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Review

Exploring Bluetooth Beacon Use Cases in Teaching and Learning: Increasing the Sustainability of Physical Learning Spaces

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Abstract: Considering the surge in e-learning growth over the last decade and the proliferation of mobile devices in the Bring Your Own Device generation, this paper reviews selected use cases of Bluetooth beacons in educational situations. We review the contribution of Bluetooth beacons to a mixed pedagogy that uses digital and physical learning spaces, and we discuss the pilot deployment of Bluetooth beacons at the Hong Kong Polytechnic University, Hong Kong, to enhance physical learning spaces. Our work represents one of the first deployments of Bluetooth beacons in a university teaching and learning capacity and provides a starting point for others attempting to utilise beacon-enabled location-based services to enhance learner experiences. The widespread adoption of beacon technology in educational institutions has not yet occurred, and the most common usage of beacon transmitters and systems in education is for attendance-taking and dissemination of teaching material. Mobile applications are constantly being developed to utilise the location-based services provided by beacons to enhance student learning and effectiveness. This paper also discusses the sustainability benefits of beacon systems, especially in the contexts of smart campus and smart city development.

Keywords: bluetooth beacon; location-based service; smart campus; teaching and learning

1. Background

Changes in learning are partially driven by the rapid growth and development of technology [1]. As new mediums and methods of knowledge transfer become available, old methods are reconsidered, revamped, or phased out. Furthermore, as technology becomes ever more ubiquitous, new approaches to disseminating information arise in education as well. With the advent of online spaces such as virtual learning environments (VLEs) with built-in discussion forums, video-hosting websites such as YouTube, and the widespread sharing of electronic educational content via e-mails and Dropbox, knowledge transfer and technology are becoming increasingly enmeshed.

The online sharing and production of knowledge is a significant change that has occurred during the 21st century. This transformative shift toward “e-learning” is moving forward, free from the bounds of institutional structures and from physical and geographical barriers to education. Universities, however, have generally capitalised on their nature as a common area for educators and students to interact, and e-learning, by definition, suggests that face-to-face contact with experts is not the only part of education. Whether this is a significant drawback is still debatable, but criticism regarding the appropriation of traditional human roles by computers emerged as early as 1976. Computer scientist Joseph Weizenbaum’s *Computer Power and Human Reason* [2] suggested a ban on “all projects that substitute a computer system for a human function that involves interpersonal respect, understanding, and love”. Faculty have protested the foisting of e-learning on professors by private education companies [3], and scholars have noted the higher drop-out and fail rates of online courses [4]. Regardless, e-learning has grown significantly each year [5].

E-learning is considered an effective and sustainable teaching and learning practice [6] that produces positive implications for students [7]. It changes the conventional teaching approach by using cutting-edge technologies [8] that allow for wide-scale knowledge and information dissemination, regardless of time and space, thereby simplifying the information release schedule and increasing the size of the target audience [8]. Furthermore, it allows for contributions from highly regarded institutions and educational partners without having to accommodate schedules and physical constraints. While the debate over its usefulness continues, e-learning is being implemented in an increasing number of institutions [9]. Regardless of this debate, the merits of e-learning, such as instantaneous content sharing and the presentation of multimedia files, can be incorporated into physical learning spaces, such as the creation of a mixed “phygital” pedagogy [10], also known as blended learning [11]. Combining a physical learning space with e-learning can consist of more than just the utilisation of educational technology, such as virtual learning environments (VLEs), or learning management systems (LMSs), such as Moodle in face-to-face teaching situations. Interfaces between the two domains, such as virtual reality (VR) headsets, or, as is the focus of this review, Bluetooth beacons, can be implemented, for example, to spatially divide a classroom or other physical learning space into various areas differentiated by the e-content disseminated by each beacon.

Bluetooth beacons are a low-cost, low-power, and location-based technology that uses the Bluetooth Low Energy (BLE) protocol [12] in conjunction with small, BLE-enabled hardware devices (beacons). Bluetooth beacons are one-way transmitters to a smartphone or other device, which require a specific mobile application to be installed to interact with the beacons. There are two significant beacon standards: iBeacon, developed by Apple, and Eddystone, developed by Google. These small portable transmitters, of which there are various suppliers, can be installed indoors or outdoors and have a battery life of approximately three years. The beacons can broadcast Bluetooth signals containing several bytes of information together with their universally unique identifier (UUID) to their surroundings. Nearby Bluetooth-enabled electronic devices can use the information to determine the user’s location and trigger a location-based action, such as a push notification, if desired. A beacon can therefore be used to trigger an associated action on any Bluetooth devices that have the appropriate mobile application installed, based on the device’s location relative to the beacons. Mobile devices can then determine the distances between the beacons and the device itself based on the received signal strength, with a weaker signal indicating a longer distance. When several beacon signals are received by the device, the user’s location can be determined via trilateration [13,14] or the fingerprinting method [15]. Both methods allow the mobile application installed on a user’s mobile device to be located successfully in order to receive the appropriate location-based information.

