IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 9 May 2024, accepted 5 June 2024, date of publication 17 June 2024, date of current version 18 September 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3415351

RESEARCH ARTICLE

Enhancing Accessibility in Academic Buildings: A Discrete Event Simulation Approach for Robotic Assistance

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This work was supported by the Grants for University Teacher Training (UTT) titled "MoSTBuilding: A Robotic and Digital Twin Framework for an Inclusive Mobility in Smart Buildings."

ABSTRACT The Convention on the Rights of Persons with Disabilities (CRPD) emphasizes the importance of a barrier-free environment that ensures autonomy to perform any task for all individuals, regardless of disabilities. This is particularly important in public administrations (academic centers, hospitals, transport stations, etc.), where governments must make sure that all citizens are equally catered for, being inclusive of all physical and mental conditions. Traditional approaches focused on architectural modifications for physical mobility fail to encompass all disabilities, leaving gaps in provisions for cognitive, visual, or hearing impairments. In this sense, solutions based on assistant robots represent promising results, yet investment risks require accurate predictions prior to implementation. In this sense, simulators perform a virtual representation of complex scenarios, ensuring that the system achieves the desired requirements before deployment. This paper presents the MoSTBuilding framework's scenario simulation by applying a Discrete Event Simulation. The purpose of the simulation is to evaluate how robot assistant reduce task completion time for students in a variety of buildings. Results from two university building scenarios indicate a 35% and 42% reduction in travel time for students with and without disabilities. In another building with a high proportion of students with disabilities, the reductions are 30% and 37% for different types of students. This research demonstrates the substantial potential of integrating robotic assistance in academic settings to improve accessibility and efficiency, offering significant benefits for students, especially those with disabilities.

INDEX TERMS Discrete-event simulation, robot assistant, accessibility, digital twin, navigation, public building.

I. INTRODUCTION

Recently, the United Nations, in its Convention on the Rights of Persons with Disabilities (CRPD) [1], has indicated that all people with or without disabilities have the freedom to carry out any type of task autonomously, and this includes different environments and contexts, thus overcoming both architectural and knowledge barriers. This is the so-called barrier-free environment [2], which indicates that all people throughout their lives, whether for reasons of health or age, will suffer some kind of disability, thus proposing the definition of an environment free of barriers and adapted to fulfill the needs of all people equally.

Traditional approaches to creating such barrier-free environments have predominantly focused on architectural modifications to facilitate physical mobility. However, these do not encompass the complete range of disabilities, leaving gaps in provisions for those with cognitive, visual, or hearing impairments.

This is particularly evident inside public buildings such as academic centers, hospitals, transport stations, museums, and administrative buildings. These are places where public

The associate editor coordinating the review of this manuscript and approving it for publication was Claudio Loconsole.

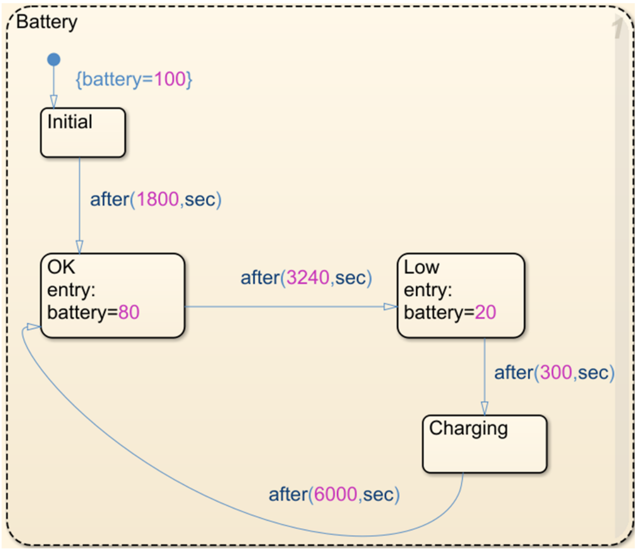


FIGURE 1. Determination of robot digital twin battery parameters using discrete-event chart blocks.

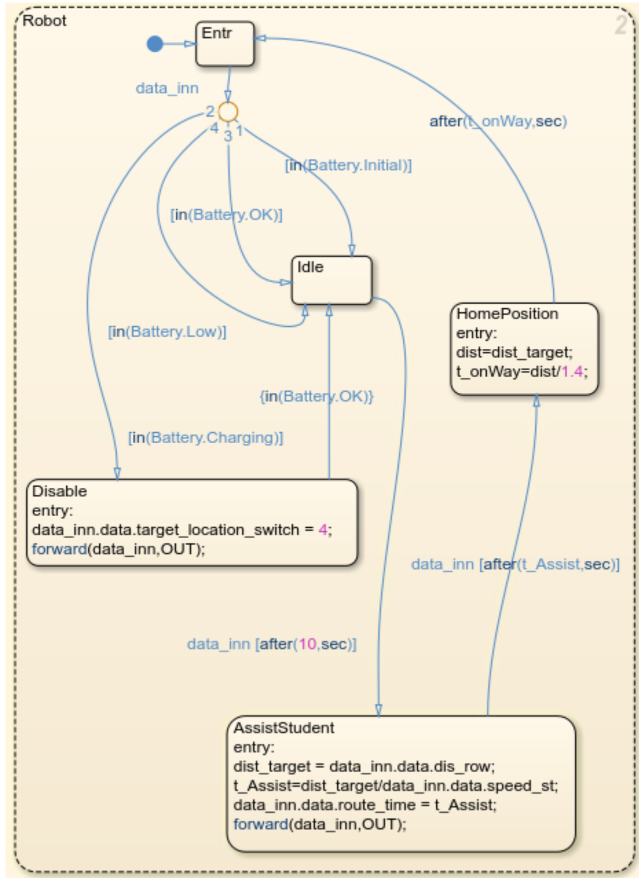


FIGURE 2. Modeling the behavior of the robot digital twin using discrete-event chart blocks.

administrations must ensure that all citizens are equally catered for, being inclusive of all physical and mental conditions. Moreover, it is important to remember that according to the CRPD [1], an individual should have the freedom to perform any task autonomously. Therefore, it is necessary to address a holistic solution that not only allows for assistance in movement but also assists them at all times in performing one or more tasks within the building (e.g., attending a class in a faculty, performing tests at the hospital, checking in and boarding a plane, etc.). It is a reality that these tasks are made up of a set of steps that make them complicated for people with disabilities, so it is necessary that the information is sent and received through different means (sound, written, visual, etc.) that are suitable for them according to their condition. In addition, the person must be guided through the building to the destination, avoiding any kind of obstacle. For this, a high level of personalization is required, which, depending on the information of each person, the building, and the task he/she wants to perform, makes the system act accordingly.

For the implementation of these systems, continuous monitoring and assistance of the person in the building via connected sensors and actuators is necessary, which in recent years has come to be known as the Internet of Things (IoT) [3]. IoT represents a network of physical devices that use the internet to send data to provide value to the user. In this case, on the one hand, wearable devices (smartwatch, smartband, smartphones, etc.) are required as they contain information about the person, for example, biometric information, location, and a personal file that indicates their condition and disabilities. In addition, in this case, the IoT system should be deployed with devices throughout the building and act as a whole to help people perform these tasks in a so-called Smart building [4]. For example, the system would include sensors and actuators in automatic doors for people with mobility disabilities, voice control for low vision people, proximity sensors to detect falls, touch screens for hearing impaired and non verbal people, etc.

However, this solution is not complete if we cannot provide an immediate and building-wide response to the person with a disability. To do this, we need to have a device that solves the problem of movement, detects obstacles in real-time, and allows interaction in all the rooms of the building. In this sense, solutions based on robots, such as [5], have obtained very satisfactory results, and thanks to their proximity sensors, they help people to move around the building, avoiding any kind of unforeseen event.

Before embarking on the investment involved in implementing a scenario for a specific building, it is necessary to reduce risks by obtaining a prediction as close as possible to the final result. In this sense, a recognized need by the scientific community [6], [7] is simulators, which perform a virtual representation of complex scenarios that allow a qualitative and quantitative prediction based on mathematics models, machine learning, and data analysis, ensuring that the system achieves the desired requirements before its implementation. In this case, the simulator should be based on the concepts represented by the Digital Twins [8], linking the tasks of a person with his or her condition information, with the real-time robot information, and that of the IoT building devices.

To this end, we propose a software framework called MoSTBuilding, an adaptable and inclusive solution for public buildings, such as academic, health, transport, or administrative facilities. MoSTBuilding comprises three essential components, namely an assistant robot, a smart building configuration, and a software system based on the simulation and definition of complex scenarios with Digital Twins to provide real-time assistance to individuals for one or more tasks.

