-based smart home automation system. *Sensors*, *21*(11), 3784. https://doi.org/10.3390/s21113784

Strachan, M., & Banfill, P. (2012). Decision support tools in energy-led, non-domestic building refurbishment. *Facilities*, *30*(9/10), 374–395. https://doi.org/10.1108/02632771211235215

Strba, A., & Krajčovič, T. (2012). Operating system for wireless embedded systems powered by energy harvesters. *Lecture Notes in Electrical Engineering*, *LNEE*(151), 331–344. https://doi.org/10.1007/978-1-4614-3558-7_27

Sun, H., Zhang, C., Si, J., & Xu, W. (2021). Smart home system design and implementation based on OneM2M. *2021 2nd International Conference on E-Commerce and Internet Technology (ECIT)*, *2021*, 344-347. https://doi.org/10.1109/ECIT52743.2021.00078

Sweetman, D., Badiee, M., & Creswell, J. W. (2010). Use of the transformative framework in mixed methods studies. *Qualitative Inquiry*, *16*(6), 441–454. https://doi.org/10.1177/1077800410364610

Taha, H. (2007). *Operations Research an Introduction*. Prentice Hall.

Tang, S., Kalavally, V., Ng, K. Y., & Parkkinen, J. (2017). Development of a prototype smart home intelligent lighting control architecture using sensors onboard a mobile computing system. *Energy and Buildings*, *138*, 368–376. https://doi.org/10.1016/j.enbuild.2016.12.069

Ugolini, D., Neri, M., Cesario, A., Bonassi, S., Milazzo, D., Bennati, L., Lapenna, L. M., & Pasqualetti, P. (2011). Scientific production in cancer rehabilitation grows higher: A bibliometric analysis. *Supportive Care in Cancer*, *20*(8), 1629–1638. https://doi.org/10.1007/s00520-011-1253-2

van de Kaa, G., Stoccuto, S., & Calderón, C. V. (2021). A battle over smart standards: Compatibility, governance, and innovation in home energy management systems and smart meters in the Netherlands. *Energy Research & Social Science*, *82*, 102302. https://doi.org/10.1016/j.erss.2021.102302

Vinagre Díaz, J. J., Wilby, M. R., Rodríguez González, A. B., & García Muñoz, J. (2013). EEOnt: An ontological model for a unified representation of energy efficiency in buildings. *Energy and Buildings*, *60*, 20–27. https://doi.org/10.1016/j.enbuild.2013.01.012

Vivint Smart Home. (n.d.). Retrieved December 14, 2021, from https://shop.vivint.com

Wang, F., Lu, Y., Li, J., & Ni, J. (2021). Evaluating environmentally sustainable development based on the PSR framework and variable weight analytic hierarchy process. *International Journal of Environmental Research and Public Health, 18*(6), 2836. https://doi.org/10.3390/ijerph18062836

Wang, T., & Cook, D. J. (2020). sMRT: Multi-resident tracking in smart homes with sensor vectorization. *IEEE Transactions on Pattern Analysis and Machine*

Intelligence, *43*(8), 2809-2821. https://doi.org/10.1109/tpami.2020.2973571

Wang, Z., Wang, L., Dounis, A. I., & Yang, R. (2012). Integration of plug-in hybrid electric vehicles into energy and comfort management for smart building. *Energy and Buildings*, *47*, 260–266. https://doi.org/10.1016/j.enbuild.2011.11.048

Warriach, E. U., Kaidell, E., Lazovik, A., & Aiello, M. (2013). An interplatform service-oriented middleware for the smart home. *International Journal of Smart Home*, *7*(1), 115–141. http://www.sersc.org/journals/IJSH/vol7_no1_2013/11.pdf

Weinstein, R. S. (2008). The s-curve framework: Predicting the future of anatomic pathology. *Archives of Pathology & Laboratory Medicine*, *132*(5), 739–742. https://doi.org/10.5858/2008-132-739-tsfptf

Wong, J., & Li, H. (2006). Development of a conceptual model for the selection of intelligent building systems. *Building and Environment*, *41*(8), 1106–1123. https://doi.org/10.1016/j.buildenv.2005.04.021

Wong, J., Li, H., & Lai, J. (2008a). Evaluating the system intelligence of the intelligent building systems Part 1: Development of key intelligent indicators and conceptual analytical framework. *Automation in Construction*, *17*(3), 284–302. https://doi.org/10.1016/j.autcon.2007.06.002

Wong, J., Li, H., & Lai, J. (2008b). Evaluating the system intelligence of the intelligent building systems Part 2: Construction and validation of analytical models. *Automation in Construction*, *17*(3), 303–321. https://doi.org/10.1016/j.autcon.2007.06.003

Wong, J. K. W., & Li, H. (2008). Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems. *Building and Environment*, *43*, 108–125. https://doi.org/10.1016/j.buildenv.2006.11.019

Wong, J. K. W., & Li, H. (2010). Construction, application and validation of selection evaluation model (SEM) for intelligent HVAC control system. *Automation in Construction*, *19*(2), 261–269. https://doi.org/10.1016/j.autcon.2009.10.002

Wong, J. K. W., Li, H., & Wang, S. W. (2005). Intelligent building research: A review. *Automation in Construction*, *14*, 143–159. https://doi.org/10.1016/j.autcon.2004.06o.001

Yaoyang, X., & Boeing, W. J. (2013). Mapping biofuel field: A bibliometric evaluation of research output. *Renewable and Sustainable Energy Reviews*, *28*, 82–91. https://doi.org/10.1016/j.rser.2013.07.027

Yin, T., Chen, Y., Tang, L., Yuan, H., Zeng, X., & Fu, P. (2022). Relationship between modifiable lifestyle factors and chronic kidney disease: a bibliometric analysis of top-cited publications from 2011 to 2020. *BMC Nephrology*, *23*(1), 1-15. https://doi.org/10.1186/s12882-022-02745-3

Yu, C., Jannasch-Pennell, A., & DiGangi, S. (2014). Compatibility between text mining and qualitative research in the perspectives of grounded theory, content analysis, and reliability. *The Qualitative Report*, *16*(3), 730-744. https://doi.org/10.46743/2160-3715/2011.1085

Zach, R., & Mahdavi, A. (2012). MOST-Designing a vendor and technology independent toolkit for building monitoring, data preprocessing, and visualization. *1st International conference on architecture & urban design 2012*, *2012*, 1195-1202.

http://92.119.236.203/bitstream/handle/1/1159/175-617-1-PB.pdf?sequence=1&isAllowed=y

Zarindast, A., Sharma, A., & Wood, J. (2021). Application of text mining in smart lighting literature - An analysis of existing literature and a research agenda. *International Journal of Information Management Data Insights*, *1*(2), 100032. https://doi.org/10.1016/j.jjimei.2021.100032

Zheng, S., Zhang, Q., Zheng, R., Huang, B. Q., Song, Y. L., & Chen, X. C. (2017). Combining a multi-agent system and communication middleware for smart home control: A universal control platform architecture. *Sensors, 17*(9), 2135. https://doi.org/10.3390/s17092135