Importantly, beacons transmit only their existence and information to other devices. They do not use background monitoring to track devices and, ultimately, people. The beacons can also be used in multiples and detected by multiple mobile applications for localisation. The sustainable use of Bluetooth beacon technology has been demonstrated in many applications, typically in location-based applications, namely, the control of air conditioning, heating ventilation, illumination, security and

sanitation based on the number of people [16], information dissemination in museums and shopping malls, the advertisement of products, and indoor navigation [17]. Jeon et al. [17] indicated that there is a large variety of use cases of beacons in commercial and industrial areas because of the sustainability of its low energy consumption, and this technology has a high potential for further applications in other disciplines.

The beacon functions have numerous use cases in the educational field, but widespread applications are still in progress. Institutions tend to develop in-house mobile applications, whereas a common mobile application with customisable functions, class lists, etc., could aid in the widespread dissemination of beacons as a component of a “phygital” pedagogy. Thus, beacons allow for the creation or subdivision of creative spaces and subsequently accommodate the personalisation of learning through the dissemination of specific information, tasks, or other learning material. A review of use cases in the field will be discussed in four categories—attendance monitoring, smart campus operation in education, dissemination of educational content to students via the beacon protocol, and instances of augmented reality (AR) combined with beacon systems—with the aim of providing an overview of common use cases and of discussing information and strategies for beacon deployment in the educational sector, as well as the positioning method used by location-based services.

Each of these implementations of beacon technology has sustainability implications. Attendance monitoring via beacons increases efficiency and saves time. It also replaces a physical attendance sheet with spatially and automatically detected attendance information. Smart campus implementations can save significant amounts of energy, for example, through energy management regimes that can take advantage of time-variable tariffs or through simpler mechanisms, such as occupancy detection [18]. Campus-wide implementation can result in saved energy [19,20] and increased sustainability of education and educational institutions. Electronic dissemination of teaching material can contribute to the sustainability of education [21] through the saving of physical resources. The digitalisation of education allows students to access educational resources remotely, thus reducing the environmental impact of learning by reducing travel costs and associated emissions. Additionally, the ability to share and reuse teaching material means that resources can be allocated to other aspects of learning, thus removing the need for the recreation of physical material and augmenting the continuity of courses [6,22]. This economy of reusable resources can be used in conjunction with beacon systems because they provide a location-based service, and in doing so, the location-based service may inspire educators with new ideas or teaching methods as well as new places to disseminate information informally or formally. Furthermore, augmented reality and virtual reality (AR/VR) in and of itself is suggested to be sustainability-enhancing, as educators can interact with their students remotely through e-learning in conjunction with AR/VR [23]. According to Sorbi [24], AR/VR educational tools also allow for instantaneous movement between products, increasing the effective speed of learning. As these products are 3D virtual objects, their associated lack of weight removes the need for storage space and renders machinery/equipment rentals obsolete [25]. It also eliminates the storage costs of teaching material if the institution owns the machinery [26], which represents a sustainability advantage that is especially pertinent to instrument or machinery-heavy disciplines such as mechanical engineering. Therefore, beacon systems can facilitate sustainable e-learning in the three areas shown in Figure 1.



Figure 1. Sustainable e-learning with a beacon system (reproduced with permission from [27]).

The data collected from use cases can be analysed from a location-based point of view such as through examining the relationship between student locations and quiz scores or the number of students asking or answering questions through the mobile application. These data can inform potential big-data applications that can help educators draw conclusions to support their teaching and student learning. A review of current beacon use cases serves to inform educators and other interested parties regarding the current development level of beacons in education and allows for new ideas to be generated and implemented, building on research that has already been conducted.

As part of the review, this article recaps the pilot work performed at our institution, The Hong Kong Polytechnic University, using iBeacons for quizzes, attendance, hands up, the pushing of multimedia content, and other functions through an in-house developed mobile application, iClassPolyU [28].

Privacy is also an important issue. Concerns regarding the storage and usage of the data were voiced during the initial stages of the project, and the issue is also mentioned in the literature on spatial computing [29]. In our work, measures to ensure the privacy of the data obtained from students were taken, such as storage of the data on secure servers and the provision of a privacy policy to which all students who used our mobile application agreed. The collection of student data and subsequent privacy issues can be dealt with by anonymising the data, as in Heo et al. [30], and appropriate ethical approvals for any work that requires the collection and storage of personal information should be sought.