This paper presents one of the MoSTBuilding framework components, namely the scenario simulation applying a Discrete Event Simulation (DES), which is thus a simulation in which the state of the systems changes based on a set of discrete events that occur at specific points in time. This method provides decision-makers with valuable insight into system behavior and enables them to assess the impact of potential operational strategies before their implementation. The objective of conducting an offline DES simulation is to create a controlled environment in which some resources exhibit expected behavior and others act stochastically. This approach allows for exploring various configurations to identify the most optimal solutions for specific scenarios. (e.g., How many robot assistants are needed to serve people with disabilities efficiently?). Therefore, the use of DES can be regarded as a best practice in the context of resource allocation planning and management.

For this study, we have modeled two students' flows using SimEvents and Stateflow toolboxes from the MATLAB Simulink environment. The Polytechnic IV building and the building of the Faculty of Business and Economics at the University of Alicante served as a scenario. The model scenario represents the current flow of students moving through this university building to their respective destinations. Specifically, we will try to address an inclusive solution that considers both students with and without disabilities. The distribution of buildings consists of four floors, which are distributed in both classrooms and teachers' offices. As indicated, the most common tasks performed by a student in an educational building are attending class and tutoring with a teacher. These tasks are included in the simulator considering the spatial specificities of the building. The purpose of the simulation is to evaluate whether or not the use of a robot assistant reduces the time required for any type of learner to perform tasks. For this purpose, two simulations are defined; one considers the current situation: there is no robot, and students with and without disabilities go to the different rooms of the building, whether classrooms or teachers' offices. In the second simulation, the robot is included to serve different students, considering the strategy of giving priority to people with disabilities. The simulation period lasts 14.5 hours, which is equivalent to one day of work at the university. The models were executed 128 times, with the number of students arriving and their movement speed being adjusted across each run based on the group of students and other parameters.

The remainder of this paper is structured as follows. Section II describes the background of general non-robotic and robot-assisted approaches to building accessibility and the application of DES for resource allocation in different research areas. In section III, we describe two main Discrete Event Simulation (DES) models. The first model simulates the current flow of students with and without disabilities in the Polytechnic IV building at the University of Alicante. The second DES model simulates the student's flow by applying the robot assistant in the building. In Section III, we present two primary models of Discrete Event Simulation (DES). Section IV represents the results we obtained from comparing two simulation model outcomes. In Section V, we analyzed the results of our research and identified potential threats. We concluded by emphasizing that these challenges present opportunities for further research and development. Finally, in Section VI, we summarized our findings and discussed possible directions for future research.

II. BACKGROUND

In this section, we have highlighted two research questions. The first one is: *How can smart building systems help people with disabilities perform various tasks independently in public buildings?* We present different approaches for people with disabilities in buildings that have been proposed in recent years.

Another important question is: *How can robot assistants be efficiently allocated to reduce the time to perform tasks in a building significantly?* In this part, we will examine how effectively the DES method is utilized to allocate resources in different research areas. The selected articles were categorized into three subsections: the main non-robotic approaches to building accessibility, existing robot-assisted approaches, and the application of DES for resource allocation.

A. TECHNOLOGICAL APPROACHES TO BUILDING ACCESSIBILITY

In recent years, there has been a growing interest in developing systems and technologies that allow for modeling and optimizing behavior in smart buildings. Smart buildings are structures designed with advanced technologies and systems that focus on the safety, health, comfort, affordability, and sustainability [9] of their occupants and environment. Accessibility [10] is the degree to which people with disabilities can use a product, service, or environment. Smart buildings can greatly benefit people with disabilities by providing inclusive environments that adapt to their specific needs. During the research, we found that most studies focus on navigation, wayfinding, and avoiding obstacles inside the building. Previous work suggests that indoor navigation is the main problem to be addressed through a variety of technological solutions.

B. GENERAL NON-ROBOTIC APPROACHES

In [11], the authors present a wireless sensor network (WSN) wayfinding prototype system called AssistMote, designed to assist individuals with cognitive, visual, and mobility impairments in indoor navigation. The system utilizes handheld PDAs and Bluetooth beacons to provide personalized and context-aware guidance to users as they navigate through complex indoor environments.

Kbar et al. in [12] introduced the development of a smart unified interface for people with disabilities (PWDs) in the workplace. The interface utilizes context-aware and adaptive technologies, including wireless RFID and sensor networks, to track users and provide various services such as smart editing, smart communication, and context-aware applications. The implementation of the system demonstrates successful context-aware search, voice command functionality, behavior tracking, and various context-aware applications. The results of usability tests showed increased performance and user satisfaction, but privacy concerns were raised.

Delnevo et al., in [13], proposed UniSAS, a system designed to enhance building accessibility using the Internet of Things (IoT). The system utilizes Raspberry Pi boards installed on doors and leverages users' mobile devices. Various user scenarios are presented to demonstrate the feasibility of the proposed approach. UniSAS aims to improve mobility and independence for individuals with disabilities in smart buildings by monitoring, controlling, managing, and supporting building access.

Another interesting approach to assist individuals with limited mobility indoors is a framework presented in [14]. It is designed to create a brain-controlled wheelchair that facilitates smooth movement. The framework consists of several components, including navigation, path planning, obstacle detection, and user interface. Users have three navigation options - manual/direct control, semi-autonomous, and autonomous. The software framework was developed based on a prototype wheelchair that is equipped with obstacle detection sensors, enabling it to detect and avoid obstacles, regardless of the chosen method.

Oriented for visually impaired people in [15], a V-Eye system that can detect and warn about moving obstacles, provide correct orientation in real-time, or support navigation between indoor and outdoor spaces was developed. The system utilizes a novel global localization method (VB-GPS) and image segmentation techniques to better understand scenes with a single monocular camera. Once all required elements are received, the system provides audible feedback to the user.

To solve some problems of visually impaired people in navigating inside unfamiliar buildings, a spatial representation framework is proposed [16]. Five factors have been identified to provide confidence and safety when traveling in buildings and public spaces, such as navigation cues, warning, profile, condition, and external appearance.

The survey found that one of the popular technologies researchers chose for accessibility is augmented reality (AR). Some of these works have been proposed for navigation in university buildings. A system developed to enhance the inclusion of wheelchair users in Smart Cities has been presented in [17]. The study discusses the system's design and implementation, including using RFID-enabled Smart Shelves and different interfaces to cater to users with varying motor disabilities. The system's evaluation involved 14 wheelchair users and provided valuable insights into the technology's efficacy and impact on inclusion and independence. Nizam et al. in [18] propose using an AR-based indoor navigation application in a university's student halls of residence. The goal is to assist new students in finding their way around the campus more efficiently and reduce the need to ask others or search for maps. The results revealed that students who have difficulty searching for a location require more time to reach their destination and seek help from others, which justifies implementing the Student Residence AR indoor navigation application. In [19], the authors introduce a system called ARSAWP, which combines AR technology and geographical mapping to assist wheelchair users in navigating independently within a university campus. The system utilizes AR smart glasses to guide users along safe and obstacle-free routes, considering factors such as the shortest path and uphill slopes. An indoor wayfinding system that supports university communities, including students with disabilities, campus students, and visitors, has been developed in [20]. The system uses QR codes, NFC tags, Bluetooth beacons, and mobile devices to provide accessible and personalized guidance. The paper also evaluates the system in three different scenarios with 18 users of three groups of three groups - students, students with disabilities, and tourists, at the site. The result demonstrated high efficiency in navigating an unfamiliar building but a loss of interest in using the app in familiar places.

Most studies focus on solutions for only one specific disability without considering others. Also requires additional installations in the building. In alignment with the presented research, this article presents the MoSTBuilding framework as a comprehensive and inclusive solution for all users, regardless of their abilities.

C. ROBOT-ASSISTED APPROACHES

Having analyzed the current literature, it can be observed that assisting visually impaired people in navigating unfamiliar indoor environments is the primary direction of existing research with robotic approaches. Thus, Lu et al. in [21] designed a deep reinforcement learning–based assistive guiding robot with ultrawide-bandwidth beacons that can navigate through routes with designated waypoints in a simulated ward. The robot provides verbal feedback to low vision and visually impaired users through a handle device and audio beacons. The proposed system has demonstrated significant success in navigating environments with dynamic pedestrians.

A wayfinding robot for people with visual impairments that can guide them to their destinations in an airport terminal has been proposed in [22]. The robot uses a lidar sensor and a camera to detect obstacles and landmarks and communicates with the user through speech and haptic feedback.

In [23], was proposed a map-free navigation system implemented on a robot to assist visually impaired individuals in reaching their destination in unfamiliar buildings. Following a study conducted with low vision people, a sign recognition and intersection detection system was developed, which then relays information to the low vision user using audio feedback.

Another system that assists people in getting to the right place in an unfamiliar environment is present [24]. Visually impaired people navigate indoor environments by holding onto a mobile robot. The system interacts with an end-user through a smartphone. This device sends requested targets and receives navigational feedback via vibration signals.

Grewal et al. in [25] present an innovative system that uses a camera, a ranging LIDAR, and computer vision to detect possible destinations in an unmapped indoor environment and navigate toward them, avoiding obstacles. The system was tested in a simulated shopping mall environment where different stores were selected as destinations. Results from the testing phase indicated that the system is highly accurate and robust in detecting and navigating to the designated destinations while remaining cost-effective and exhibiting low power consumption.

One of the studies [26] aims to provide location information and navigational guidance to people with cognitive disabilities in assistive attention centers using a low-cost robot. This system incorporates essential components such as a screen, loudspeaker, microphone, and camera, in addition to various sensors and motors. The research detailed in this work outlines the robot's capabilities, enabling it to autonomously create a reference map and navigate to a predetermined destination. To facilitate this navigation, specific points of interest are marked with QR codes.

Compared to the mentioned studies, our proposed framework integrates social robot assistants and IoT infrastructure to create a personalized intelligent building environment in real-time. The robot is equipped with a comprehensive map of the building and has access to valuable information regarding the human condition and special requirements. As a result, it can expertly select the most appropriate route. In addition to navigation, the robot can help with other tasks such as finding out the teacher's schedule at the faculty, taking tests at the hospital, checking in for a flight, and boarding an airplane. By assisting users to perform their everyday tasks in public buildings, this solution has the potential to significantly improve their quality of life.

D. APPLICATION OF DISCRETE EVENT SIMULATION FOR RESOURCE ALLOCATION

At the stage of implementation of a new solution, there is a need for preliminary prediction to determine the possible risks and reveal the effective scenario. Discrete event simulation (DES) is a powerful method [27] for evaluating different scenarios, identifying bottlenecks, and selecting the most effective strategy. At the same time, DES can serve as a valuable tool for allocating both existing and anticipated resources for implementation. Over the years, many approaches have been developed that use DES to solve this very issue. They are mainly focused on the areas of healthcare [28], [29], [30], [31] and manufacturing industry [32], [33], [34], [35]. The analysis of the current literature presents that the emergency department is the most sought-after area for DES [36], [37], [38], [39]. As indicated in [29], without effective models, hospitals risk suboptimal resource allocation. To optimize the budget of the emergency process and simultaneously minimize the total waiting time performance, the DES was used in [39]. After analyzing both issues, the authors determined the best solution to improve the timing rate to 83.9%. In [40], to remove bottlenecks and optimize the use of physicians and nurses at an Emergency Department's Green Zone, the authors derived several resource allocation options. Findings show that the proposed new physician and nurse schedule reduces the average waiting time for patients, lowers the high workload of physicians and nurses, and increases the number of patients served. Additionally, it allows for optimal use of consultation rooms compared to the current utilization rate. To investigate the effect of patient volume fluctuations on resource allocation in a rehabilitation hospital, the DES was successfully utilized in [28]. The utilization of beds, nurses, physicians, and the number of patients waiting for surgery were estimated using the model.

Authors in [35] experimented with several scenarios to improve the design of a new production line. Using DES technology, they analyzed key assembly line factors such as bottlenecks, throughput, and worker quantities and obtained statistical data sufficient to make assembly line reform decisions. Addressing throughput maximization problems, Wu and Chen in [33] created a model of a production system and developed a discrete event simulation scheme. As a result, the authors verified that their algorithms could find reasonable solutions for resource allocation for both small and large tasks.

As the results show, DES is presented as an efficient way to allocate resources and improve the capacity of buildings and institutions with large flows of people or intricate systems. Simulation models are an essential tool for evaluating operational changes before they are implemented, providing flexibility and cost-effectiveness. Therefore, this technique was chosen for our study to estimate the efficiency of the allocation of the robot assistant to reduce the time to orient the flow of people, including those with special needs, in a new or inaccessible building.

III. A DISCRETE-EVENT SIMULATION CASE STUDY DEFINITION

In this study, we have modeled two scenarios, one involving a robot and one without, with the purpose of evaluating whether such a robot in the Polytechnic IV building is suitable for implementation. Before embarking on the investment involved in implementing a scenario for a specific building, it is necessary to reduce risks by obtaining a prediction as close as possible to the final result. In this sense, a recognized need by the scientific community [44] is simulators, which perform a virtual representation of complex scenarios that allow a qualitative and quantitative prediction based on mathematics models, machine learning, and data analysis, ensuring that the system achieves the desired requirements before its implementation. Simulation models can be created in a variety of ways. One of the valuable methods is a discrete event simulation (DES), which is used to evaluate and enhance complex processes and systems, particularly when significant expenses or risks are involved [45]. A DES is thus a simulation in which the state of the systems changes based on a set of discrete events that occur at specific points in time [46]. This approach enables decision-makers to effectively evaluate different scenarios, develop complex operational models, and analyze different strategies for efficient learning and performance improvement of their systems. The objective of conducting an offline DES simulation is to create a controlled environment in which some resources exhibit expected behavior and others act stochastically. The movement of students from one location to another represents a stochastic phenomenon. The length of time that students take to reach their desired destinations varies significantly due to several factors. These factors include the degree of familiarity that students have with the layout of the building, any disabilities they may possess, the availability of an elevator or ramp, or if they require support from others. This means that DES makes it possible to model events characterized by irregularity and unpredictability. This allows us to run simulations with different configurations to obtain accurate predictions and insights into the potential outcomes of various decisions.

For forecasting purposes, we use another increasingly important technology called Digital Twin (DT). Digital twins [47] are virtual mirrors of physical objects or processes that allow for better understanding, prediction, and optimization of their performance. It displays the parameters of individual objects, such as robots, students, and building IoT devices, as well as their interaction in the complete building system. The DT model can be easily customized to different scenarios. With its predictive nature, it allows for analyzing and making decisions before introducing a new object into the overall system.

In the present study, we have incorporated an integration with a DES using the SimEvents toolbox of the MATLAB Simulink tool. Simulink is a graphical tool for modeling, simulating, and analyzing dynamic systems using blocks and signals that can be customized and connected [48]. The scenario comprises the creation of two Student Twins - one with disabilities and the other without. Within the DES environment, the Entity generator block reflects all the parameters and behavior of the student's movement in the building. These entities interact with a Discrete-Event Chart block representing a Robot Twin, which is an event-based representation of the state machine [49]. This allows us to represent the current scenario of the students' flow in the academic building (Appendix A) versus the proposed scenario involving a robot assistant (Appendix B).

IV. SIMULATING THE REAL-WORLD SCENARIOS OF ASSISTANT ROBOTS IN AN ACADEMIC BUILDING

The building that served as a prototype in our simulations is Building IV of the Polytechnic School of the University of Alicante. The basement and ground floors of the building comprise 35 classrooms, laboratories, and halls. The first and second floors are comprised of three blocks and encompass 131 offices and laboratories of various departments. The building boasts three elevators, six staircases, and three ramps, of which two are positioned at the entrances while the third one leads to the basement. For the study, we rely on open data provided by the Student Support Center of the University of Alicante, specifically from the academic year 2021/2022 [41]. According to this data, there are a total of 56 students with disabilities enrolled in the Computer Science program, and their distribution is as follows: 3% have a hearing disability, 11% have a visual disability, 53% experience mental disabilities, and 9% face mobility disabilities. We used open data from the University of Alicante website [42] to gather precise details about the location of the offices. Subsequently, we employed the Google API to calculate distances between the above-mentioned locations. The resulting table of distance values has been generated to facilitate further analysis [43].