2. Methodology

The review of use cases was conducted using Google Scholar and the library database of The Hong Kong Polytechnic University, Hong Kong. Peer-reviewed articles on the uses of beacon protocols in educational settings were found using various combinations of the terms “beacon”, “iBeacon”, “learning”, “university”, “education”, “student”, “sustainable”, and “sustainability”. Blogs and webpages from pilot and small implementations of beacon protocols were also reviewed, as some use cases of the beacon protocols have not been formally published in peer-reviewed journals. Some studies reviewed were project proposals rather than actual implementations, but they were included due to the unique proof-of-concept displayed in the publications. Reference lists of articles found in databases were also screened for relevant publications that may not have been returned in the initial search. Studies published at any time in the last 20 years were included. All beacon-related papers were published after 2013, as the iBeacon protocol was released during that year. Select mobile applications and application development platforms that support beacon-facilitated location-based services were also reviewed. In addition to reviewing the application of beacons in teaching and learning, the methods used for positioning were also studied.

3. Results

3.1. Overview

A total of 33 studies was reviewed, in addition to two mobile applications and one mobile application development platform. Of these 33 studies, seven focused on the use of beacons in attendance monitoring, nine focused on the use of beacons to create a smart building or smart campus, and 15 addressed the location-based dissemination of educational information. Two studies discussed combining AR with beacon technology in an educational setting.

3.2. Attendance Monitoring

One of the most widespread use cases of beacon technology in higher education is the expedition of administrative tasks such as attendance monitoring. Of particular interest is the use of this technology in large classes, as attendance-taking requires more time in large classes than in smaller ones. Electronically monitoring and analysing attendance information could help alert educators at an earlier stage if students are having difficulties.

Some implementations of beacon technology for attendance purposes utilise in-house-developed mobile applications that must be downloaded and installed by end-users. Ex Libris created CampusM [31], a campus mobile application that can handle attendance, among other administrative tasks, and can be utilised by various institutions based on built-in functions such as viewing grades and enrolment. Similar mobile applications, such as TeacherKit [32], also exist. However, courses and students must be added manually by the instructor, and the mobile applications are unable to generate attendance reports for individuals.

In terms of independently developed systems, Noguchi et al. [33] built upon an existing system at Ibaraki University that allowed students to scan their student ID on the instructor's terminal. Their development allowed for the scanning of a student's card on a student's individual Android device, saving queueing time compared to the case of scanning on a single terminal. This was accomplished by the development of a system that uses BLE beacons to transmit a "magic number" set by the instructor to students' Android devices. When the companion Android attendance mobile application is installed, a student can then scan his/her ID on his/her smartphone (via near-field communication) and send his/her student ID information, name, and magic number back to the server that contains the set of student IDs and names of the class for matching. BLE beacons are fundamentally necessary to this system, as only students in proximity to the beacon can receive the magic number, ensuring no false attendance records. Deugo [34] created a mobile application called EventTracker to handle classes with over 1000 attendees. The system allows for accurate attendance monitoring based on the user mobile application detecting beacons at an event. An attendee can register attendance only for events that are associated with the beacons detected by the mobile application. Similarly, Redetzke et al. [35] developed an Android-only attendance mobile application utilising a username-and-password method for students to record their attendance. A similar undergraduate research project was undertaken at the University of Greenwich [36] that also enabled location-based attendance monitoring using a standalone mobile application. Bae and Cho [37] created a system that uses the Bluetooth communication function of students' smartphones to automatically check the location of an individual student. If the location is valid, the system records the presence of the student, removing the need for any action on the part of the student or instructor; thus, this system is the most automatic system for attendance recording to date. Lau et al. [38] developed an automatic attendance tracking mobile application that uses beacons to verify the presence of students and then records the information automatically. This mobile application also includes attendance report, absence letter submission, and manual attendance functionalities for students without smartphones.

A novel implementation of the location-monitoring capacity of beacons was piloted by Lucas et al. [39]. They proposed that autistic children, who may react unpredictably to normal social stimuli, be equipped with irremovable beacon bracelets at the start of class to help teachers monitor the

children's location. When a beacon approaches a door for more than two seconds, an alert is sent to the server, which is then retrieved by the teacher's smartphone application. The authors suggest that this process increases the teacher's ability to adequately monitor the students and reduces the period between an alert and an action.

3.3. Smart Building and Smart Campus

In addition to attendance systems, beacon technologies can serve as energy-saving "smart building" occupancy-detection systems for heating, ventilation, and air-conditioning control purposes. Beacon technologies are now also being developed for use in educational settings [18], augmenting the physical campus learning space and working in tandem with attendance registration systems to streamline these necessary processes. Additionally, campus-wide usage of beacons can provide specific location-based information for different groups of people. Gibbons [40] at the University of Bradford used beacons in conjunction with the CampusM mobile application on university open days to provide visitors with specific information based on their proximity to various beacons. The data recorded by the mobile application, e.g., the number of notifications sent, allows the institution to understand the movement flows around campus, modify future information, and provide data for creating suggested paths for mobile application users.