We employ an exponential distribution to generate student inter-arrival times (1). We define different arrival rates (λ) during different time intervals. Specifically, we utilize time intervals that align with the university's class schedule to determine the rates of the distributions. For instance, when the time falls at the beginning of university classes, the arrival rate is higher, and vice versa.

$$dt = -\frac{1}{\lambda} \times log\,(1 - U) \tag{1}$$

After determining the arrival rate (λ) based on the current time, we use sampling with inverse transformation to generate a random time between arrivals (dt) according to an exponential distribution, where U is a random variable evenly distributed in the interval [0,1]. Subsequently, the time between arrivals (dt) is incremented to the current time (2). The updated time (T_{new}) is then used for the next iteration to determine the arrival rate for the next inter-arrival time.

$$\mathrm{T_{new}} = \mathrm{T_{old}} + \mathrm{dt} \tag{2}$$

By exploiting the mathematical properties of exponential distributions, we can generate inter-arrival times that effectively capture the variability and randomness inherent in real-world systems.

When an entity is created, various attributes are also generated that describe the entity and affect its progression in the simulation model. Attributes such as the definition of the type of disability, the need for robotic assistance, and the student's destination were determined using a normal distribution with varying probability values (Table 1).

Another indispensable attribute is the speed of students on the road. The rate may vary depending on the student's

TABLE 1. Probabilities of student assignment and direction.

Student Type	Robot Assignment	Direction - Classes	Direction - Consultations
With Disabilities	70%	60%	40%
Without Disabilities	5%	70%	30%

TABLE 2. Speed intervals for students in different states.

Types of Disabilities	Speed Range without Robot (m/s)	Speed Range with Robot (m/s)
Auditive	0.34– 0.92	0.34−1.24
Visual	0.20−0.70	0.30−0.90
Mental	0.20−0.80	0.30−1.09
Motor	0.10−0.70	0.30−0.80
Without Disabilities	0.34– 0.92	0.34−1.24

disability and whether the student is accompanied by a robot. A range of mean values for this parameter has been derived from previous studies [51], [52], [53], [54], [55]. For the scenario without the robot, we determined the interval based on the mean value considering the standard deviation (Table 2).

For student movement in the robot scenario, we adjusted the speed by selecting the average value with the help behavior [53]. For students with motor disabilities, movement in both the electric and manual chairs was considered.

In calculating distance travel time, we added the probability of error in finding the correct destination (3). This equation implies that the base time increases by a factor of F on the first attempt, reflecting the additional difficulty of getting through the path without prior knowledge.

$$T = F \times (\frac{\mathrm{S}}{\mathrm{V}} + P \times M) \tag{3}$$

The expected number of mistakes can be approximated by multiplying the probability (P) of making a mistake by the time penalty per mistake (M). We have chosen a P equal to 10%, and F may randomly go up to 50%. The penalty is based on the average distance within the building, considering the standard deviation.

A. THE ORIGINAL STUDENT' S FLOW IN THE ACADEMIC BUILDING

The general purpose of this paper is to model the student's flow with and without disabilities in an academic building under different scenarios. The main simulation model of the actual process organization (see Appendix A. Fig. 3.) begins from the moment the students arrive at the university building. According to the schedule, the university is open 14 and a half hours a day from 7:30 a.m. to 10 p.m. The schedule shapes the flow of students, with the highest number of students arriving at the start of classes, forming the peak hours. The entity generators create two flows of students with and without disabilities, defining all their related attributes (Table 1, 2).

The following simulation step is a combination of two flows of students into a common queue. This queue block is enhanced with Simulink Functions, in which two crucial attributes are specified. The first one calculates the distance between the origin and destination points, while the second one defines the exact start time of the trip, which is used to calculate the total duration of the route. Students are then directed to the selected destination for which a switch is used. The calculation of travel time is performed in the entity servers. The process then feeds into two subsystems represented by the classroom and consultation blocks, respectively (see Appendix A. Fig. 4 and 5). Within each subsystem, there is a switch to separate students based on disability status. The function blocks connected to two entity queues calculate the final travel time for students before they proceed to their respective classes or consultations. The route calculation in the function is based on the data collected from the SIGUA API [50]. After this, the students are combined back into the common flow and directed toward the appropriate premises for which two servers are responsible. The class server, which stores arriving entities for a specific period of time, is configured according to the class schedule, whereas the consultation server has been set up to operate within a specific time range.

Finally, the four entity terminators with scope blocks terminate the entities. The simulation is accomplished by calculating the distance and time to reach the destination, considering the speed differential for each type of student.

B. STUDENTS FLOW IN THE ACADEMIC BUILDING WITH THE APPLICATION OF A ROBOT ASSISTANT

The second model shows the flow of students combined with the use of a robot assistant (see Appendix B). The model essentially comprises the same blocks as the first model, with the addition of a Discrete-Event Chart block identified as a Robot Twin. The Discrete-Event Chart (DEC) is an event-based approach tool used to represent reactive systems that change their mode of operation based on specific conditions [56]. DEC is based on UML state machine diagrams [57], which are essential for creating digital twins. These diagrams provide a formal framework for modeling and monitoring the dynamic behavior of physical systems in the digital world. By using state machines, we can represent the various states that a physical system can transition through and the events or conditions that cause these transitions. This model is particularly useful for illustrating the dynamic appearance of a system, especially when modeling the behavior of interfaces, classes, or digital twins. By operating based on events rather than time intervals, DEC provides an exceptional level of timing precision. This allows events to occur exactly when required, without the limitations imposed by predetermined time intervals. This property is particularly beneficial in representing the behavior of devices, which is a crucial property of Digital Twins (DT).

Fig. 1 represents a battery parameter of Robot DT that comprises a set of states such as active, low battery, and on charge. Since the charging time is about 50 minutes at 25°C ambient temperature and 150 minutes at 35°C, we take an average of 100 minutes to charge to 80%. Assume that the robot is utilized for the entire simulation time, in which case, the battery will require a charging time of 90 minutes. In 72 minutes, the robot reaches 20% of the 100% battery charge. In 54 minutes, the battery discharges to 20% of 80%. When only 20% remains in the battery, the robot heads to the charging station after 5 minutes.

According to the model scenario, students could choose the robot if it is available after entering the building (see Fig. 2). As an entry point, the system verifies the robot's battery charge. When the battery charge is either "Battery.Initial" or "Battery.OK", indicating that it is above 80%, the robot is at the initial stage and ready for operation. To ensure optimal performance, a 10-second buffer period is added before the robot begins serving a new student. During the student assistance stage, the distance and speed values are utilized for the computation of the travel time to the destination. Once the travel time is computed, the robot effectively guides the students to their desired location. Upon reaching the destination, the robot returns to the home position by traveling the same distance at an average speed of 1.4 m/s. The robot remains in the operational state until its battery level reaches 20% or less, at which point it is sent to recharge. Therefore, if the battery state is "Low" or "Charging," students switch to the traditional method of navigation.

We sorted the students by priority, adding a queue block to the simulation and prioritizing people with disabilities. Furthermore, we added two queue blocks to account for the number of students with and without disabilities who need a robot assistant.

The simulation time covers the entire 14-and-a-half-hour period of operation of the university building. The two models were launched 128 times. The simulation results from the DES models will show the average travel time for different combinations of departure and arrival points that represent the current and proposed scenario for all selected student groups.

C. ENHANCING CREDIBILITY: COMPARING SIMULATION RESULTS ACROSS DIFFERENT ACADEMIC BUILDINGS

We applied our simulation models to another building of the University of Alicante to enhance the credibility of our findings. The data input for this analysis was sourced from the building of the Faculty of Business and Economics. Thus, a significant increase in the number of students with disabilities at the Faculty of Social Sciences and Law was revealed, totaling 222 students. The building is different in its construction from the Polytechnic building and contains 3 entrances, 2 elevators, and 2 main staircases. This indicates that the faculty is in greater need of accessibility and ensuring equal opportunities for all students.

TABLE 3. Comparison of the current scenario and scenario with the use of a robot.

Student type	Direction	Use of robot	Average time (min)	Percentage decrease (%)
With Disabilities	**Class**	No rob	2,13 ± 1,56	**35.68**
		Rob	1,37 ± 0,88	
	Consultation	No rob	2,87 ± 1,49	**51.90**
		Rob	1,38 ± 0,87	
Without Disabilities	**Class**	No rob	2,01 ± 1,01	**28.86**
		Rob	1,43 ± 0,67	
	Consultation	No rob	2,05 ± 1,08	**25.85**
		Rob	1,52 ± 0,40	

V. RESULTS

To obtain the result, both models were run 128 times, representing the current scenario and scenario with the allocation of one robot. Multiple iterations of simulation are a valuable tool within DES to obtain more accurate estimates for scenarios that feature non-deterministic parameters. In this regard, four random values were generated for each iteration to represent the number of arriving students, class and counseling times, and two values for the student movement speed indicator. This approach enables the identification of the most probable outcomes by running simulations repeatedly, which reduces the margin of error and improves the reliability of the results. During the simulation, we analyzed the average time it takes students in a particular academic building to cover the distance between two points (a building entrance, a classroom, or a professor's office) with and without using a robot. Another metric is the average number of students served by the robot. Each simulation has a length of 14.5 hours, which corresponds to the period of operation of the university building. The final goal is to show that the proposed resource allocation solution is better than the current solution.

Table 3 presents a comprehensive comparison of the results achieved under both scenarios. After analyzing the results, we divided them into four discrete groups. The findings indicate a significant decrease in the mean value in all groups. Specifically, the group of disabled students who used the robot to go to their classes recorded a decrease in travel time from 2.13 to 1.37 min, which is roughly a 35% reduction.

Another group of disabled students utilized a robot to attend consultations, resulting in a significant reduction in travel time. Without the robot, their travel time was 2.87 min, but with the robot, it reduced to 1.38 min, which is a 52%

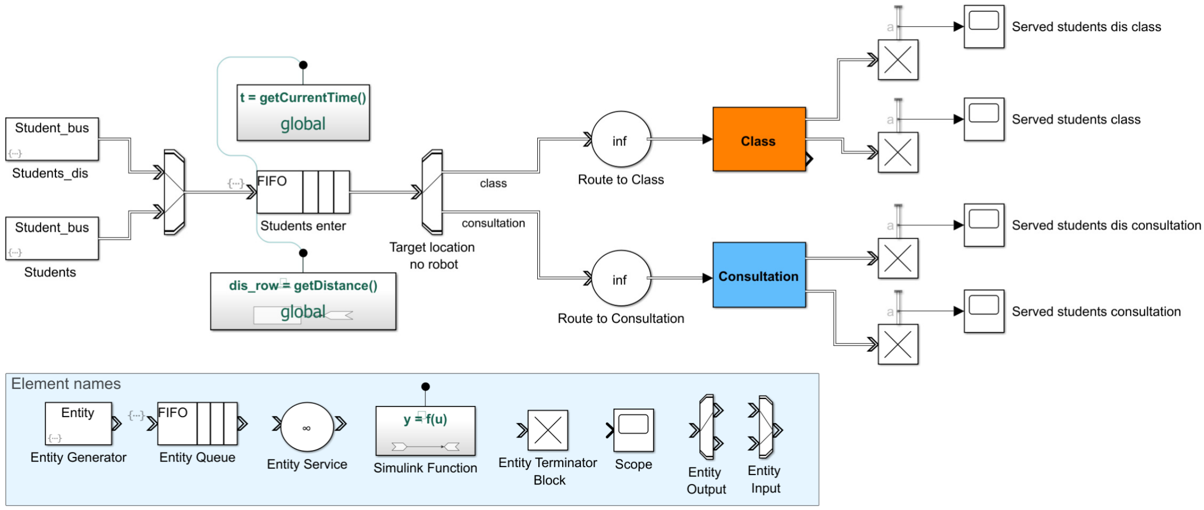


FIGURE 3. The main model of the current students' flow.

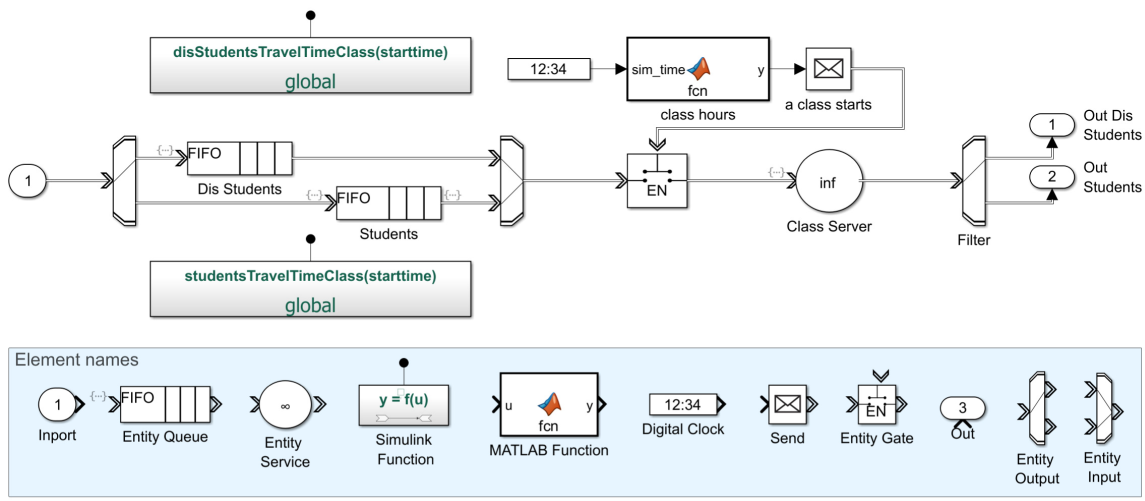


FIGURE 4. The sub-model of the route to the classroom.

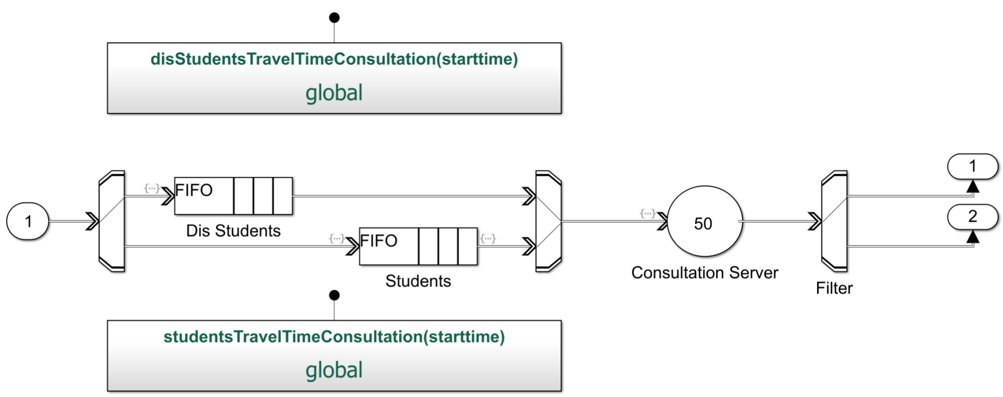


FIGURE 5. The sub-model of the route to consultation.

reduction. Similarly, the group of students without disabilities who used the robot to attend classes experienced a 28% reduction in travel time. Meanwhile, the group attending consultations recorded a 25% reduction. Overall, we observed a

TABLE 4. Number of students served by the robot.

Student type	Direction	Students generated	Students need robot	Departed Students
With Disabilities	Class	52.25+-21.21	62.87 +-26.16	10.95 ± 1.60
	Consultation			2.33 ± 1.09
Without Disabilities	Class	648+-20.36	71.25+-24.50	4.69 ± 1.79
	Consultation			2.19 ± 1.66

43% reduction in travel time for disabled students and 27% for students without disabilities.

The wide spread of the standard deviation is due to the variability in student speed, which may be decreased if the student is unfamiliar with the building. Also, the difference in the range of the destination influences the time index. As we can see, using the robot also reduces the deviation range, bringing it closer to the mean. The robot's assistance has been a valuable asset to students with disabilities, serving an average of 13 students on each simulation repetition. It has also been helpful in serving 7 students without disabilities (Table 4). The success rate in serving students who require assistance is remarkable, with about 30% of them receiving the help they need.

We utilized the raw data obtained from the building of the Faculty of Business and Economics of the University of Alicante to increase the credibility of our results. We customized the simulation model to generate the required number of students for a particular faculty. Following the same process, we first simulated the original student' s flow in the academic building and then the student's flow with the assistance of a robot. The findings for the group of disabled students who used the robot to go to their classes and consultations decreased by 35% and 39%, respectively (Table 5). Similarly, the group of students without disabilities recorded a 31% and 29% reduction in travel time. The student service success rate for the Department of Economics and Business was 18%. Thus, we can conclude that with the increase in the number of students requiring the robot, the effectiveness of the robot is maintained.