A "smart campus" that demonstrates the functions of its different areas, such as exhibition spaces, can be facilitated by beacons, as proposed by Merode et al. [41]. An integrated system consisting of beacons, the Smart Campus smartphone application, and a database with a content management system was developed to push information about a Belgian university's campus to students, staff, and visitors, functioning as a "guided" tour of the university. Similarly, the Android-based application uBeacon was developed by Husni [42] to help students navigate campus, provide information, and take attendance. Smallwood [43] developed a mobile application for Clevedon School that provides functions such as a school map, a bell schedule, and directions and pushes notifications to mobile devices when a student is near a beacon transmitter. Based on the signal received from the nearby transmitter, relevant content can be downloaded by users. A learning platform including a mobile application for use with beacon transmitters was developed by [44] at the University of Hradec Králové that integrates attendance, navigation, the provision of information, and other functions into one mobile application. The mobile application then works together with a server and location databases to augment the physical campus learning space.

Bhattacharya et al. [45] developed a campus-wide beacon system at the University of Hawaii Maui College. The beacons installed provide corresponding information for campus users, including but not limited to daily menu items at the cafeteria, library opening hours, classroom schedules and booking availability. Chen et al. [19] presented a prototype mobile application that combines beacons and the Global Positioning System (GPS) for seamless indoor and outdoor route guidance. Users can easily reach their destinations on campus through a route guidance service. Casado-Mansilla et al. [46] developed a beacon-based mobile application to guide users to supporting recycling. When a user is standing in front of a vending machine or recycling point with beacons installed, the mobile application is triggered by the beacon's signal, which guides the user to the closest recycling bin, thus demonstrating the use of beacon technology for sustainability purposes.

3.4. Dissemination of Electronic Teaching Material and Information Via Beacons

Beacon technology can be used to spatially divide physical learning spaces and provide pertinent information in the associated sub-space. This is an example of beacon technology supporting a sustainable practice. Areas such as libraries can benefit greatly from supplemental audio-visual information that aids learners in utilising the learning space in the most effective way. Bradley et al. [47] created a library tour mobile application for the Newman Library at Virginia Polytechnic Institute and State University. The tour is self-guided and primarily consists of audio and video recordings that prompt students to visit certain areas of the library. Beacons have also been used in the University of

Edinburgh's Library Labs [48], projecting videos via Google Glass to visitors of an exhibit and providing self-guided tours of the library and exhibition space via a smartphone application. The location-based mobile application 49er Alerts, developed by Wu et al. [49], works in conjunction with beacon transmitters for use in the University of North Carolina at Charlotte Library. The information provided is library-specific and focuses on library outreach in an academic setting, including providing information on study spaces, resources, and workshops and providing students and librarians with a new channel for communication, engagement, and learning enhancement.

McDonald and Glover [50] used beacons to divide an art studio into three separate areas, with each pushing different resources that aided in production, presentation, and collaboration on student devices via the protocol. The functions included training, sharing learning materials, and presenting a peer-review system. The system received positive feedback from students, as it facilitated work sharing, increased inspiration, and augmented the physical learning space by diversifying it and allowing for different activities to take place in segregated zones. De la Guia et al. [51] divided a classroom into two zones using beacons to aid in language learning. The system was used to push notifications to devices shared between students, facilitating the creation of task-based language learning scenarios. Additionally, the results were stored for instructor use, removing the need for manual record-keeping and allowing for greater assessment potential. Wu et al. [52] implemented beacons to create a ubiquitous learning environment in a classroom instead of spatially segregating it. Information about smart green building technology was explained via information cards, which were stored on the cloud and pushed to student devices when they approached the relevant beacon. Significant increases in student scores between pre and post-activity quizzes were recorded, demonstrating the effectiveness of the beacon system in knowledge transfer and in engaging students in activities. The researchers also attempted to use the beacons to implement incremental learning, in which notifications were pushed in a sequential order to build a knowledge map and avoid overloading the learner with notifications.

Tsai et al. [53] built on the attendance monitoring capabilities of beacon systems and further developed an Interactive Feedback Portfolio (IFEP) system that allows attendance-taking and student responses to questions facilitated by beacons. The student mobile application uploads UUIDs and the distance between the smartphone and beacon to the cloud server. Student IDs are also sent to the server, and when an instructor posts questions on the main screen, the IFEP system pushes the question to the students' smartphones. The mobile application can therefore display the real-time statistics of student answers to multiple-choice questions, giving instructors real-time feedback regarding students' level of understanding. The use of the IFEP system increases engagement levels, as well as improving teaching and learning time. Kim [54] developed a similar mobile application for increasing interaction that successfully removed the limitations of teacher-student interaction in large classes and reduced the time required for interactions to take place.