VI. DISCUSSION

The novel contribution of this proposal to the scientific community is first acknowledged. The integration of Discrete Event Simulation (DES) for simulating robotic assistance in academic buildings represents a significant advancement in the field. This approach not only exemplifies the innovative application of DES in new domains but also highlights the potential of simulation technologies in enhancing accessibility in public spaces. The study sets a precedent in utilizing advanced simulations to tackle real-world challenges, particularly in creating more inclusive environments for individuals

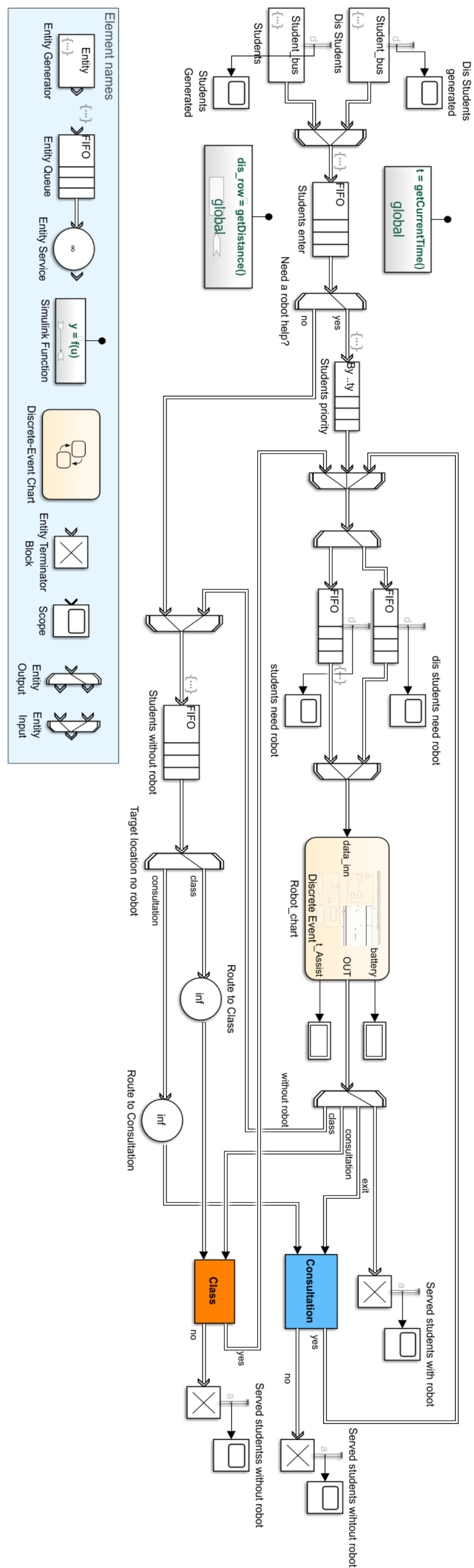


FIGURE 6. The main model of student flow using a robot.

with disabilities. Such interdisciplinary applications of DES in combining technology, social good, and practical utility mark a meaningful stride in scientific research.

TABLE 5. Comparison of the current scenario and scenario with the use of a robot at the faculty of business and economics.

Student type	Direction	Use of robot	Average time (min)	Percentage decrease (%)
With Disabilities	**Class**	No rob	2.04 ± 1.23	**34.82**
		Rob	1.33 ± 0.66	
	Consultation	No rob	2.14 ± 1.16	**39.69**
		Rob	1.29 ± 0.68	
Without Disabilities	**Class**	No rob	1.84 ± 0.94	**31.97**
		Rob	1.25 ± 0.61	
	Consultation	No rob	1.95 ± 1.01	**29.56**
		Rob	1.37 ± 0.75	

TABLE 6. Number of students served by the robot at the faculty of business and economics.

Student type	Direction	Students generated	Students need robot	Departed Students
With Disabilities	Class	104.5 ± 31.46	121.69± 33.02	17.55 ± 4.83
	Consultation			3.52 ± 2.05
Without Disabilities	Class	609.25± 64.78	22.98± 5.74	3.89 ± 2.667
	Consultation			1.69 ± 1.11

Moving to the potential threats of this proposal, it's important to approach these with a balanced view, recognizing the inherent challenges while not overshadowing the study's merits. One of the subtler threats lies in the dependency on the accuracy and comprehensiveness of the simulation model. While DES provides a detailed framework for analysis, the effectiveness of the results hinges on the model's fidelity to real-world conditions. Small discrepancies between the simulation and actual scenarios, such as variations in human behavior or unforeseen environmental factors, could impact the precision of the findings.

Another consideration is the scalability and adaptability of the system. The successful implementation in an academic building is promising, yet replicating this success in other buildings with different architectural designs and user demographics may require significant adjustments. The threat here is not of outright failure but of the need for careful customization and iterative refinement to ensure the system's effectiveness across diverse settings.

To mitigate these concerns, ongoing research and development are essential. Collaborations with practitioners in architecture, robotics, and disabled people can provide a multidisciplinary perspective, enriching the model's robustness and applicability. Moreover, pilot implementations and user feedback will be invaluable in continually adapting and enhancing the system, ensuring it meets the varying needs and expectations of its users.

In conclusion, while acknowledging these threats, it's crucial to emphasize that they do not detract from the groundbreaking nature of the study. Instead, they offer pathways for further research and development, underscoring the dynamic and evolving nature of scientific inquiry in the pursuit of societal betterment.

VII. CONCLUSION AND FUTURE WORK

This study aims to provide a comprehensive and accurate assessment of the performance of robot allocation within a university building before its implementation, utilizing the Discrete Event Simulation (DES) modeling methodology. The simulation models are designed, tested, and analyzed through the use of the SimEvents toolbox, which is a component of the MATLAB Simulink tool. We present simulations of two distinct scenarios: first, the current flow of students, and second, the flow of students using a robot assistant. Using the Digital Twin paradigm, we've established two Student Twin, one with disabilities and one without, which are represented with Entity generator blocks. Additionally, we have created a Robot Assistant Twin as the primary object of study, which is represented using a Discrete-Event Chart block.

Both models were run 128 times to obtain more accurate estimates for scenarios that feature non-deterministic parameters and reduce the margin of error, which improves the reliability of the results.

We modeled the buildings of two different faculties with different numbers of students with disabilities. Analysis of empirical data has revealed that there was a significant reduction in travel time for students when using the assistant robot, both with and without disabilities. Specifically, in the first case, students with disabilities experienced a reduction of 35%, whereas for students without disabilities, the reduction was 42%. With a success rate of approximately 30%, the robot has been able to successfully help a significant number of students who require its assistance. In the second case, with a large number of students with disabilities, the approximate reduction is 37% for students with disabilities and 30% for students without disabilities, with a success rate of 18%. As the first stage of the study, simulation modeling is a fundamental method for predicting scenarios before they are implemented. The results support the promise of implementing a robot assistant to increase accessibility, offering significant benefits for students, especially those with disabilities.

In the future, simulation using multiple robot assistants can be integrated with the Robot Operation System to achieve the development of more accurate DTs. Moreover, the present study can be extended to various universities, hospitals, and other public buildings with varying degrees of accessibility.

ACKNOWLEDGMENT

The authors are grateful for the collaboration of the administration and services staff of the University of Alicante, who provided them with actual data on students, both in terms of attendance at EPS IV and the number of students with disabilities.

APPENDIX A

See Figure 3-5.

APPENDIX B

See Figure 6.

REFERENCES

[1] United Nations Enable. *Guiding Principles of the Convention*. Accessed: Jan. 10, 2024. [Online]. Available: https://www.un.org/development/desa/disabilities/convention-onthe-rights-of-persons-with-disabilities/guiding-principles-of-theconvention.html

[2] *Accessibility for the Disabled. A Design Manual for a Barrier Free Environment*. Accessed: Jun. 18, 2023. [Online]. Available: https://www.un.org/esa/socdev/enable/designm/intro.htm

[3] K. K. Patel, S. M. Patel, and P. G. Scholar, ''Internet of Things-IoT: Definition, characteristics, architecture, enabling technologies, application & future challenges,'' *Int. J. Eng. Sci. Comput.*, vol. 6, no. 5, pp. 6122–6131, May 2016. [Online]. Available: https://fardapaper.ir/mohavaha/uploads/2019/09/Fardapaper-Internet-of-Things-IOT-Definition-Characteristics-Architecture-Enabling-Technologies-Application-Future-Challenges.pdf

[4] A. H. Buckman, M. Mayfield, and S. B. M. Beck, ''What is a smart building?'' *Smart Sustain. Built Environ.*, vol. 3, no. 2, pp. 92–109, Sep. 2014, doi: 10.1108/sasbe-01-2014-0003.

[5] J. C. C. Caicedo, J. D. G. Arciniegas, and C. M. Bedoya. *Asistente Robótico Para Personas Con Discapacidad Visual*. Trabajo Fin de Grado, Fundación Universitaria los Libertadores, Bogotá, Colombia. Accessed: Jan. 9, 2024. [Online]. Available: https://repository.libertadores.edu.co/handle/11371/3431

[6] G. D'Angelo, S. Ferretti, and V. Ghini, ''Simulation of the Internet of Things,'' in *Proc. Int. Conf. High Perform. Comput. Simulation (HPCS)*, Jul. 2016, pp. 1–8, doi: 10.1109/HPCSim.2016.7568309.