Some beacon deployments have occurred in informal learning settings, such as in public university locations. Zimmerman et al. [55] created a beacon platform called Places that included a content management system (CMS), a server hosting the CMS, and data analytics. The Places mobile application was installed on iPads, and beacons were placed in biological, geographical, ecological, and hydrological exhibits in the Arboretum at Penn State University. When devices with the mobile application installed were in the Arboretum, the mobile application launched an appropriate map when it detected a beacon identified on that map. The beacons allowed the mobile application to push information to learners at a precise level, such as regarding a specific tree or an exhibit component, meaning that the beacons could support visitors comparing specimens or exhibits that were just metres apart. The beacons were used to help 26 summer camp children learn about geographical, hydrological, biological, and ecological phenomena and then link the information to their local community and the Arboretum. The authors concluded that the beacon system supported students' scientific engagement and stimulated their imaginations, prompting students to engage in detailed observations of the Arboretum based on the content provided by beacons at specific locations.

Beacon technology has also been implemented in museums. Chen et al. [56] studied informal learning in a science museum augmented by mobile exhibit labels that were pushed to visitors' devices when they reached the relevant beacons. While a relationship between better learning performance and the use of mobile labels promoted by beacons has yet to be established, participants did spend more time at each exhibit on average when presented with mobile labels on their phones. Furthermore, participants presented with mobile labels showed greater interactions with the labels and the exhibits. Museum administrators could then use the data from the system to assess, for example, the layout effectiveness. Chen et al. [57] developed a ubiquitous learning system composed of beacons, a wireless network, and a mobile application. The system was used in a science museum to aid visitor learning. Two experimental groups and a control group were created out of 33 students. The first experimental group received location-based push notifications, whereas the second experimental group used the mobile application without notifications. The control group was a non-guided tour with no mobile devices used. The groups were evaluated through a quiz, a museum experience scale questionnaire, and a mobile technologies usability questionnaire. The researchers found that the first experimental group benefited from improved learning outcomes and visiting experiences in the areas of knowledge, learning, and meaningfulness. Follow-up interviews revealed that the beacon tours enhanced the interaction between the students and the museum exhibits. In contrast, the second experimental group did not benefit from improved learning outcomes or visiting experience.

Similarly, Chang [58] used the automatic detection of location information to create a proactive guidance system for visitors in an art museum. The system includes beacons, a smartphone application, and a guidance management system. If Bluetooth is on, a visitor's smartphone receives the notification and helps the beacon ascertain the location. Pictures, videos, text, audio, and other multimedia can be pushed to smartphones to guide users to the next exhibit based on where they are located.

To assist second-language English learners, Jeng et al. [59] developed an English learning mobile application that uses beacons as an English learning device. The mobile application sends a notification to a mobile phone when it detects a device. Corresponding English learning activities are made available at specific locations, including vocabulary and sentences commonly used in a particular type of location, e.g., at a museum. English learning can then be enhanced by connections made between the environment and the learning materials, enforcing content retention and memory [60]. A similar learning mobile application was developed by Chan et al. [61] for children with intellectual learning disabilities. It uses the location-based nature of the beacon system to support these children's communication by displaying a set of symbols that are relevant to the user's location; e.g., pencils and books are displayed when the user is in a classroom. They conclude that, in a pilot test, their system has functionality that mimics actual mechanisms in human communication, thus enhancing the learning experience of intellectually disabled children. The authors hope to further develop the system by including user learning profiles based on input frequencies. In this way, learning support can be ameliorated as students' strengths and weaknesses become clearer to speech therapists and teachers.

Finally, resources with which users can create their own location-based mobile applications for both iOS and Android also exist in the form of Locly Native [62], a mobile application platform that supports BLE beacon technology for location-based content delivery. An educational case utilising Locly is the Stephen Perse Foundation Schools' student mobile application [63], which disseminates location-based content uploaded by teachers and students and facilitates group formation and group content delivery.

3.5. Combining Augmented Reality Content with Beacon Technology

Jurkovičová et al. [64] created an AR system that is also based on a standalone mobile application and uses beacon technology to guide students around a learning space using complementary overlaid visual information displayed on their own devices. Students point their smartphone camera at certain predetermined objects ("learning interest points") with their associated beacons in the laboratory. The objects are identified within the mobile application via the associated beacons, and information

about them is overlaid on the camera view. The beacons indicate a static laboratory as well as workspaces within the lab and other interest points—for example, it indicates that a workspace will be freed in a certain amount of time. In their testing phase, the beacon system effectively guided students physically around the lab in tutorials in a course on products and quality.

Karlsson et al. [65] used Beacon–AR synergy to develop an educational quest game called ArQuest. The game utilises beacons to give “quests” to students in conjunction with overlaid visual markers detectable by smartphone cameras. The beacons provide range and location detection for accurate dissemination of the quests to students. AR primarily serves not only to assist in eliciting student engagement and interest but also to help students visualise subjects in three dimensions rather than two. The quests include group and individual quests, stimulating cooperation and collaboration, and students may also design and implement quests with their instructors’ approval. The inclusion of AR is shown to be financially feasible, requiring only the purchase of beacons and the development of a mobile application that can support the functions. ArQuest represents a utilisation of pre-existing technology (smartphones) to stimulate teaching and learning in a flexible and innovative way. It presents new engagement pathways and collaboration opportunities, and it allows students to develop their own quests and learn collaboratively.