[7] E. Ojie and E. Pereira, ''Simulation tools in Internet of Things: A review,'' in *Proc. 1st Int. Conf. Internet Things Mach. Learn.*, Oct. 2017, pp. 1–7, doi: 10.1145/3109761.3158400.

[8] Y. He, J. Guo, and X. Zheng, ''From surveillance to digital twin: Challenges and recent advances of signal processing for industrial Internet of Things,'' *IEEE Signal Process. Mag.*, vol. 35, no. 5, pp. 120–129, Sep. 2018, doi: 10.1109/MSP.2018.2842228.

[9] R. Jia, B. Jin, M. Jin, Y. Zhou, I. C. Konstantakopoulos, H. Zou, J. Kim, D. Li, W. Gu, R. Arghandeh, P. Nuzzo, S. Schiavon, A. L. Sangiovanni-Vincentelli, and C. J. Spanos, ''Design automation for smart building systems,'' *Proc. IEEE*, vol. 106, no. 9, pp. 1680–1699, Sep. 2018, doi: 10.1109/JPROC.2018.2856932.

[10] E. O'Sullivan and S. Senécal, ''Accessibility,'' in *Encyclopedia of Quality of Life and Well-Being Research*. Dordrecht, The Netherlands: Springer, 2014, pp. 9–10, doi: 10.1007/978-94-007-0753-5_8.

[11] Y.-J. Chang and T.-Y. Wang, ''Indoor wayfinding based on wireless sensor networks for individuals with multiple special needs,'' *Cybern. Syst.*, vol. 41, no. 4, pp. 317–333, May 2010, doi: 10.1080/01969721003778584.

[12] G. Kbar, A. Al-Daraiseh, S. H. Mian, and M. H. Abidi, ''Utilizing sensors networks to develop a smart and context-aware solution for people with disabilities at the workplace (design and implementation),'' *Int. J. Distrib. Sensor Netw.*, vol. 12, no. 9, Sep. 2016, Art. no. 155014771665860, doi: 10.1177/1550147716658606.

[13] G. Delnevo, L. Monti, F. Foschini, and L. Santonastasi, ''On enhancing accessible smart buildings using IoT,'' in *Proc. 15th IEEE Annu. Consum. Commun. Netw. Conf. (CCNC)*, Jan. 2018, pp. 1–6, doi: 10.1109/CCNC.2018.8319275.

[14] H. AlMazrua and A. B. Najjar, ''Towards the development of a brain semi-controlled wheelchair for navigation in indoor environments,'' *Int. J. Adv. Comput. Sci. Appl.*, vol. 12, no. 5, pp. 574–584, 2021, doi: 10.14569/ijacsa.2021.0120569.

[15] P.-J. Duh, Y.-C. Sung, L. F. Chiang, Y.-J. Chang, and K.-W. Chen, ''V-eye: A vision-based navigation system for the visually impaired,'' *IEEE Trans. Multimedia*, vol. 23, pp. 1567–1580, 2021, doi: 10.1109/TMM.2020.3001500.

[16] W. Jeamwatthanachai, M. Wald, and G. Wills, ''Spatial representation framework for better indoor navigation by people with visual impairment,'' *J. Enabling Technol.*, vol. 13, no. 4, pp. 212–227, Dec. 2019, doi: 10.1108/jet-12-2018-0068.

[17] Z. Rashid, J. Meliá-Seguí, R. Pous, and E. Peig, ''Using augmented reality and Internet of Things to improve accessibility of people with motor disabilities in the context of smart cities,'' *Future Gener. Comput. Syst.*, vol. 76, pp. 248–261, Nov. 2017, doi: 10.1016/j.future.2016.11.030.

[18] D. N. M. Nizam, L. W. Shin, Z. H. A. Sani, P. Thamrongrat, and N. M. Tuah, ''An indoor navigation support for the student halls of residence using augmented reality: A design perspective,'' *Pertanika J. Sci. Technol.*, vol. 29, no. 4, pp. 2659–2673, Oct. 2021, doi: 10.47836/pjst.29.4.23.

[19] F. Ajmi, S. B. Abdallah, S. B. Othman, H. Zgaya-Biau, and S. Hammadi, ''An innovative system to assist the mobility of people with motor disabilities,'' in *Proc. IEEE Int. Conf. Syst., Man Cybern. (SMC)*, Oct. 2019, pp. 4037–4043, doi: 10.1109/SMC.2019.8914332.

[20] C. Prandi, G. Delnevo, P. Salomoni, and S. Mirri, ''On supporting university communities in indoor wayfinding: An inclusive design approach,'' *Sensors*, vol. 21, no. 9, p. 3134, Apr. 2021, doi: 10.3390/s21093134.

[21] C.-L. Lu, Z.-Y. Liu, J.-T. Huang, C.-I. Huang, B.-H. Wang, Y. Chen, N.-H. Wu, H.-C. Wang, L. Giarré, and P.-Y. Kuo, ''Assistive navigation using deep reinforcement learning guiding robot with UWB/voice beacons and semantic feedbacks for blind and visually impaired people,'' *Frontiers Robot. AI*, vol. 8, pp. 1–15, Jun. 2021, doi: 10.3389/frobt.2021.654132.

[22] S. Liu, A. Hasan, K. Hong, C.-K. Yao, J. Lin, W. Liang, M. A. Bayles, W. A. Rogers, and K. Driggs-Campbell, ''Designing a wayfinding robot for people with visual impairments,'' 2023, *arXiv:2302.09144*.

[23] M. Kuribayashi, T. Ishihara, D. Sato, J. Vongkulbhisal, K. Ram, S. Kayukawa, H. Takagi, S. Morishima, and C. Asakawa, ''PathFinder: Designing a map-less navigation system for blind people in unfamiliar buildings,'' in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, Apr. 2023, pp. 1–16, doi: 10.1145/3544548.3580687.

[24] Q.-H. Nguyen, H. Vu, T.-H. Tran, and Q.-H. Nguyen, ''Developing a way-finding system on mobile robot assisting visually impaired people in an indoor environment,'' *Multimedia Tools Appl.*, vol. 76, no. 2, pp. 2645–2669, Jan. 2017, doi: 10.1007/s11042-015-3204-2.

[25] H. S. Grewal, N. T. Jayaprakash, A. Matthews, C. Shrivastav, and K. George, ''Autonomous wheelchair navigation in unmapped indoor environments,'' in *Proc. IEEE Int. Instrum. Meas. Technol. Conf. (I2MTC)*, May 2018, pp. 1–6, doi: 10.1109/I2MTC.2018.8409854.

[26] S. Maldonado-Bascón, F. J. Acevedo-Rodríguez, F. Montoya-Andúgar, and P. Gil-Jiménez, ''Low cost robot for indoor cognitive disorder people orientation,'' in *Proc. IEEE Int. Conf. Ind. Technol. (ICIT)*, Feb. 2018, pp. 1769–1774, doi: 10.1109/ICIT.2018.8352451.

[27] E. M. Rocha and M. J. Lopes, ''Bottleneck prediction and data-driven discrete-event simulation for a balanced manufacturing line,'' *Proc. Comput. Sci.*, vol. 200, pp. 1145–1154, Jan. 2022, doi: 10.1016/j.procs.2022.01.314.

[28] M. Zouri, C. Cumpat, N. Zouri, M.-M. Leon, A. Mastaleru, and A. Ferworn, ''Decision support for resource optimization using discrete event simulation in rehabilitation hospitals,'' *Revista de Cercetare si Interventie Sociala*, vol. 65, pp. 82–96, Jun. 2019, doi: 10.33788/rcis.65.6.

[29] G. J. Melman, A. K. Parlikad, and E. A. B. Cameron, ''Balancing scarce hospital resources during the COVID-19 pandemic using discrete-event simulation,'' *Health Care Manage. Sci.*, vol. 24, no. 2, pp. 356–374, Jun. 2021, doi: 10.1007/s10729-021-09548-2.

[30] B. J. Bartos, M. Mioduszewski, M. Renner, and R. McCleary, ''An application of discrete event simulation for planning and resource allocation in a state hospital system servicing both criminal and civil commitments,'' in *Proc. Winter Simulation Conf. (WSC)*, Dec. 2017, pp. 4509–4511, doi: 10.1109/WSC.2017.8248182.