3.6. Positioning Methods

Beacon technology is also widely used in indoor location-based services, where mobile devices can determine their position based on a beacon’s signal. The positioning method chosen depends on what each specific use case demands in terms of positioning accuracy, time constraints, the number of beacons available, and other parameters. There are three main positioning methods used with beacon systems to determine the position of mobile devices. These are proximity, trilateration, and fingerprinting.

3.6.1. Proximity

This positioning approach is the simplest, requiring only one beacon. This approach involves checking whether a mobile device is within radio coverage of a beacon, and the position of the user is estimated to be within the coverage of the beacon signals. The more beacons there are, the more precise the position will be, as radio coverage overlap can be utilised to find the most likely position [66]. This approach does not provide an absolute position and is generally used in commercial settings, e.g., when a customer enters a store and the operators wish to notify entrants of a promotion.

3.6.2. Trilateration

This approach necessitates at least three beacons. Trilateration functions by computing the distance from a mobile device to at least three known points, i.e., beacons. The intersection points of the three circles are used to determine the position of the mobile device, as shown in Figure 2. As actual distances cannot be directly measured, the distance between a beacon and mobile device is commonly derived using a received signal strength indicator (RSSI). The more beacons there are, the more accurate the position will be with least squares adjustment.

Trilateration is less time- and labour-intensive than the last of the three methods, fingerprinting, at the cost of being sensitive to walls, doors, and people. As it results in an absolute position, trilateration is suitable for other use cases that require finer positioning granularity than proximity-based approaches can offer. However, filters may have to be used to improve the accuracy due to the sensitivity of the method [67]. Room-level positioning is easily achieved with trilateration, but reliable, scalable, and adaptable systems with metre-level accuracy are an ongoing area of research [68], including solutions such as filtering [13] and integration with other systems such as Pedestrian Dead Reckoning [69]. In ideal test conditions, trilateration-based approaches have achieved 0.5 m positioning accuracy [70]. While trilateration does not inherently consider attenuation, the use of correction factors can alleviate this issue. The advantages of trilateration include adaptability, less time and labour consumption, and the availability of filtering approaches to improve the positioning accuracy.

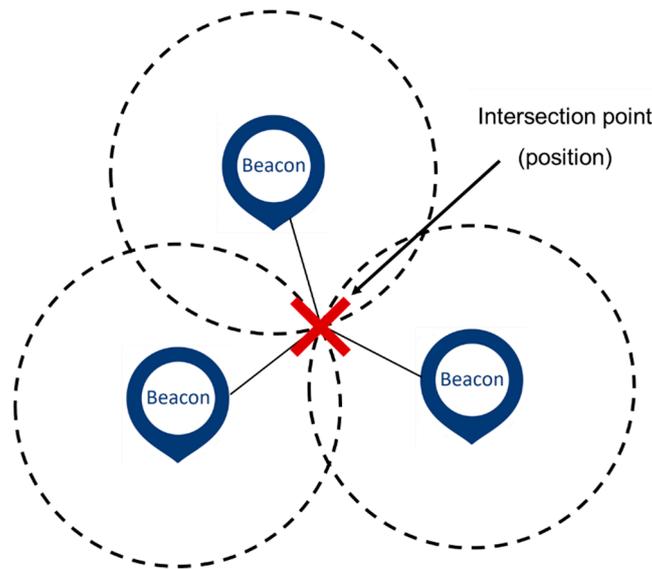


Figure 2. Trilateration principle.

3.6.3. Fingerprinting

This method of positioning generally has higher accuracy than trilateration [71], but it requires the manual measurement of RSSI values in the form of an evenly spaced grid to create a fingerprint database. A fingerprint is the pattern of radio strength signal measurements recorded at a certain point in space, as illustrated in Figure 3. It comprises some form of signal identity information, such as MAC addresses, as well as corresponding RSSI values. Fingerprint databases are generally manually constructed, with readings taken at regular intervals in a given space [12].

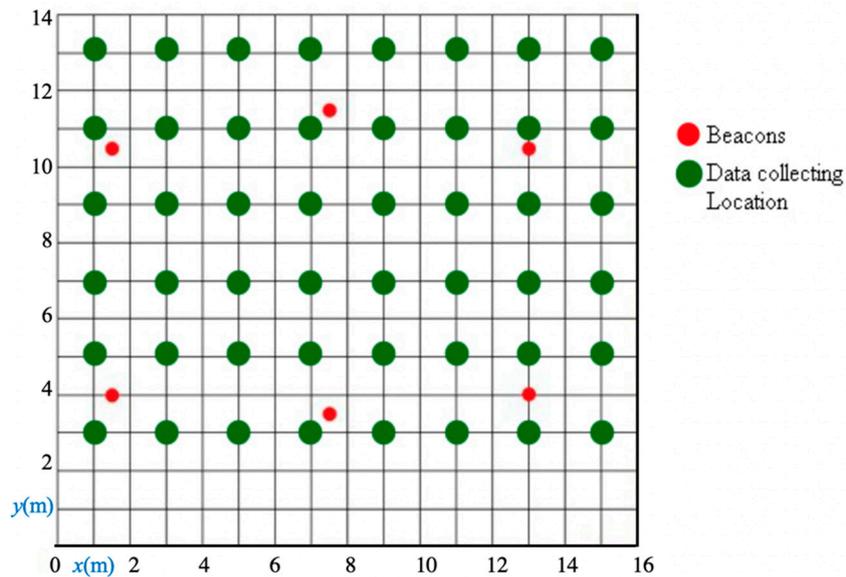


Figure 3. Illustration of a fingerprint database and beacon deployment.

Once the RSSI has been measured for every point, deterministic or probabilistic methods can be employed to determine the location (within the database boundaries) of any device based on RSSI. Fingerprint databases may require regular resurveying due to changes in the target space, such as furniture movement and the density of people [12]. Fingerprinting is inherently less adaptable than trilateration because it requires the creation of a new database for every new space. However, as fingerprinting accounts for attenuation in the database creation process, it generally results in better

positioning accuracy. No correction factor is required for fingerprinting because the actual signal strength is calculated at each point, accounting for attenuation.

4. Review of Pilot Work at the Hong Kong Polytechnic University (PolyU)

4.1. Overview of iClassPolyU

iClassPolyU is a pilot location-based mobile application developed by our team at PolyU (Figure 4). As iBeacon-based systems can facilitate functions such as question and answer, attendance monitoring, student discussion, group formation, and other location-based functions, iClassPolyU was developed to allow for the utilisation of these functions and to determine the feasibility of deploying iBeacon-based systems in PolyU for enhancing teaching and learning outcomes.

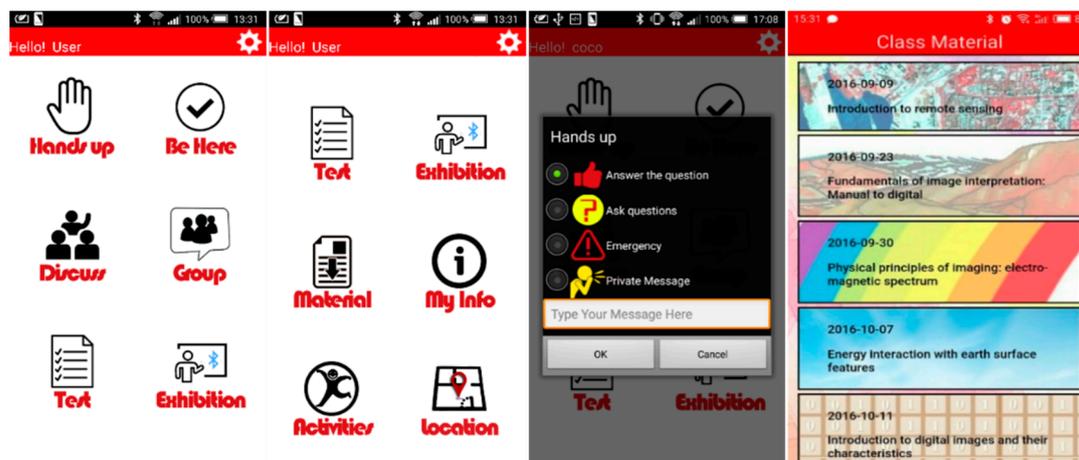


Figure 4. Functions of iClassPolyU.

4.2. iClassPolyU Testing

Pilot testing of a location-based iBeacon system with iClassPolyU was carried out in classes of up to 100 students and smaller classes of 20–30 students [28]. The pilot work consisted of introducing the iClassPolyU mobile application, assisting in downloading it, and familiarising students with its functions, such as attendance and hands up, quizzes, and discussion. The iBeacons were used to determine the position of hands up in classrooms, disseminate quizzes and surveys, take attendance, and ask questions, among the other aforementioned functions using the fingerprinting method. These functions were implemented in classes throughout the school year. Quiz scores, participation information, attendance data, hands-up data, and discussion forum data were collected to evaluate the usage of the mobile application. A survey based on the Technology Acceptance Model 2 (TAM2) [72] was administered to participating students to gauge their responses to the mobile application and its effects on their learning. Over 80% of participating students in the pilot testing completed all quiz tasks in the mobile application, illustrating how location-based services can encourage learner participation and increase engagement.