[31] E. Romano and D. Iuliano, ''A simulation/optimisation approach to support the resource allocation in service firms,'' *Int. J. Procurement Manage.*, vol. 11, no. 1, pp. 53–75, 2018, doi: 10.1504/ijpm.2018.088615.

[32] A. H. Sakr, A. Aboelhassan, S. Yacout, and S. Bassetto, ''Simulation and deep reinforcement learning for adaptive dispatching in semiconductor manufacturing systems,'' *J. Intell. Manuf.*, vol. 34, no. 3, pp. 1311–1324, Mar. 2023, doi: 10.1007/s10845-021-01851-7.

[33] Y. Wu and S. Chen, "Machine allocation in semiconductor wafer fabrication systems: A simulation-based approach," *J. Syst. Sci. Syst. Eng.*, vol. 32, no. 3, pp. 372–390, Jun. 2023, doi: 10.1007/s11518-023-5558-8.

[34] V. Fani, B. Bindi, and R. Bandinelli, "Designing and optimizing production in a high variety/low volume environment through datadriven simulation," in *Proc. Eur. Council Modelling Simulation*, Jun. 2021, vol. 35, no. 1, pp. 10–15, doi: 10.7148/2021-0010.

[35] W. Zhou, S. Li, Y. Huang, and J. Wang, "Simulation-based planning of a kind of complex product general assembly line," *Proc. CIRP*, vol. 76, pp. 25–30, Jan. 2018, doi: 10.1016/j.procir.2018.01.032.

[36] L. Aboueljinane and Y. Frichi, "A simulation optimization approach to investigate resource planning and coordination mechanisms in emergency systems," *Simul. Model. Pract. Theory*, vol. 119, Sep. 2022, Art. no. 102586, doi: 10.1016/j.simpat.2022.102586.

[37] Y.-Y. Feng, I.-C. Wu, and T.-L. Chen, "Stochastic resource allocation in emergency departments with a multi-objective simulation optimization algorithm," *Health Care Manage. Sci.*, vol. 20, no. 1, pp. 55–75, Mar. 2017, doi: 10.1007/s10729-015-9335-1.

[38] A. Battu, S. Venkataramanaiah, R. Sridharan, A. Battu, and R. Sridharan, "Patient flow optimization in an emergency department using simpy-based simulation modeling and analysis: A case study," in *Applications of Computation in Mechanical Engineering*. Singapore: Springer, 2022, doi: 10.1007/978-981-19-6032-1_22.

[39] N. Ahmad, R. Ramli, J. Z. Hew, A. H. Teo, N. A. Ghani, and W. K. Abduljabbar, "A generic simulation optimization model of emergency department resource capacity," *J. Eng. Appl. Sci.*, vol. 12, no. 6, pp. 1558–1565, 2017, doi: 10.3923/JEASCI.2017.1558.1565.

[40] N. S. M. Yusoff, C.-Y. Liong, A. Y. M. Noh, and W. R. Ismail, "Discrete event simulation and data envelopment analysis models for selecting the best resource allocation alternative at an emergency department's green zone," *Sains Malaysiana*, vol. 47, no. 11, pp. 2917–2925, Nov. 2018.

[41] Centro de Apoyo al Estudiante. (2021). *Memoria De La Universidad De Alicante 2021–2022*. Accessed: Jan. 10, 2024. [Online]. Available: https://web.ua.es/es/memoria21-22/vr-estudiantesempleabilidad/centro-de-apoyo-al-estudiante.html

[42] *Politécnica IV—Edificio Docente Y Departamental. Infraestructuras Y Espacios*. Accessed: Jan. 10, 2024. [Online]. Available: https://eps.ua.es/es/infraestructuras-espacios/infraestructuras-yespacios/politecnica-iv-edificio-docente-y-departamental.html

[43] *PlacesUA*. Accessed: Jan. 20, 2024. [Online]. Available: https://docs.google.com/spreadsheets/d/1_9GZf_YKe_dqq7sajXtcwhUdQiyydO6/edit?usp=sharing&ouid=105331770483205781049&rtpof=true&sd=true

[44] V. G. Ferreira, C. G. Herrera, S. Souza, R. R. D. Santos, and P. S. L. D. Souza, "Software testing applied to the development of IoT systems: Preliminary results," in *Proc. 8th Brazilian Symp. Systematic Automated Softw. Test.*, Brazil, Sep. 2023, pp. 113–122, doi: 10.1145/3624032.3624049.

[45] D. C. Sena, E. M. M. Silva, A. P. R. Costa, J. A. B. Montevechi, A. F. Pinho, and R. C. Miranda, "Dynamic allocation of additional human resources using hybrid simulation," *Int. J. Simul. Model.*, vol. 16, no. 1, pp. 84–95, Mar. 2017, doi: 10.2507/ijsimm16(1)7.371.

[46] S. Robinson, "Conceptual modeling for simulation," in *Proc. Winter Simulations Conf. (WSC)*, Dec. 2013, pp. 377–388, doi: 10.1109/WSC.2013.6721435.

[47] Y. Wu, K. Zhang, and Y. Zhang, "Digital twin networks: A survey," *IEEE Internet Things J.*, vol. 8, no. 18, pp. 13789–13804, Sep. 2021, doi: 10.1109/JIOT.2021.3079510.

[48] MathWorks. (2023). *Get Started With Simulink*. Accessed: Jan. 10, 2024. [Online]. Available: https://www.mathworks.com/help/simulink/getting-started-withsimulink.html

[49] MathWorks. (2023). *Discrete Event Chart. Simulink*. Accessed: Jan. 15, 2024. [Online]. Available: https://www.mathworks.com/help/simevents/ref/discreteeventchart.html

[50] *SIGUA—Sistema De Información Geográfica De La Universidad De Alicante*. Accessed: Jan. 28, 2024. [Online]. Available: https://web.ua.es/es/sigua/api-rest.html

[51] M. L. Pedralli and G. H. Schelle, "Gait evaluation in individuals with down syndrome," *Brazilian J. Biomotricity*, vol. 7, no. 1, pp. 21–27, 2013. Accessed: Mar. 31, 2024. [Online]. Available: https://www.redalyc.org/articulo.oa?id=93026211003

[52] E. E. Guzman-Muñoz, L. B. Gutierrez-Navarro, and S. E. Miranda-Diaz, "Postural control in children, adolescents and adults with down syndrome," *Revista Médica Internacional Sobre el Síndrome de Down*, vol. 21, no. 1, pp. 12–16, Jan. 2017, doi: 10.1016/j.sdeng.2016.09.003.

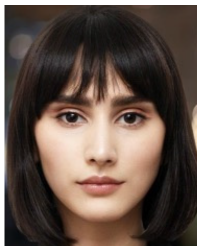
[53] L. Fu, Y. Liu, H. Qin, Q. Shi, Y. Zhang, Y. Shi, and J. T. Y. Lo, "An experimental study on bidirectional pedestrian flow involving individuals with simulated disabilities in a corridor," *Saf. Sci.*, vol. 150, Jun. 2022, Art. no. 105723, doi: 10.1016/j.ssci.2022.105723.

[54] L. Fu, Y. Liu, Y. Shi, and Y. Zhao, "Unidirectional pedestrian flow in a corridor involving individuals with disabilities: A modified floor field modelling approach," *J. Stat. Mech., Theory Exp.*, vol. 2021, no. 7, Jul. 2021, Art. no. 073402, doi: 10.1088/1742-5468/ac0f6e.

[55] J. Kim, C. Ahn, and S. Lee, "Modeling handicapped pedestrians considering physical characteristics using cellular automaton," *Phys. A, Stat. Mech. Appl.*, vol. 510, pp. 507–517, Nov. 2018, doi: 10.1016/j.physa.2018.06.090.

[56] C. Heinzemann, U. Pohlmann, J. Rieke, W. Schäfer, O. Sudmann, and M. Tichy, "Generating simulink and stateflow models from software specifications," in *Proc. 12th Int. Design Conf., Design Soc. (Design)*, Dubrovnik, Croatia, 2012.

[57] S. Al-Fedaghi, "Modeling the semantics of states and state machines," *J. Comput. Sci.*, vol. 16, no. 7, pp. 891–905, Jul. 2020, doi: 10.3844/jcssp.2020.891.905.



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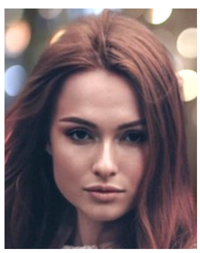

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