The results from the modified TAM2 survey suggested that students believed their physical participation could be increased through using the mobile application and that they thought it was user-friendly, effective, flexible and informative [28]. Students also indicated that they were willing to continue using the mobile application to enhance their classroom learning, and this feedback demonstrated that they accepted the iClassPolyU technology. Students also requested, via the modified TAM2 survey, the inclusion of AR, VR, and/or mixed reality features. These features would augment the physical learning spaces to a greater degree, for example, by allowing visual overlays based on where the camera is pointing. AR has been effectively used to teach [64,73], and the inclusion of such features encourages the development of novel and engaging learning experiences. Mobile applications

create a separate pathway for students to engage in learning activities, which assists in the attainment of learning goals. Data for functionalities such as quiz results, hands up, and attendance can be utilised by instructors to evaluate their classes. Data from various classes can also be combined to perform evidence-informed investigations of the possible relationships between these functions or between these functions and the effectiveness of teaching and learning.

To improve the usefulness of the system and encourage its adoption, our team decided that engaging learning experiences would be best facilitated by a portable, location-based holistic system that uses iBeacon technology as part of a teaching and learning project to support mixed pedagogies and augment various learning spaces. It was determined that the focus of the system development should be the effectiveness of iBeacon technology for teaching and learning, along with the perceived ease of use and usefulness, as these two factors are the most vital in the adoption of e-learning material and new technology. Through the pilot implementation, sustainability was enhanced, as the surveys were administered via iClassPolyU. In addition to ensuring the modification and reuse potential, this digital dissemination saved paper. Quizzes were also administered via the mobile application, allowing for question reuse/re-working in the next semester, and attendance was taken via the mobile application, increasing efficiency and saving paper. The mobile application also reduced the academic staff workload, as staff no longer had to record attendance manually. The data from iClassPolyU implementation are being analysed for relationships between student performance and variables such as attendance, number of hands up, and use of the mobile application itself. We also suggested that adaptive learning and personalised learning pathways could be developed based on individual student data collected, giving new dimensions to the data gathered and increasing the sustainability of mobile applications such as iClassPolyU in augmenting and enhancing student learning experiences. Based on the concept of iClassPolyU, a new system is undergoing testing in the research team and others in Hong Kong, and the finding that student movement between campus areas can be related to student performance [30,74] is a starting point for our investigation into the relationship between student movement within a physical learning space and student academic performance. For the sake of sharing the research output in this study, we are prepared to share the key components of the source codes in iClassPolyU at the reader's/user's request.

5. Conclusion

The boom in smartphone ownership conveniently satisfies many of the hardware requirements for beacon-based system implementation in educational settings. Teaching and learning can be supported by beacons and other location-based services that provide active learning opportunities, engagement pathways, interaction platforms, and other functionalities. Current beacon implementations do not take full advantage of the opportunities afforded by the BLE protocol in terms of what types of data can be pushed to learners, as a comprehensive application that allows learners to engage in various task types and download relevant information has still not been widely implemented. Teams may be inclined to develop their own mobile applications, as functionalities can be tailor-made. However, the benefits of a customisable platform should not be ignored, as it would allow greater compatibility between learners across institutions or across countries and save development costs. If each team that wanted to implement beacons did not have to develop their own platform, beacons would proliferate with less difficulty due to the lower start-up requirements.

However, in the current climate, platforms supporting e-learning with a location-based foundation do not have the wide functionality necessary to increase engagement and augment teaching and learning. They mostly focus on attendance and administrative tasks, despite the existence of mobile applications such as CampusM and TeacherKit. Although they may allow for the dissemination of class material and attendance-taking, student learner profiles cannot be assembled from attendance data and other data. That is, currently, physical and digital learning spaces work in tandem but are not integrated "phygitally". For instance, VLEs are accessible at any time during a lecture or outside of a lecture but do not provide any significant advantage to students who attend lectures. In contrast,

beacon transmitters can provide pre-loaded content that may only be accessed in lectures or provide engagement pathways that lead to more stimulating learning progress than do obtaining and studying content from VLEs en masse.

From a sustainability viewpoint, the benefits associated with beacon systems are generally extensions of the benefits associated with e-learning, such as eliminating the need for physical copies of information and supporting efficiency in terms of time saved and workload reduced (for example, through attendance monitoring or the reuse of assessments). Beacon systems present a unique advantage in energy savings; however, smart campus applications can use beacons to determine occupancy. The low energy usage of individual beacons also contributes to the sustainability impact of a beacon system, as even deploying a significant number of beacons will not significantly affect the overall power usage of a project unless settings such as the transmission power are increased, reducing the overall battery life. Beacon systems implemented in multi-building campuses therefore hold energy-saving potential as well as physical resource-saving benefits. Further research could quantify the sustainability benefits of beacon systems in information dissemination, attendance-taking, and smart campus contexts. The adoption of smart campus systems is underway [75,76], but widescale, complete adoption across entire campuses is not yet a reality. As beacon technology becomes more efficient and the costs of manufacturing are lowered, the incorporation of this technology into the Internet of Things (IoT) systems could increase, and the sustainability benefits of e-learning in conjunction with beacon-enabled systems could be reaped by educational institutions worldwide.

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